SMAR 2024

Book of accepted Abstracts

7th International Conference on Smart Monitoring, Assessment and Rehabilitation of civil structures

Salerno, Italy
4-6 September 2024

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Table of contents

Preface

SMAR 2024, the 7th international conference on Smart Monitoring, Assessment and Rehabilitation of civil structure, is co-organised by the Structural Engineering Laboratory of Empa, the Swiss Federal Laboratories for Materials Science and Technology, and the Department of Civil Engineering of the University of Salerno, Italy. It is hosted at the Main Campus of the University of Salerno between 4 and 6 September 2024.

A total of 324 abstracts were accepted for presentation in SMAR 2024 and 280 of them were also converted into full paper to be eventually published in the conference proceeding, which, for the first time, are going to be published by Elsevier in a dedicated issue of **Procedia Structural Integrity** (Online ISSN: 2452-3216) an open access journal publishing under a CC-BY-NC-ND license full papers presented in scientific conferences.

However, as a well-established tradition in SMAR Conferences, the present volume collects all the abstracts related to presentations scheduled during SMAR 2024. It is organised in the following sections corresponding to the main topics and mini-symposia organised as part of the conference:

- Keynote Lecture
- Durability issues as related to harsh environments
- Performance and damage assessment
- Practical applications and case studies
- Shape memory alloys in civil structures
- Structural health monitoring
- Structural strengthening and repair
- MS1: Multifunctional materials for sustainable constructions: integrated thermal, structural and sensing systems
- MS2: Research and development of Iron-based Shape Memory alloys and their engineering application technology in China
- MS3: Digital Manufacturing in Construction
- MS4: Intelligent digitalization in structural health monitoring and lifetime maintenance of complex structures
- MS5: Smart FRP and steel structures
- MS6: Innovative Methods in Strengthening of Concrete Bridges using FRP
- MS7: Bio-based composites for rehabilitation and retrofitting of buildings and structures
- MS8: Advances in the investigation of the bond mechanism of externally bonded composites and FRP bars
- MS9: Advances in Fiber Optical Sensing Solutions for Infrastructure, Geotechnics and Earth Sciences

MS10: Economic assessment and Life-Cycle performance in building and civil engineering works
MS11: Seismic-Fire combined assessment and optimization of interventions for buildings and infrastructures
MS12: Innovative solutions for fatigue strengthening of existing structures
MS13: Natural fibres for eco-compatible solutions in seismic and energy upgrading of masonry structures
MS14: Advancements in Risk and Reliability Assessment of Existing Structures
MS15: Shape Memory Alloys (SMAs) for Engineering Applications
MS16: Systems and methods for transport infrastructure surveillance and monitoring
MS17: Advancements in Object Digitization and Analysis: A Mini-Symposium on Innovative Tools and Methods

The aim of this volume, in conjunction with the conference programme, is to guide the conference attendee and any research or practitioner interested in SMAR 2024 to have a quick access to the conference contents, which can be eventually studied in further details by reading the related full papers that will be made available in the conference proceedings.

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Salerno (Italy), September 2024

Keynote lectures

ID: FA

Transcending discreteness in infrastructure monitoring

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Abstract

Detecting and quantifying local anomalies over large areas poses a significant challenge in structural health monitoring of civil infrastructure. Conventional practice relying on strategic placement of discrete sensors demands comprehensive prior knowledge of susceptible regions. Correlating localized flaws to changes in global measurements such as vibration characteristics remains difficult and implementing dense sensor networks proves impractical for extensive coverage. Therefore, breaking free from discrete sensing and embracing spatially distributed measurements marks an essential leap forward. Traditional methods for distributed sensing involve fiber optic sensing technologies and vision-based techniques. In recent years, mimicking biological skin, a concept that is well-advanced in the field of robotics, has found application in civil infrastructure monitoring. Following an in-depth review of artificial sensing skins for mapping defects and strain fields over large surfaces, the focus shifts to our recent work on developing multifunctional cementitious sensing skins. Self-sensing cementitious composites have the potential to revolutionize monitoring of civil infrastructure due to their compatibility with concrete. Their implementation requires a considerable journey ahead and faces several hurdles, the most critical of which will be outlined.

Keywords

Spatially distributed sensing, Fiber optics, Vision-based monitoring, Sensing skins, Multifunctional composites

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AI-enhanced Digital Inspection of Bridges

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Abstract

Civil infrastructure inspection -and consequently maintenance- is carried out primarily through visual inspections. AI-enhanced (Artificial Intelligence) digital inspection methods, integrated with risk-based probabilistic approaches, have been promoted to keep existing structures, especially infrastructures, safe and predictable. Drones are used to obtain a significant number of images to cover the surface of a bridge, which are further integrated into a digital 3D (three-dimensional) model. According to the IFC standards (Industry Foundation Class), this 3D model is GPS-positioned (Global Positioning System) and connected to BIM (Building Information Modelling). Post-processing the accumulated data volume of all digital images is very time-consuming. For this reason, appropriate AI-based algorithms streamline this process significantly, enabling partially automated damage detection and assessment. To this end, images of various types of damage on different bridges are used to train and test the AI-enhanced models. In addition, damage identification and classification are developed. Six visually detectable defects can be identified, and theoretical models estimate the associated structural diseases. Finally, a probability-based risk assessment presents the basis for defining the criticality of the structure. With the help of digital images, it is possible to create a high-fidelity digital model and quantitative surface and spatial data records of the structural health condition of bridges and other infrastructures.

Keywords

Artificial Intelligence, Digital Inspection, Damage Detection, Structural Diseases, Bridges

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Seismic retrofit of buildings in Italy through seismic isolation or energy dissipation

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Abstract

Seismic isolation and/or supplemental energy dissipation is used in Italy since the 1970s in new structures. However, the applications of these technologies in existing buildings became relatively common after the destructive 2009 L'Aquila earthquake.
Seismic isolation, when feasible, is the most effective retrofit technique, thanks to strong reduction of accelerations and interstorey drifts, and the removal of torsional problems. Seismic isolation was applied in many buildings damaged by recent earthquakes, but not so damaged to make more affordable demolition and rebuilding. The Italian reconstruction law imposes that the retrofit of buildings strongly damaged by an earthquake improves the seismic behaviour at least at a level of 60% of the performance of a new building on the same site. It is not easy to reach this level with conventional techniques, while seismic isolation allows to reach even higher levels without works on the superstructure. This makes seismic isolation ideal to retrofit undamaged buildings as well, without interrupting their use, apart in a small portion (usually basement or ground floor).
Supplemental energy dissipation devices are also very useful to retrofit existing buildings. They reduce the request of ductility to existing structural elements, and thus reduces their damage. The structures that benefit most from supplemental energy dissipation are framed buildings that are too flexible as well as to weak under seismic actions. Energy dissipation devices are often used in braces, to exploit the excessive interstorey drifts of said buildings. However, there could be other positions for the installation of energy dissipation devices.
The lecture presents many practical examples of use of seismic isolation and energy dissipation devices in existing buildings in Italy.

Keywords

Earthquake, seismic retrofit, seismic isolation, energy dissipation, building

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AI-Aided Structural Engineering Inspection and Decision-Making

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Abstract

During the assessment of our civil infrastructure, engineers collect vital information in the form of images, structural drawings, readings (from sensors), and make informed decisions about the state of the structure supported on this information. Deep learning and computer vision have proved powerful tools for automating the information extraction from these data sources and supporting the inspection activities. This presentation will be divided into two parts: (1) Automating the extraction of unbiased and task driven information from more than 100,000 building images and 10,000 bridge images. (2) Using historical data to recommend and update decisions based on changing conditions. Emphasis will be made on considerations to be made in balancing the costs and risks associated with increasing the levels of AI involvement to enable engineers to better manage their resources. This presentation will discuss the methods and share important lessons from these investigations on the power of artificial intelligence to aid the work of the engineer in performing these tasks.

Keywords

Deep learning, structural inspection, image classification, decision-making

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Advancements in Carbon Fiber Reinforced Polymer Tendons for Structural Rehabilitation

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Abstract

Over the past three decades, the application of carbon fiber-reinforced polymers (CFRP) in the post-strengthening of civil structures mainly in the form of externally bonded CFRP sheets and near surface mounted CFRP strips has evolved significantly. While steel tendons still dominate the field of external post-tensioning for the rehabilitation of structures, recent breakthroughs in the application of CFRP tendons will pave the way for their widespread acceptance in rehabilitation. The early 1980s witnessed the pioneering development of anchors for CFRP parallel wire bundles, to addressing the challenges posed by deteriorating steel cables. Notably, the successful application of CFRP parallel wire bundles on the Stork Bridge in 1996 marked a pivotal moment in the history of bridge construction. Shortly thereafter CFRP parallel wire bundles replaced in a post-tensioned concrete box girder bridge corroded steel cables. Despite their early success, their high costs associated with the anchors for CFRP parallel wire bundles posed a significant barrier to widespread adoption. To circumvent this challenge, the introduction of pin-loaded CFRP straps emerged as a cost-effective and reliable alternative. A pivotal point was reached in 2020 when bridge engineers embraced the use of pin-loaded CFRP straps in the construction of network arch bridges. Basic research and development, coupled with comprehensive qualification experiments required by German authorities, confirmed the superior sustainability and cost-effectiveness of CFRP hangers compared to their steel counterparts. The paper meticulously outlines the production process of these tendons and delves into the rigorous qualification experiments that encompass fatigue, fire exposure, and lightning strike tests. Drawing on the successful integration of CFRP tendons in various network arch bridges, this paper envisages their wider use in the economic and sustainable rehabilitation of both concrete and steel structures.

Keywords

Rehabilitation, external post-tensioning, CFRP tendons, network arch bridge, fatigue

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Management of Road Bridge Networks in Italy by Means of Integrated SHM Systems

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Abstract

Management of stocks with large number of bridges is a relevant issue for the Italian roadway system. In the last years the use of integrated SHM (Structural Health Monitoring) systems is being introduced within the framework of the modern BMS (Bridge Management Systems) with the aim of implementing a continuous damage identification strategy. In this framework, ambient vibration-based SHM has received most attention owing to its minimal intrusiveness, non-destructive character and global damage identification capabilities. A lot of research effort has been devoted in the last years to SHM techniques but ease of use, interpretability and minimal intervention of expert judgement are essential issues for the fruitful application of SHM in real and wide bridge networks. ANAS S.p.A., the main road managing Authority in Italy, is implementing a huge monitoring program on its bridge network with the main purpose of addressing the recent indications of the Italian guidelines for assessing and monitoring of bridges, and the University of Padova, together with the University of Perugia, Technical University of Milan and the other Universities of FABRE Consortium are supporting ANAS for the real application of modern SHM techniques. According to these actual needs, a new software suite called P3P has been developed and is being applied to a real stock of more than one hundred bridges distributed in all the Italian territory.

Keywords

Iron-based shape memory alloys (Fe-SMA), UHPC, Shape memory effect, Martensitic transformation, Prestressing

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Durability issues as related to harsh environments

ID:036

Development of Corrosion Protection Method of Reinforcement in RC Structures by Electromagnetic Induction

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Abstract

Various degradations have been occurring on most of RC structures and the early deterioration of RC structures becomes an social problem. Much more attention is paid to the corrosion of the reinforcement especially rebars, because it cause the reduction of the structural and the durability performance. Therefore, it is very important to protect the occurring of corrosion on the reinforcement.
The protection method currently in use are Impressed Current System and Galvanized Anode System in which the both of the mechanism is decrease of a potential deference on between the anode and cathode. However, it takes too much cost to replace the anode material etc. and the chipping of concrete surface to expose the rebars cause damage to the structures and then its damage can result in the performance of structure and durability.
In this study, a new cathodic protection method of rebars in RC structures by electromagnetic induction, which does not cause damage to the structures at all, was proposed. The principle of the proposed method is that the eddy current, which is generated on the rebar surface due to electromagnetic induction, is used as a protective current to prevent the formation of anodes and cathodes on the rebar surface. In this paper, it is noted that the feature of the eddy current on the rebar due to the both of the experimental and the analytical results was discussed, and then the performance of the corrosion protection proposed in this paper was estimated. Finally, it should be noted that the proposed method is applicable to prevent the occurrence of corrosion on rebars due to the comparison with the experimental estimation.

Keywords

Corrosion, corrosion protection, electromagnetic induction, RC

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ID:258

Theoretical effects of corrosion on lateral stress along reinforcement bars in concrete

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Abstract

Literature review of latest research findings on the bond behavior of corroded reinforcing steel bars suggests that the bond mechanism is minimally affected by corrosion. However, discrepancies exist among researchers concerning the influence of corrosion on the critical parameters that govern bond behavior of bars.
Former studies have primarily focused on the diminishing bond strength caused by corrosion. Several key factors influencing bond strength have been identified, including corrosion of the main bar, concrete cover thickness, concrete type, stirrups, stirrup corrosion, and corrosion rate. However, existing bond strength models are largely based on specific test results and lack generalizability.
This work is a part of a wider study aiming to evaluate main concrete and steel parameters effect on corroded reinforced concrete structures. The scope of present paper is to evaluate the effect several parameters on bond behavior. Some concrete exposure classes are considered, and corrosion process is simulated using a non-linear analytical model. Three bond theories are considered to have comparative results. Corrosion simulation has been done using different concrete and steel parameters to evaluate their effects on RC corroded elements' bond capacity.

Keywords

Steel corrosion, theoretical modelling, parametric analysis, bond behavior, reinforced concrete structures.

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ID:309

Degree of composite action of steel beams with precast concrete hollow core slabs

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Abstract

Different construction challenges followed by harsh environmental conditions, triggered the human intention for precast composite structures. The precast concrete hollow core (PCHC) slabs have been popular especially for multi-story long-span composite structures. In comparison to conventional solid concrete slabs, they have the advantages of being more light-weighted, fire-resistant, soundproof, and sustainable. However, the composite action between the steel beams and PCHC slabs is neglected in the design codes. This paper aims to investigate the composite action between the PCHC slabs and steel beams through an experimental study. Two full-scale flexural tests were performed on specimens of 203- and 254 cm depth connected to the steel beam via 19- mm diameter shear studs. The failure modes and crack formations were recorded by instrumentations and data acquisition system. The degree of composite action (DCA), an important parameter to describe the structural behaviour of the composite beam, was calculated based on the displacement method.
The digital image correlation (DIC) technique was also applied to capture the neutral axis position during the loading process. Finally, the experimental results were verified based on the DIC technique.

Keywords

Composite Construction, Precast Concrete Hollow Core Slab, Composite Interaction, Flexural Test, Shear connector

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ID:361

Live Load Design and Safety Concept for Building Materials with Time Dependent Properties

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Abstract

For all buildings and structures a sufficient safety standard is essential. In building codes like the EN 1990 failure probabilities are defined for different buildings members and applications. Materials as well as actions are characterized by safety factors to fulfil the failure probability requirements and to enable in this way a safe design. But materials with time dependent properties can complicate this process.
In this paper different ways to handle variable loads in design are presented. GFRP materials have different resistances depending how long, and how often and at which temperature the different actions apply. For this reason it is important to define different categories for different actions and to check for the effect of these actions. Therefore a new model is proposed, which uses the known y factors to categorize actions according probability and resistance of the material. All is based on a semi-probabilistic safety concept.
In addition different safety concepts for these materials are discussed regarding technical, economical and practical aspects. As examples the approaches from the EN 1992-1 Annex R, the approach from ACI 440 and CSA and the German approval abZ 1.6-238 are evaluated. A combined performance based approach for a higher economical efficiency with the same proven level of safety is presented at last. This is all shown with practical values and examples.

Keywords

GFRP rebar, live load, combination factor, safety concept, design, long term testing, time dependent property

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ID:382

Durability of GFRP composites produced by pultrusion under thermal environments

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Abstract

Composites materials (also known as fibre reinforced polymers - FRP) are being increasingly used in civil structural applications due to their advantages over conventional materials. Regarding durability, the relatively long experience of using FRP in various applications provides evidence of their improved performance, namely in relatively harsh conditions. However, such empirical experience also highlights aspects such as (i) susceptibility to degradation due to several environmental agents, and (ii) lack of data for relatively thick laminates produced by pultrusion. To address this, an extensive experimental program about the durability of relatively thick pultruded glass-FRP (GFRP) plates, combining laboratory and in-situ field tests is carried out. This paper presents preliminary results from the thermal ageing environments of GFRP plates produced by pultrusion under different temperatures, namely -15 ºC, 20 ºC, 40 ºC and 60 ºC for 12 months, and thermal cycling between -15 ºC and 60 ºC for 100 and 200 cycles. After exposure, the degradation of the thermomechanical and mechanical properties of the aged GFRP plates was evaluated by means of different types of tests, namely: dynamic mechanical analysis, tension, compression, flexural, in-plane shear and interlaminar shear.

Keywords

Pultruded GFRP composites, Durability, Thermal Ageing, Thermomechanical properties, Mechanical properties

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ID:435

Development and validation of a creep frame adapted for ELS (End Load Split) test

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Abstract

In industry, structural bonding can play an important role in repairing and reinforcing metallic structures. To ensure this, the design strategy for adhesively bonded joints should be selected carefully. One reliable method is to use fracture mechanics tests that allow the determination of fracture toughnesses in mode I, II or mixed-mode. Such strategy can be used during the analysis of the initial design, but also through the aging study. Several authors have carried out investigations on the evolution of fracture toughness following different environmental aging. Nevertheless, few studies were conducted to inspect the effect of applied load on the mechanical behavior of bonded joints. To fulfill this target, it is important to develop and validate experimental methodologies able to maintain constant loads during samples' ageing. In addition, these samples need to be amenable to subsequent fracture mechanics testing. In this study, only mode II is considered by using the End Load Split (ELS) test. An adaptation of the sample's geometry is required to allow the combination of both ELS and creep configurations. This paper aims to present this adaptation as well as the developed creep frame. The new sample configuration is compared to a traditional sample geometry, revealing both similarities and differences. An optical fiber is employed to monitor crack propagation, thereby enhancing this comparison.

Keywords

Adhesively bonded joints, ELS test, Creep frame, Experimental validation.

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Durability of concrete assessed via different unsaturated and steady-flow methods

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Abstract

Recently there is a growing interest in how to decrease the environmental impact of concrete and how to increase its durability. As concrete is mostly unsaturated during its service life, measuring unsaturated flow (through imbibition or diffusion) can provide information to assess its durability. Additionally, permeability values are often used to describe concrete's ability to withstand the ingress of aggressive agents. However, it is not known whether the measured performance is representative of service-life behavior. In this research, the results obtained via 2 unsaturated flow methods (imbibition and diffusion) and 2 permeability tests (CEMBUREAU and Torrent method) were compared. In order to do this, 6 concrete mixes with 3 different cement types (CEM I, CEM II and CEM III) and two water to cement (w/c) ratios (0.4 and 0.7) were tested after 28 days and 120 days of curing. First of all, capillary imbibition was tested on specimens with a diameter of 100 mm and a height of 100 mm for 1 week. Furthermore, water vapour diffusion through the concrete was measured using the cup method, which consists of creating a moisture gradient, using a hygroscopic salt, with a concrete slice as a barrier. The results showed that for concrete with a w/c of 0.4 all test methods indicated that CEM III performed worse in comparison to CEM I and CEM II, which had a similar performance. However, for a w/c of 0.7, CEM III performed superior in comparison to CEM I and CEM II in the capillary imbibition test and the water vapour diffusion which can possibly be explained by an increased tortuosity. In the gas permeability tests, CEM III performed worse in comparison to CEM I and CEM II.

Keywords

Concrete, durability, performance assessment

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Performance and damage assessment

ID:014

Resilient Seismic Performance of Self-Centering Hybrid Rocking Reinforced Concrete Wall: Numerical Simulation

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Abstract

A reinforced concrete rocking wall is designed to withstand seismic forces. Its motion helps absorb the earthquake's energy, reducing the wall's stress and preventing it from collapsing. the self-centering wall is an effective solution for areas prone to earthquakes, it is designed to be self-centering, meaning it can return to its original position after an earthquake. It is more durable than traditional concrete walls. An innovative self-centering hybrid rocking wall with a replacement steel energy dissipator (RSED-CSHRW) is suggested to minimize concrete wall damage during earthquakes and the challenging repair afterward. The resilient performance of the proposed model RSED-CSHRW was numerically examined; utilizing the ABAQUS platform, a finite element model validated by experimental data was built to further analyze the suggested RSED-CSHRW's robustness, with a focus on the RSED's energy-dissipating capacity. Furthermore, a group of RSED-CSHRW samples was assessed under cyclic loading to investigate the resilient performance while taking into account the main influencing factors of the prestressed unbonded tendons' cross-sectional area, the initial value of the prestressing force, the location of the Pos-tensioned strands, and the thickness of the replacement energy dissipator device. These findings demonstrate that the suggested self-centering hybrid rocking wall with a replacement energy dissipator has excellent resilient properties such as great energy dissipation capacity, good self-centering ability, and high strength and stiffness, achieving the goal of low damage level during the earthquake and quick rehabilitation after, the simulation outcome of the samples indicates that the numerical model based on ABAQUS is sensible.

Keywords

Reinforced concrete walls, resilient system, finite element models, seismic performance, a replacement energy dissipator.

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ID:024

Accuracy of Ground Penetrating Radar (GPR) in locating post-tensioned cables

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Abstract

The inspection and assessment of post-tensioned (PT) bridges is a complex issue, first involving the evaluation of the conservation status of the cables. One of the most crucial pieces of information to be confident with is the cables' location since it allows for all subsequent tests (both non-destructive and destructive). Many non-destructive techniques (NTDs) are studied and employed by the scientific community and practitioners for the cables' trace determination in PT beams; one of the most promising is the Ground Penetrating Radar (GPR). This technique is commonly employed in the location of metallic elements, both under the ground (pipes, utilities, etc.) and inside the concrete (reinforcements, ducts, etc.). The GPR technology exploits electromagnetic waves typically in the range of 1000-5000 MHz in the inspection of structures and tunnel lines. The variation of electromagnetic properties of the materials results in changes in the speed of travel, attenuation, and redirection of signals. The present research deals with the determination of the GPR accuracy in locating cables in PT structures. A laboratory testing campaign on specially designed samples was conducted for this aim. The tested walls contain both metallic and plastic ducts.

Keywords

NDTs, GPR, PT bridges, Inspection

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ID:031

Evaluation of concrete frost resistance using concrete drilling powder

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Abstract

Concrete structures in cold climates suffer from frost damage. The evaluation of frost resistance requires big samples, which is not suitable for structural assessment. Therefore, developing an evaluation method that induces minimal damage to the structure is necessary. The drilling powder method has been proven to cause minimal damage to the concrete (1 mm hole) and can be used to estimate the concrete compressive strength. In this study, this technique is further investigated on its applicability to evaluate concrete frost resistance. Concrete specimens were prepared with various water-to-cement ratios and amounts of air-entraining admixture. The extraction of concrete powder and freeze−thaw cycle exposure were performed on the specimens to evaluate the pore structures and frost resistance, respectively. Mercury intrusion porosimetry was used to evaluate the pore structures of the drilling powder. Additionally, the feasibility of the drilling powder method was investigated by comparing the obtained result with that of a 5 mm concrete core. The results showed that the drilling powder method can be used to evaluate the frost resistance of normal concrete. However, the 5 mm concrete core cannot be used to estimate the frost resistance owing to the variation in coarse aggregate portion in the small-sized sample. These results imply the potential use of the proposed method in minimal damage assessment.

Keywords

Minimal damage, Frost resistance, Concrete powder, Concrete core, Porosity

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ID:035

On the assessment of the in-place concrete quality: Rebound hammer and Pull-off tests reliability

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Abstract

Several non-destructive and partially destructive tests are available for assessing of the in-place concrete quality. In this article, rebound hammer and pull-off tests are used to check the in-place concrete quality of reinforced columns after one year of exposure to natural conditions, and which have been previously characterized in compression based on the influence of core diameter. Both tests were performed on different locations through the height of the columns (top, middle and bottom). Results of the compressive strength values derived from the rebound hammer test reveal a variability through the different zones, with a standard deviation greater than 13%. On the other hand, the results of the partially destructive test (pull-off test) show an increasing trend of the tensile bond strength toward the bottom of the columns (tensile bond strength of the upper zone is lower than that of the middle and bottom zone), with a standard deviation greater than 11% for each reinforced concrete column. Based on these results, the reliability of both tests has been discussed.

Keywords

Concrete quality, non-destructive tests, zone effect, reliability.

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Performance assessment of overhead conductors subjected to combined thermal and wind loads

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Abstract

The overhead power conductors carry electricity power from distribution feeders to consumers, providing a necessary service. In the Australian distribution network, Aluminium Conductor Steel Reinforced (ACSR) cables are widely utilised. They offer increased strength and conductivity by combining both steel and aluminium strands. Due to factors like current flow, elevated ambient temperatures, direct sunlight exposure, and short circuit currents, these conductors can be subjected to elevated temperature levels. Operating at higher temperatures can alter the mechanical characteristics of the conductor materials. Consequently, the mechanical strength of conductors diminishes when powerlines consistently operate under these conditions. Conductors are set up in various environmental conditions, resulting in different wind load impacts. While the temperature rise can be somewhat offset by these wind variations in terms of cable strength, it still introduces extra tensile stress in the conductor. Hence, this research aims to determine the combined effects of thermal and wind factors on the reduction of strength and increased tension in ACSR cables. In this study, laboratory tests were performed to determine the decrease in the tensile strength of conductors under steady-state elevated temperature scenarios. Additionally, CFD modeling was employed for numerical simulations to examine the combined influences of wind and temperature. Using results from both methods, precise forecasts were provided to understand the performance of conductors when subjected to combined temperature and wind effects.

Keywords

ACSR cables, Power network, Strength, CFD modelling, Deterioration process

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ID:066

Wave-based fault detection in concrete by the Full Waveform Inversion considering noise

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Abstract

In the field of non-destructive testing of concrete, the use of ultrasonic waves became state of the art, among other techniques. Nevertheless, there is still room for improvement, in particular concerning resolution and robustness of the monitoring results.
One approach is the application of the Full Waveform Inversion (FWI) originating from geotechnical engineering, known here as seismic tomography. The forward and backpropagation of waves within a numerical model are deployed to identify material parameters, like the primary and secondary wave velocity as well as density. This approach forms a non-linear, and ill-posed mathematical problem. Its solution is computationally demanding and time-consuming.
Within the presented approach, the Full Waveform Inversion is used on an artificial concrete specimen. Here, the synthetic ultrasound data is compromised by the consideration of different levels of Gaussian white noise. Additionally, several sizes and positions of faults are computed to simulate a variety of possible defects within the concrete material as in reality. Subsequently, the identifiability of the fault together with its recognition quality are investigated. Additionally, recommendations on sensor positioning and layout are given.

Keywords

Non-destructive testing, Ultrasound, Concrete, Full Waveform Inversion, Gaussian white noise

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ID:067

Dynamic Validation and Assessment of an Historical Bell Tower

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Abstract

The work investigates the dynamic validation and seismic assessment of a bell tower located in Caserta Vecchia, emphasizing its relevance in structural engineering. Given the tower historical significance, understanding its structural behavior under seismic loading is vital for preservation efforts.

To capture the bell tower structural intricacies, advanced photogrammetric surveying techniques were utilized. This produced a detailed 3D model of the bell tower, which was subsequently integrated into the Abaqus software for finite element analysis. This approach facilitated a comprehensive examination of the tower structural dynamics and vibrational characteristics.

The study's robustness has been further enhanced through a validation process. Frequency analysis outcomes from Abaqus were cross-referenced with real-world seismic data collected using structural health monitoring (SHM) systems. This seismic data was analyzed using the Frequency Domain Decomposition (FDD) technique. This method ensured that the analytical model results were consistent with observed seismic responses, thereby validating the model's accuracy and reliability.

Further dynamic analyses were conducted to evaluate the bell tower potential vulnerabilities during high-intensity seismic events. These analyses are essential for predicting the structural response and potential damage patterns during earthquakes, facilitating better preparedness and mitigation strategies.

The applicability of the methodologies used in similar contexts offers opportunities for advancing heritage preservation and optimizing the seismic safety of such complex structures.

Keywords

Masonry, Dynamic, Assessment, FEM, Failure

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ID:079

Structural Performance of Buildings affected by Mining Activities: A review

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Abstract

Subsidence and earthquakes induced by mining activities often cause significative damage in the near surface structures. These damages may endanger the life safety of the occupants and deteriorate the structural performance of the buildings under serviceability and ultimate limit state conditions. As many of these structures might have not been designed to withstand the new loads and displacements imposed by the mining activities, an accurate prediction of their structural performance is of great importance. The purpose of this paper is to present a comprehensive review of the analytical methods and standard guidelines that are now available to assess the performance of buildings located near mining areas and that are subjected subsidence and mining induced seismicity. In the paper, the framework required for an accurate performance assessment of this group of buildings is also presented. Based on the results a detailed step-by-step procedure is then developed to help engineers to assess the performance assessment of structures located near mines.

Keywords

Mines, seismicity, subsidence, damage, structural behavior

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ID:098

Unraveling factors affecting the reversibility of martensitic phase transformation in FeNiCoAlTi

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Abstract

The reversibility of the martensitic phase transformation is crucial for the functionality of shape memory alloys. The easier the martensite is pinned, the faster the degradation of the shape memory alloy occurs during cyclic loading. This study investigates various factors influencing the stabilization of martensite during deformation of single-crystalline states in the FeNiCoAlTi system. Complementary in situ methods, such as digital image correlation and acoustic emission, are used to characterize the evolution of martensitic phase transformation and the role of dislocations during deformation. Thereby, experimental evidence was elaborated pointing at mechanisms that so far have been underrated in terms of functional degradation. In addition, high-resolution electron backscatter diffraction (HR-EBSD) measurements were utilized to identify residual stresses in the austenitic matrix, which significantly contribute to the reverse transformation. Micro-mechanical experiments using pillar compression tests were carried out to study the influence of back stresses on the reversibility of the martensitic phase transformation. The findings from this study foster the understanding of pinning mechanisms during loading of the FeNiCoAlTi shape memory alloy eventually enabling targeted optimization for enhanced superelastic material behavior.

Keywords

Iron-based shape memory alloy, martensitic phase transformation, superelasticity, in situ, acoustic emission

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ID:120

Effect of Extrusion based 3D Printing Parameters on Electrical Sensing of Carbon Fiber reinforced Cementitious Composites

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Abstract

The effect of 3D printing parameters on the mechanical properties of fiber-reinforced cementitious composites (FRCC) was fully investigated. However, research on the effect of 3D printing parameters on the electrical properties and even sensing properties is rare. In this paper, extrusion-based 3D printing was performed to control chopped polyacrylonitrile-based (PAN) carbon fiber alignment, and the effects of extrusion velocity, nozzle movement velocity, and nozzle dimension were considered. Experimental results showed that aligning the fibers by controlling the velocity ratio and narrow nozzle size weakens electron conduction due to fiber-to-fiber disconnection that led to a significant drop in electrical conductivity by at least three orders of magnitude. However, the random distribution of short carbon fibers extruded by large nozzle dimensions has maximum electrical conductivity due to the larger possibility of fiber-to-fiber contact or closure, strengthening the electrical network. By controlling the 3D printing parameters, sensitivity in the piezoelectric property of FRCC before cracking can be tailored. This novel ability to instantaneously control the electrical conductivity of FRCC through the alignment of carbon fibers opens up new possibilities for the direct embedding of conductive pathways into 3D-printed multifunctional composites that are capable of self-sensing, probably including crack detection.

Keywords

3D printing, Fiber-reinforced cementitious composite, fiber alignment, electrical

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ID:174

Long-term Corrosion Monitoring for Evaluating the Performance of Repair Measures

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Abstract

For a highway operator, such as ASFiNAG, bridges are very important assets. Despite all regular maintenance measures, these structures are strongly subjected to ageing and degradation, because of their exposure. Chloride contamination poses a significant challenge, gradually reducing the durability and service life of these structures, necessitating repair measures. This paper focuses on the comprehensive analysis of data collected through on-site monitoring and nearby weather stations.
Bridge components that were and are exposed to high chloride levels were rehabilitated with different systems and monitored over more than a decade. In the paper the rehabilitation methods, the sensor principles and initial corrosion data are presented. Seasonal corrosion trends revealed interdependencies and offered insights into repair effectiveness and its durability.
This study provides insights into cost-effective and prospective maintenance strategies, based on key indicators such as humidity, electrical resistivity, and corrosion potential. It assesses the condition of structures rehabilitated by hydrophobic treatment and coating using long-term monitoring data from a Vienna overpass. This offers valuable insights into the effectiveness of repair measures.
The continuous monitoring allows for ongoing evaluation of degradation and maintenance efficiency, that guide decisions on future maintenance intervals. This research serves as an assessment of maintenance effectiveness, ultimately contributing to save costs, extend lifespan and reduce line closures of critical road infrastructure.

Keywords

Bridge durability, corrosion monitoring, maintenance effectiveness, chloride contamination, structural condition.

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Multiphysics-Lattice Discrete Particle Model: possible strategies for upscaling

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Abstract

The optimisation of civil infrastructures maintenance and management is a challenging task, disseminated of open issues requiring the synergic development of effective structural health monitoring systems and reliable models to be addressed. Relevant to concrete structures, models cannot disregard the multi-physics nature of the problem: moisture and heat transport phenomena in uncracked and cracked conditions, the ingress of aggressive agents and the ensuing chemical reactions - that the latter may trigger - heavily affect the mechanical performance. Most of the mentioned processes happen at a scale typically smaller than the structural one. Then, it is also necessary to perform multiscale analysis, capable of adapting structural models upon the insights resulting from lower scale analyses.

In the last decade, the Multiphysics-Lattice Discrete Particle Model (M-LDPM) has been successfully adopted to model a wide range of phenomena in civil engineering involving concrete structural members: ageing, environment-induced degradation, shrinkage, creep, and usage of advanced construction materials. Furthermore, the discrete nature of the model has shown the capability of predicting the cracking patterns accurately. However, such comprehensive and accurate model simulates the material at the mesoscale, and computational and theoretical burdens pave the path towards the exploitation of the insights resulting from lower scale modelling at the structural level.

In this work a review of the state-of-the-art concepts that allow upscaling micro- and mesoscale mechanical and multiphysics models is presented to explore alternatives for the formulation of computationally efficient macroscale models that leverage on the predictive quality of M-LDPM, in capturing and predicting the material constitutive behaviour, and the computational affordability that features the classical Finite Element Method for the structural analysis of complex systems. Finally, a preliminary proposal for the model upscaling is presented.

Keywords

Upscaling, multiscale model, multiphysics model, state-of-art, concrete, durability

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ID:228

NDT Technologies for Post Tensioned Concrete: National Highways' 'Structures Moonshot'

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Abstract

The "Structures Moonshot" project, initiated by National Highways and led by Atkins, Jacobs, and supported by VSL, advances non-destructive testing (NDT) for highway structures, with a focus on post-tensioned bridges and half joints. Launched in late 2022 and continuing until 2024, its vision to revolutionise asset management for vulnerable bridges, enabling better and more efficient data collection, leading to self-monitoring and self-diagnosis for National Highways' most critical structures.

The project comprises two phases; The first involves testing high Technology Readiness Level (TRL) NDT technologies on bridge sections from the dismantled A14 Huntingdon Viaduct. These are compared with the as-found physical conditions after hydro-demolition. The goal is to evaluate current NDT methodologies, identify areas for improvement, and enhance efficiencies in deployment.

The second phase centers on developing low TRL NDT technologies tailored for post-tensioned bridges. This includes the use of guided wave technology, with the aims of enabling direct tendon deterioration measurements without intrusive inspections.

Through the collaborative efforts involving National Highways, AtkinsRealis, Jacobs, VSL and the NDT supply chain engaged with the project, this work is leading to a better understanding of how we can determine the condition of post-tensioned bridges and half joints. The project will also provide valuable insights for future bridge inspections and structure maintenance works, enabling the development of clear training and guidance on optimal NDT deployment. This in turn will improve our overall asset management practices, ultimately leading to better safety of our structures and those using and maintaining them, and reducing disruption on our road networks.

Keywords

NDT, Post Tensioned Bridges, Inspection, Structural Health Monitoring

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ID:245

Diaphragm effect of unreinforced and retrofitted historical masonry vaults

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Abstract

In historical masonry structures, and particularly in churches, vaults have a fundamental role in bearing the vertical loads of floors and roofs. However, in past earthquakes they have proved vulnerable, representing a source of fragility for churches and palaces. In addition, the global seismic behaviour of masonry structures is strongly affected by the stiffness of flooring elements (diaphragm effect), which, when sufficient, allows for transfer of horizontal actions to stiffer wall working in-plane.
In this paper, the diaphragm effect of historical masonry vaults under horizontal loads is investigated numerically. A nonlinear Finite Element model of a cross vault is subjected to in-plane shear actions on two supports to evaluate the stiffness degradation following damage during an earthquake. Appropriate and compatible retrofitting actions are also studied to assess their effectiveness in enhancing the seismic response of the vaults. This work is preparatory for future physical testing activities on scaled prototypes to be performed within a broader research project, aimed at the enhancement and exploitation of artistic and cultural heritage.

Keywords

Cross vaults, In-plane loading, Nonlinear modelling, Seismic retrofitting, dynamic analysis

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Alternative ULS Assessment Methodology for Existing Freyssinet Concrete Hinges in UK Highway Structures

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Abstract

This paper outlines a method of assessment for the Freyssinet concrete hinges present at the existing structures on the A465 Heads of the Valleys Section 5 & 6 Scheme in the UK beyond that provided by National Highways' Design Manual for Roads and Bridges (DMRB) document CS468, which does not provide a sufficient mechanical model to demonstrate either safety or previous acceptable performance of the hinges in service.

Until the release of CS468 Assessment of Freyssinet concrete hinges in highway structures (Nov 2019), no assessment standard was available for Concrete Hinges. The previous standard, BE 5/75, covered design only and was withdrawn as the use of concrete hinges in new design in the UK is no longer permitted, unless in exceptional circumstances.

CS 468 undertakes assessment at the Serviceability Limit State on the basis that cracking and spalling to the concrete in or around the throat will lead to the ingress of water and subsequent corrosion to the reinforcement. However, recent application of the CS468 SLS assessment approach to the existing bridges on the A465 has identified that it will typically not be possible to satisfy the resistance to cracking check it contains at the Serviceability Limit State. The resistance to end block splitting is also often not satisfied due to low reinforcement in the hinge end block.

It is noted that the existing Freyssinet concrete hinges on motorway and all purpose trunk road bridges in England have generally been found on site to perform well at SLS and be structurally reliable to date and therefore a mechanical model based on ULS strength is presented here to provide justification of their acceptable performance and safety.

Keywords

Bridge, Concrete, Assessment, Freyssinet Hinge

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ID:298

Nondestructive test for visualization of water movement in concrete using neutron imaging

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Abstract

Water penetration in concrete has been introduced into Japanese Standard Specifications for Concrete Structures 'Design' in 2018. This clearly shows that water ingress through surfaces can affect steel corrosion. Test method for water penetration rate coefficient of concrete subjected to water in short term was indicated at the same time. In 2022, Specifications 'Maintenance' has involved this coefficient to estimate progress of steel corrosion. The proposed test method can be useful for maintenance on the one hand and has a problem on the other. The test is performed in destructive way and needs nine circular specimens (100 mm in diameter and 200 mm in height). The aim of this research is to develop nondestructive test method which can visualize water movement in concrete. Neutron imaging is chosen to attain this goal and is conducted at the RIKEN Accelerator-driven compact Neutron Source, RANS. For incident neutrons, transmittance is changed by the element distributed to the transmission direction and the volume. Especially, hydrogen strongly scatter incident neutrons and water is imaged as shades.

Keywords

Concrete, Water Movement, Neutron Imaging, Nondestructive test, Compact Neutron Source

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ID:304

3D Deep Learning for Segmentation of Masonry Tunnel Spalling

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Abstract

Historic masonry lined tunnels form a large proportion of the world's railway tunnel stock. However, as many of these date from the second industrial revolution over 150 years ago, they typically contain large areas of structural deterioration. Masonry spalling is a pervasive form of surface damage and its severity, defined by the depth of spalling, is indicative of a tunnel's structural condition. Current tunnel spalling condition assessment procedures are largely manual, so the extent of spalling observed on many historic tunnels presents a challenge for timely and cost-effective assessment. Automated machine learning based workflows have shown substantial potential for automating and reducing the subjectivity of the assessment process. A key step in these workflows involves segmenting the location of masonry joints from 3D point clouds of the tunnel lining in order to isolate masonry block locations. The most prevalent method is to unroll 3D tunnel lining data into 2D before applying U-Net based convolutional neural networks to segment joint locations. However, recent developments in 3D point based neural networks enable semantic segmentation to be conducted directly on the input point cloud. Point based methods such as KPCONV provide 3D feature characterization and enable semantic segmentation of a wider variety of tunnel geometries by default, since a handcrafted unrolling strategy is not required. This study conducted a performance comparison between 3D KPCONV, 2D U-Net, and XGBOOST feature classifier based joint identification techniques. In order to effectively compare a real-world use-case where time consuming manual data labelling should be minimized, the methods were only trained on a 9.94m section of tunnel. It was found that a 2D U-Net combined with tunnel unrolling workflow could be more successfully trained on the case study dataset and due to effective transfer learning, achieved superior performance to KPCONV and XGBOOST methods.

Keywords

Masonry Tunnel, Deep Learning, Lidar, Condition Assessment

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ID:352

Assessment of the structural integrity of glulam using modal analysis and finite element updating

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Abstract

The increasing adoption of glued laminated timber (Glulam) as an environmentally conscious material in construction has been driven by its excellent structural properties and lower carbon footprint compared to other conventional materials. However, its organic nature underscores the need to ensure the long-term integrity of these glulam structures. This paper proposes a novel approach to non-destructive testing through the combined application of modal analysis and updated finite element modelling. These advanced techniques allow a more accurate and detailed assessment of the structural condition of glulam. Modal analysis identifies changes in natural frequencies and vibration modes caused by potential material degradation, providing valuable structural health information without compromising the integrity of the material. To achieve this objective, the paper proposes to compare the real values measured in the modal analysis with those obtained from the numerical model by formulating an objective function that measures the error between the two. The differences between the two models are reduced using techniques based on Particle Swarm Optimization (PSO). The work presents a specific formulation aimed at achieving greater efficiency in the search for defects in this material. This approach enables the adjustment of the numerical model by identifying damaged areas. The results of the proposed method are verified by laboratory tests. For this purpose, glulam samples with different defects were tested and their identification was verified by updating the finite element models, demonstrating the ability and accuracy of the method to identify areas where the structural stiffness has decreased due to deterioration.

Keywords

Glulam, modal analysis, finite element updating, particle swarm optimization

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ID:463

The dynamic analysis of the Troja footbridge – the analysis of the possibility of the early warning before the collapse

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Abstract

The subject of this paper is to summarize the results of the analysis of the Troja footbridge collapse. The footbridge from 1984 carried pedestrian traffic across the Vltava River in Prague. The superstructure consisted of a stressed ribbon bridge with the main span 96.00 m. On Saturday, 2 December 2017, the footbridge collapsed and four people were injured.
The analysis included the inspection of the remains, creation of the numerical models for the global and local analysis and analysis of the measurement and dynamic tests, done on the bridge. The analysis included the impact of variable influences, including the defect of the tendons, temperature and boundary conditions. Based on variable methods, such as non-linear analysis, dynamic analysis of the mode shapes and natural frequencies, changes in the modal flexibility matrix, change of mode surface curvature CAMOSUC(j),x the conclusions are given, if the failure could have been detected by used methods.
Paper also gives recommendation for the monitoring and dynamic tests of similar structures, the density of the sensor net and temperature measurements so that the damage can be detected.

Keywords

Bridge; Collapse, Modal analysis, Monitoring; Damage detection

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Practical applications and case studies

ID:027

Seismic vulnerability evaluations of a masonry tower by considering creep effects

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Abstract

Historical masonry constructions were typically designed and built by considering exclusively the gravity loads. Unfortunately, their structural weaknesses are mostly related to two different factors: the horizontal loads (earthquake) and creep effects. The first is currently object of intense research activity, which results in updated design codes and guidelines at both national and international level. The latter is a rarer event which affect mainly those structure carrying huge dead loads such as towers. In order to assess the structural vulnerability of high masonry buildings, commonly these two factors are considered non mutually in the analysis. Since historical towers are attended to be preserved in a long-time period, the seismic vulnerability should be considered by taking into account the creep effects occurred along the decades or centuries of service life. At this scope, a case-study is presented herein referring to an ancient masonry tank tower located in the south of Italy within a low seismicity region. The tank's use drastically affected the structures which was severely overloaded and creep effects are not negligible. By means of *Finite Element Method* (FEM), associated to available masonry creep analytical laws, the structural behavior was simulated at different grades of creep deformation. A preliminary experimental investigation was performed in order to know the materials and the structural details. Then a push-over analysis was conducted by varying the mechanical parameters of the masonry according to the creep law at different ages. The conclusions of the study offer valuable information that include the creep effects with respect to the seismic vulnerability assessment.

Keywords

Historic tower, Creep, Crack pattern, FEM, Structural assessment

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ID:040

Preliminary bridge damage assessment through machine learning

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Abstract

Bridges worldwide are failing at increasing rates as they heavily suffer from deterioration, leading to the transport infrastructure system disruptions and millions in losses. For example, the failure of the Polcevera bridge alone cost € 359 million in the immediate wake, with estimated annual losses to the Italian economy in the vicinity of one billion euros. Despite the aid of technologies involving digital measurements and data collection from remote and structural health monitoring, bridges still fail. The reasons behind those failures are mainly due to the fact that damage is not easily discoverable despite the data at hand and the scarce availability of design drawings to the asset assessors, especially for old bridges. Furthermore, the construction sequence of the asset or level of prestressing are often unclear, hence the as-built condition and properties of bridges are largely unknown. Deck scanning techniques are often expensive therefore are rarely adopted by transportation stakeholders and operators. This is a capability gap that can only be filled with engineering judgement as well as meaningful data collection and evidence in aid of decision-making. This paper provides a unique approach for undertaking a preliminary bridge damage assessment. The landmark balanced cantilever bridge of Polyfytos, located in the North-West part of Greece, was utilised in this paper. Heterogenous data and evidence were initially collected and deployed in order to inform and backtest an advanced numerical model of the bridge aiming to match measured deck displacements. Damage scenarios were then examined to explain vertical deflections accounting for a range of concrete Young’s Modulus and variable damage patterns in the tendons. The unsupervised machine learning algorithm k-Nearest Neighbours (k-NN) was finally adopted to strengthen the damage identification capability and classify the observed bridge deflected shape−for which the Young’s modulus has been identified−to the closest training set sample damage scenario. It was showcased that the presented methodology could be utilised to efficiently interpret deflections that are measured on the bridge deck.

Keywords

Bridge, point cloud deflections, damage, machine learning, decision-making

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ID:041

Implementation of the Non-destructive Testing for Damage Analysis in Structural Engineering

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Abstract

The renovation of existing buildings and infrastructures is becoming in the last years increasingly important. This results in a greater and greater need to understand the real condition of building components and what can determine its level of damage. There are many known methods in the field of structural health monitoring and damage control. Among them, non-destructive testing (NDT) methods assume particular importance as they enable the evaluation of structural integrity without compromising functionality. A NDT technique that gives a view into the interior of the material at laboratory scale and in practice is computed tomography (CT). This technique can be particularly useful in concrete, where insight into the interior can enable a detailed analysis of the reinforcement and potential risks to its integrity, such as corrosion. By taking X-ray scans from different sides of concrete elements, 3D data can be created, which makes it possible to determine cracks, pores, and defects. This article will explore the potential of non-destructive testing using CT in the context of damage analysis for concrete structures. An example will be shown on a small laboratory concrete sample, focusing on how to methodically approach the scan and process the resulting data. Finally, the results will be discussed, and some further research possibilities will be presented.

Keywords

Damage control, non-destructive testing, computed tomography (CT), reinforced concrete (RC)

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ID:068

Assessing Asphalt Pavement Pre-Compaction with Paver Screed Frequency Measurements

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Abstract

The quality and longevity of an asphalt road hinge on the meticulous compaction of the asphalt pavement. Particular emphasis should be placed on the pre-compaction process involving the paver's screed. Inadequate or excessive pre-compaction can result in paving errors and inhomogeneities within the pavement, which even expert roller operation cannot rectify. In practical paving, however, the degree of pre-compaction is rarely determined, so that one is dependent on the empirical knowledge and assessments of the paving personnel.

Within the context of the research initiative, InfraROB (Grant Agreement No.: 955337), an innovative system was devised to infer the extent of pre-compaction by leveraging the resonance frequency of the paver's screed. This system comprises a rugged, enclosed acceleration sensor capable of capturing high-speed accelerations and a Wi-Fi-enabled control unit for data storage and processing.

To validate this system, a series of test pavements were constructed using an asphalt binder mix (AC 16 BS), deliberately varying the speed of the tamper compaction unit in four steps from 0 rpm up to 1500 rpm. Half of the test lanes were longitudinally compacted with rollers, allowing for the examination of the asphalt pavement in its partially pre-compacted state. To achieve this, drill cores were extracted, and their density was assessed in the laboratory. Through the application of Fast Fourier Transformation, the measured resonance frequency data was analyzed and subsequently correlated with the outcomes of the drill core inspections. This analysis revealed a strong logarithmic relationship between the average peak acceleration and the bulk densities measured, with a high coefficient of determination exceeding 0.9.

The presented method enables real-time assessment of the pre-compaction status of asphalt pavement, offering support to paving personnel, optimizing roller usage, and ultimately enhancing asphalt pavement quality.

Keywords

Asphalt, Paver, Compaction, Resonance Frequency, Acceleration Sensor

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ID:092

Structural Monitoring and Rehabilitation of a Gerber Bridge

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Abstract

Many existing reinforced concrete bridges exhibit behaviour at the Service Limit State and the Ultimate Limit State which can be considered unsatisfactory with respect to the current provisions of Codes, but which are actually deficiencies deriving from obsolete calculation methods, structure age, material degradation, diffuse or localized corrosion and increased loads. Among these, cantilever bridges with half-joints may present a decrease in global safety coefficients for the most stressed current sections of the deck or in the local ones, that affect the performance of elements sensitive to degradation, such as Gerber saddles. In order to perform vulnerability assessment, the validation of FEM models against experimental test is of fundamental importance for acquiring information on the constraint conditions, verifying the structural scheme by identifying the degree of collaboration between the various structural elements and identifying the state of cracking. Thus, for a case of study the results of a structural assessment performed with Finite Element model are presented through validation with in-situ investigations. Then, a simple strengthening intervention through external prestressing that reduce the tensile stress in concrete areas subject to cracking, as well as the deformability of the points that have accumulated displacements over time (due to creep or degradation), is implemented without the need to recourse to interventions of greater impact, obtaining an improvement in the structural behaviour or a variation of the static scheme that improves the overall performance. The results of the analysis in the present state, the deficiencies found as well as the possible level of increase in the safety coefficients at ULS with the proposed intervention are presented.

Keywords

Structural Monitoring, Gerber Bridge, External Prestressing, Creep, SLS

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ID:110

Combined strain, vibration, and acoustic monitoring of the Jules Verne viaduct

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Abstract

Prestressed concrete viaducts have been widely built in France and Europe in the past decades and are often strategic assets for the road networks, which deserve structural health monitoring (SHM) techniques to assess and anticipate the effects of their ageing.
The Jules Verne viaduct near Amiens in France has been chosen as a case study to gather high volumes of data on its response to the live loads through a long period of time, in the frame of a common research by OSMOS Group, the Université Gustave Eiffel, the CEREMA, and Le Mans Université.
The viaduct is a 943 m long bridge with 19 spans. It is made of two independent parallel decks, the first one built in 1988 and the second one in 2002, with similar geometry but significant differences in terms of prestress design. Both decks have been equipped with strain and acceleration sensors since February 2022, continuously gathering measurements at each passage of heavy vehicles on the bridge. In addition, a campaign of acoustic emission measurements was organized in July 2022.
This contribution summarizes the various data analysis methods used on the large quantity of records gathered over almost two years, to obtain synthetic useful information from the combination of diverse monitoring techniques. Results and perspectives are discussed, focusing on this interesting opportunity to compare the behavior of two similar prestressed concrete structures with 14 years age difference, in field conditions and under real traffic loads.

Keywords

Structural Health Monitoring, Prestressed Concrete, Acoustic Emission, Datascience

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ID:125

Rebar detection: comparison of stepped frequency continuous wave and pulsed GPR

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Abstract

Reinforced concrete structures are widely used in civil engineering owing to their versatility, strength, and durability. One of the most recommended methods for rebar mapping is Ground-Penetrating Radar (GPR) because of its non-destructive and non-invasive character. In concrete mapping, GPR is mainly used for locating subsurface objects (rebars, tendons, ducts), measuring concrete cover, mapping mesh configuration (spacing), and detecting bottom of slab. To achieve these, concrete scanning GPR practitioners often need very high-resolution images. This work presents a comparison in rebar mapping between two GPR systems with different modulation techniques: Stepped frequency continuous wave (SFCW) and pulsed radar. The SFCW system used has a frequency range of 400-6000 MHz, while the pulsed system used a ground-coupled central frequency antenna of 2.3 GHz. Measurements were conducted on laboratory specimens, with rebar diameters ranging from 8 to 32 mm. Three different specimens were used, with one for calibration and other two to analyze both the horizontal and vertical resolutions of the frequency antennas.

Keywords

Ground-penetrating radar, rebar specimens, detection, frequency domain, time domain

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ID:166

Load capacity assessment of traffic superstructures for roads and tramways

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Abstract

The load-bearing capacity of traffic superstructures is usually assessed based on deformation measurements. The bearing capacity is defined as the superstructure's resistance to short-term deformations. However, different measurement concepts and evaluation methods are required for different superstructures to assess the bearing capacity. Therefore, different methods for road and tramway superstructures will be presented in this paper and exemplified by practical examples.

The bearing capacity of road pavements is typically assessed by deflection measurements using the falling weight deflectometer (FWD). In this dynamic measurement method, a falling weight is applied to the road surface, and the resulting deformation basin is recorded for a short time. This can then be evaluated. Non-destructive measurements can be carried out with the FWD, so comparative repeat measurements at individual points are also possible later. Evaluations of various measurements in Germany are presented.

The assessment of load-bearing capacity in the tramway sector is not currently established in German regulations. An individual measurement concept was developed and applied to assess the load-bearing capacity in urban transportation. In addition to vertical deflection, lateral displacements, as well as torsion of the grooved rail and torsion at the rail head, are to be considered. The measurements aimed to determine the in-situ deformations of the grooved rail with a selected type of fastening during the passing of tramways. In addition, the serviceability during operation was checked. The measurements were carried out on an open construction (grass track) and a closed construction (asphalt). Furthermore, track sections with tight curves and straight track were investigated. The applied measurement concept was developed for application in a large German city and can detect the above-mentioned movements. Based on the deformations determined, conclusions can also be drawn about the service life.

Keywords

Non-destructive testing, pavement, tramway, load-bearing capacity, deflection

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A framework for the assessment of road network resilience: application to different urban contexts

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Abstract

Road networks include strategic and critical infrastructures that must operate effectively at any moment for the well-functioning of a country's economy. In this context, the risk of traffic closure and/or limitations is constantly present due to a plurality of natural and man-made hazards. In this work, a novel framework for the assessment of road network resilience to both single and multiple hazards is proposed for applications to large road networks located in densely populated urban/extra-urban areas. Multiple potential sources of hazards and their potential consequences are identified. Strong interaction between the infrastructure and the urban or extra-urban area is considered. Disaster resilience is evaluated by considering both the infrastructure's own assets – such as bridges and viaducts – and the buildings of the urban/extra-urban area where the infrastructure is located. This allows several interdependencies between the road network and buildings to be modelled and considered in the computations, such as the failure of some network connections due to the collapse of some buildings. The main resilience assessment is herein done with respect to earthquake ground motion. Then, some hints are provided for resilience assessment that also accounts for land monitoring data, allowing identification of the optimal connections in post-disaster efficiency assessment of the road network by incorporating information on geohazards from both terrestrial and satellite systems.

Keywords

Road Networks, Network Resilience, Infrastructures, Multi-hazard Risk Assessment, Earthquake Engineering.

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Best practices for SHM in conservation: the case study of a Saint John, NB cathedral

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Abstract

Heritage buildings stand as a testament to past generations and a promise to future ones, linking those who built them, those they were built for, and the people who continue to tread their floors. Given their profound cultural significance, enabling their continued use is crucial for sustainability in the built environment. Effectively conserving these structures presents a unique set of challenges and considerations distinct from those encountered in new construction. Structural health monitoring (SHM) allows for a better understanding of performance metrics in historic buildings on a case-by-case basis, enabling heritage professionals to precisely target conservation efforts with minimal disruption.

In this paper, we describe the steps and challenges involved in using SHM in the conservation of historic buildings via a case study of the Cathedral of the Immaculate Conception at Saint John, New Brunswick, Canada. First, the problems created by previous conservation efforts are discussed and the current and future conservation plans are outlined for at a site progressing towards failure without intervention. Next, we present the approach used for implementing an SHM system to monitor the Cathedral's masonry walls and spire, followed by the early-stage results. This SHM system is expected to assist in damage detection and minimize the cost of intervention.

Keywords

Structural Health Monitoring (SHM), Structural Conservation, Historic Masonry, Structures at Risk of Failure

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ID:300

The role of in situ dynamic tests on model updating of existing RC infilled structures

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Abstract

Infill masonry walls are one of the most common non-structural elements worldwide adopted to create external and internal partition walls in reinforced concrete (RC) frame structures. Both in the design of new RC frame buildings and in the assessment of the existing ones, it is common practice to neglect the presence of infill walls that are only considered as added masses and loads. However, as revealed by earthquakes, the performance of this type of building can be significantly affected by the presence of infill walls according to their type and distribution in the plane and along the height.

In last decades, often vibration-based tests have been adopted to investigate in-situ the influence of the non-structural elements on the dynamic behaviour of buildings.

This paper discusses the usefulness of the dynamic characterization of buildings based on the use of ambient vibration tests at different phases of rehabilitation works to highlight the role of internal and external infill walls. The case study is an existing RC framed building designed for gravity loads and containing unreinforced masonry infill walls. Three ambient vibration tests, i.e., on the as built structure, after the demolishment of the internal partition walls and after the demolishment of the internal partition walls, have been carried out. The 3D finite element model of the building has been successfully updated based on the global modes identified by the in situ tests, pointing out the important role of the non-structural components for this type of building. The experimental tests integrated with traditionally non-destructive in-situ tests for the estimation of the material mechanical properties, also have allowed the monitoring of the evolution of the building modal properties during the main phases of rehabilitation works.

Keywords

Infill walls, dynamic test, OMA, r.c. structure, model updating

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ID:333

Case study: Câmara Municipal de Guimarães. HBIM modeling from non-destructive techniques

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Abstract

This study focuses on the application of HBIM for the comprehensive monitoring of the structural health of the Câmara Municipal de Guimarães. To carry out this comprehensive assessment, advanced inspection techniques were employed, including ground-penetrating radar (GPR), thermal imaging, terrestrial laser scanning (TLS), and visual inspection. GPR was used to assess wall thickness and detect potential hidden voids within the building, providing detailed information on material integrity and identifying structural anomalies. This non-destructive technique allowed for a precise evaluation of the physical condition of the structure. Thermography was applied to locate beams and areas affected by humidity, offering essential data for corrective interventions and structural strengthening. The combination of TLS and visual inspection enabled the creation of an accurate 3D BIM model. This method provides a detailed virtual representation of the geometry and current condition of the building, facilitating subsequent structural monitoring and allowing the inclusion of particularly useful data for future studies or restorations. This case study highlights the successful implementation of innovative technologies for the preservation and strengthening of architectural heritage. It serves as a model for future research and the practical application of advanced solutions in structural health monitoring.

Keywords

Ground penetrating radar, Terrestrial laser scanning, Heritage-BIM, Thermal imaging.

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Global Insights into Wind Turbine Safety Standards: A Comparative Analysis of Policies in Emerging Economies

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Abstract

This paper presents an extensive comparative analysis of wind turbine safety standards and regulations in emerging economies, aiming to understand how these countries can mitigate catastrophic accidents in wind energy production. The study is rooted in the increasing global reliance on wind energy, juxtaposed against the lack of comprehensive analysis in the existing literature regarding policies and practices in wind turbine accident prevention, particularly in emerging countries.

The research adopts a methodical approach, beginning with a thorough collection and categorization of wind turbine accident data from several countries, including the United States, the United Kingdom, Germany, Denmark, and others. This data collection, spanning over a decade, includes detailed records of accidents categorized as fire, structural, installation, and maintenance incidents. The study's scope is further narrowed to four countries based on the size and frequency of reported accidents.

In the core of the analysis, the wind turbine policies of these countries are mapped and examined. This includes an in-depth look at manufacturing and maintenance standards, with specific focus on their alignment with or deviation from international standards like IEC 61400. The study delves into the specific clauses of wind power policies as they pertain to various types of accidents, critically assessing their strengths and weaknesses.

A significant part of the research involves comparative analysis. By contrasting the wind turbine policies of different countries, the study identifies best practices and policy gaps. It provides insights into successful measures adopted by some countries in preventing specific types of accidents and offers recommendations for others to enhance their policy frameworks.

The findings of this research are particularly significant for policymakers, industry stakeholders, and regulators in the wind energy sector. They offer a comprehensive understanding of the complexities and challenges in framing effective wind turbine safety standards and suggest pathways for improving these standards globally. The study's conclusions are expected to contribute substantially to the discourse on enhancing the safety of wind energy infrastructure, thereby supporting the sustainable development of this crucial renewable energy source.

Keywords

Wind turbine, accidents, policy analysis, data mining.

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Global Perspectives on Recycled Concrete Aggregates (RCA): a Comprehensive Review of Worldwide Applications and Best Practices

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Abstract

Given the high consumption of natural resources, sidewalks are considered one of the most cost-intensive pieces of infrastructure. The use of recycled concrete aggregates in road pavements can provide a beneficial approach to improving economic, social and environmental sustainability. RCA is considered a multi-layered solution that protects natural resources, minimizes road construction costs, and limits harmful emissions.

Research has found that RCA can be effectively applied to a variety of pavement layers, including base and surface layers. It was also observed that the mechanical and physical properties of RCA can be studied and compared with those of natural aggregates. Additionally, several technologies that can be used to improve RCA performance on pavement are revealed.

Although RCA may be considered a viable and sustainable alternative to NA in pavement applications, recommendations regarding replacement rates in asphalt mixtures still vary widely. To ensure a balance between sustainability, functionality and quality of pavements, the continued rollout of RCA implementation relies on in-depth research leading to a unified and homogeneous set of standards and specifications. This article highlights the role of RCA as an important driver of sustainable road construction as well as circular economy strategies. It may also call for advanced research and shared decision-making to realize the full potential of RCA.

Keywords

Recycled concrete aggregates (RCA), sustainability, pavement, circular economy.

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ID:433

In-situ testing and modeling of a masonry bridge in Surrey (UK): Waverley Mill bridge

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Abstract

Many historic masonry arch bridges within the road and railway systems across Europe and the United Kingdom remain operational despite exhibiting structural deficiencies. In the United Kingdom alone, there are more than 70,000 masonry arch spans have undergone design modifications and load adjustments over the years. These modifications typically entail incorporating new materials and bearing elements, with compliance to modern standards being rare. Such circumstances lead to limited understanding of these structures, impacting the accuracy of the bridge capacity assessments. This study is dedicated to the examination of a composite bridge composed of two spans with limited accessibility, located in Waverley Abbey, Surrey. The research delves into two primary aspects: firstly, the diagnostic phase involving in-situ non-destructive methods such as Ground Penetrating Radar (GPR) and more intrusive techniques like slit trenches. The second phase entails a numerical assessment using a three-dimensional Finite Element model and kinematic static analysis. To improve the structural reliability, a conventional rehabilitation method is assessed numerically. This involves reinforcing the intrados of the arch and the bridge piles using repointing and jacketing, respectively. As the Waverley bridge serves as a representative example of the numerous structures predominantly found in the Surrey region, this investigation can be extended to include bridges sharing similar material, geometry, and shapes.

Keywords

Masonry bridge, Kinematic analysis, In situ tests, FEM analysis, Strengthening.

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ID:437

Stability-Based Optimum Design of Tuned Mass Damper using Chaos Game Optimization in Pole Placement Scheme

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Abstract

The present work investigates the optimization of Tuned Mass Dampers (TMDs) for improving the seismic behavior of structures by considering system stability using a robust Chaos Game Optimization (CGO) metaheuristic algorithm. In this regard, a new approach was introduced to locate the poles of the system as an objective function in the optimum design of TMDs. In this scheme, the mechanical parameters of TMD are designed to find the pole placement of the structural system with more stability. This research presents a dynamic analysis and comparative evaluation of various cost functions—including relative controlled drift response, the transfer function (TF) of acceleration response, and pole placement scheme—to determine the most effective design for TMD parameter optimization. Structural control performance indexes are used to compare the seismic behavior of each design. The results demonstrate the cost function based on the pole placement scheme's capability to enhance TMD design, suggesting valuable theoretical and practical understandings for more resilient and efficient structural designs.

Keywords

Tuned Mass Dampers (TMDs), Pole Placement Scheme, Transfer Function, Seismic response, Chaos Game Optimization (CGO)

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Shape memory alloys in civil structures

ID:022

Slenderness effect on failure modes in RC beam strengthening with unbonded Fe-SMA strips

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Abstract

This paper presents an experimental investigation on reinforced concrete beams with different slenderness strengthened with unbonded Fe-SMA strips. The retrofitting system acts as an external prestressed tendon with a mechanical anchorage. In a first step, the strips are positioned against the concrete bottom surface and fixed against the concrete substrate with a direct fastening system. Activation and hence prestressing of the strips is performed with a gas torch and a subsequent temperature control. The concrete elements are afterwards subjected to 4-point bending up to failure. The aim of the investigation is to assess the structural behavior of the retrofitted members as well the additional strain and stress development in the Fe-SMA strips under additional loading after prestressing. Stress increase in the external strip resulting from the flexural loading has a direct influence on the failure mechanism in a sense that the ultimate stress is governed by the anchorage resistance. It is for instance shown that failure in bending with slender beams and plates is governed by concrete crushing in the upper compression zone, whereas beams with a reduced span exhibit premature failure by steel bar failure in tension or by ultimate anchorage resistance. The experimental results are compared with numerical simulations from an advanced cross section analysis tool established for unbonded strengthening systems.

Keywords

External unbonded Fe-SMA strips, flexural strengthening, failure mode, girder slenderness

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ID:065

Effect of thermomechanical training on recovery stress of Fe-based shape memory alloy

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Abstract

This research explores the impact of thermomechanical treatment on the recovery stress induced by the shape memory effect in an Fe-based shape memory alloy with the composition of Fe-17Mn-5Si-10Cr-4Ni-1(V,C) wt.%. Fe-based shape memory alloys have gained considerable attention for their potential applications in vibration control, energy dissipation, and structural strengthening or re-centering within the construction industry. To evaluate the recovery stress behaviour of this Fe-based shape memory alloy, specimens underwent a two-step aging heat treatment process, involving initial aging at 600 °C for 20 hours, followed by subsequent aging at 680 °C for 8 hours. Then heat-treated samples subjected to a cyclic thermomechanical treatment, involving a combination of deformation up to 2% and heating at 200 °C for 15 min in each cycle. The microstructure and mechanical properties were assessed using techniques such scanning electron microscopy, as well as tensile tests. The results revealed that the thermomechanical treatment had a notable impact on the microstructure and mechanical properties of the Fe-based shape memory alloy. It resulted in an enhancement of the shape memory effect and recovery stress. These improvements were associated with an increase in the martensitic phase fraction, an elevation in crystal orientation, and a reduction in grain size. Additionally, the presence of VC precipitates and the formation of specific textures in the treated samples contributed to the enhancement of the shape memory effect.

Keywords

Iron-based shape memory alloy, recovery stress, thermomechanical treatment.

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ID:069

Potential of Fe-Mn-Al-Ni shape memory alloys for prestressing applications in civil engineering

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Abstract

Iron based shape memory alloys (SMAs) attracted considerable attention in recent years, especially with respect to potential applications in civil engineering. The inherent shape memory phenomena like superelasticity and the shape memory effect (SME) offer great opportunities for use as damping, coupling or prestressing elements. Considering the SME, a deformation initially remains after unloading and the shape recovery can be initiated by subsequent heating. If the shape recovery is constrained during heating, e.g. by a firm anchorage to another structure, a considerable mechanical stress builds up. In the field of civil engineering, this effect can be used to reinforce concrete structures by prestressing with shape memory alloy elements. In contrast to traditional prestressing technologies using high strength steels, the use of SMAs opens up new design opportunities and simplifies retrofitting of existing buildings. Fe-Mn-Al-Ni SMAs are one of the most promising SMAs for the envisaged application. The present study shows the prestressing potential of the alloy and the influence of different process parameters. Due to the growth of nanosized precipitates in the same temperature regime required for activation of shape recovery (150°C-300°C) the prestress level can be tailored as a function of both, maximum heating temperature and dwell time. This also includes the possibility of subsequent increase of prestress level during service life.

Keywords

Iron-based shape memory alloy, Prestressing, Retrofitting, Tailorable properties, Precipitates

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ID:070

Effects of semi-cyclic loading on the recovery stresses of iron-based shape-memory alloy bars

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Abstract

Shape-memory alloys (SMAs) have attracted considerable interest in structural engineering because of their ability to ‘memorise’ their original form when subjected to thermomechanical variations, a phenomenon termed the shape memory effect. By controlling the heating and cooling (activation) of SMAs under constrained deformation, recovery stresses can be generated, making SMAs suitable for use as prestressing reinforcement in concrete structures. However, recent studies suggest that the benefits of reinforcing with iron-based SMA (Fe-SMA) could be considerably reduced under semi-cyclic loading, due to the decrease on recovery stresses.
This paper focuses on analysing the behaviour of 16 mm diameter Fe-SMA reinforcing bars when subjected to consecutive activations and semi-cyclic tensile tests. Activations at different temperatures (160, 200 and 250 ºC) were performed, followed by semi-cyclic load tests until high strain levels were carried out. The results show a correlation between the temperature reached during the activation and the recovery stress achieved. Furthermore, the data reveals that high strain levels induced by semi-cyclic loads can lead to a complete loss of the initially generated recovery stresses. However, by re-activating the Fe-SMA samples, it is possible to restore a similar level of the initial recovery stresses. Moreover, for practical structural engineering applications in RC beams, where strain increments might be modest, only partial stress losses would be produced. These partial losses could be treated, for designing, as a prestressing loss.

Keywords

Iron-based Shape Memory Alloys, Activation, Recovery stresses, Semi-cyclic loads

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ID:071

Experimental study on semi-cyclic loading effects on Fe-SMA reinforced concrete structures

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Abstract

Concrete structures often face unforeseen challenges, whether from degradation or unexpected actions, requiring innovative strengthening techniques to extend their lifespan. In the last decade, shape-memory alloys (SMAs) have gained significant attention in structural engineering owing to their unique ability to recover from deformation, attributed to the shape-memory effect (SME). When constrained, SMAs can act as prestressing reinforcement, generating recovery stresses upon activation (heating and cooling). Among the various SMAs, iron-based SMAs (Fe-SMAs) have demonstrated exceptional potential for structural strengthening. Nonetheless, recent research has shown that Fe-SMA reinforcing bars may experience losses in recovery stresses when subjected to semi-cyclic loading.

This paper presents the results of an experimental campaign focused on assessing the impact of semi-cyclic loading on concrete elements reinforced with Fe-SMA rebars. The reinforced concrete test specimens were subjected to semi-cyclic loads before and/or after the activation of the Fe-SMA rebars. The preliminary findings show the effectiveness of Fe-SMA rebars as prestressing reinforcements despite semi-cyclic loads, especially when considering multiple activations throughout a structure's lifecycle. Therefore, this research provides valuable insights into enhancing the durability and safety of existing reinforced concrete structures by using Fe-SMAs.

Keywords

Iron-based shape memory alloys, Activation, Prestressing reinforcements, Pre-camber, Semi-cyclic loading

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ID:075

Activation strategies for Fe-SMA bonded to glass substrates

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Abstract

Previous research has demonstrated the potential of improving glass beams' performance through prestressed bonded iron-based shape memory alloys (Fe-SMAs). The bonded Fe-SMAs significantly enhance both the initial glass cracking load and the residual load-bearing capacity of glass beams, compared with unstrengthened ones. Ductile failure modes can be achieved after being reinforced with Fe-SMA, compared with unreinforced counterparts exhibiting brittle failure modes. Achieving the desired prestress level in Fe-SMAs involves controlled heating and natural cooling of Fe-SMAs. The achieved prestress level of Fe-SMAs depends on the activation strategies, which include activation position, length, and temperature. An appropriate activation strategy is essential to achieve a high prestress level and prevent premature failures, such as glass breakage or debonding during activation. This work investigates two strategies: one-time activation and segmented activation, aiming to attain high prestress levels while avoiding glass breakage and debonding. The study compares these activation strategies by analyzing their influence on temperature transition and stress distribution. The findings in this research will contribute to the effective design of strengthening glass elements using adhesively bonded Fe-SMA, achieving high prestress levels and minimizing stress concentration.

Keywords

Iron-based shape memory alloy, Adhesive joints, Structural glass, Activation temperature, Prestress loss

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Complementary in situ characterization of Fe-Mn-Al-Ni-Ti shape memory alloys

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Abstract

Prospective materials for large-scale structural applications, Fe-based shape memory alloys stand out due to their cost-effectiveness and the relatively low temperature dependence of their transformation stress. Coupled in situ investigations were conducted on a Fe-Mn-Al-Ni-Ti single crystal subjected to compression and two Fe-Mn-Al-Ni-Ti oligo-crystals deformed in tension. The superelastic material behaviour was investigated by combining characterization techniques such as digital image correlation, infrared-thermography and acoustic emission. A poor strain reversibility and a premature plastification of the parent phase was observed in case of the single crystal due to an unfavorable crystal orientation. Contradictory transformation behaviours were observed in the two oligo-crystals. One specimen exhibited a promising strain reversibility and characteristic signs of degradation, while the other specimen displayed a poor strain reversibility due to an unusual confinement of the martensitic phase transformation within an unfavorably oriented grain. In the former case, an increase in the dislocation density within five cycles was detected through a shift in the median frequencies of the acoustic signals. In the latter case, a strong coupling between martensite nucleation and dislocation generation led to a pronounced martensite stabilization after a single loading cycle.

Keywords

Iron-based shape memory alloy, martensitic phase transformation, superelasticity, in situ, acoustic emission

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Mixed-Mode Cohesive Failure of CFRP to Steel and Fe-SMA to Steel bonded Joints

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Abstract

The integrity of CFRP to steel and Fe-SMA to steel adhesively bonded structural strengthening patch must be maintained to ensure a durable application. The influence of the adhesive thickness, surface preparation, and adherend material behavior on the joint fracture has been well documented in the literature. The influence of mode-mixity has yet to be investigated and is studied experimentally and analytically in this study. Lap-shear involving mixed-mode fracture of bonded CFRP and Fe-SMA were conducted. The mode-mixity is introduced via an eccentricity between the loading axis and the adhesive plane. Furthermore, a novel theoretical model has been developed considering (i) adherend material behavior and (ii) mode-mixity. Experiments show that loading eccentricity decreases the joint capacity, up to 70% for CFRP and 32% for Fe-SMA. Analysis supported by the proposed model shows this difference is caused by the Fe-SMA material nonlinearity. The local mixity contains more Mode II in the Fe-SMA case than the CFRP. Fe-SMA yielding hinders the development of opening forces at the crack tip.
These findings hold significant meaning relative to the structural resilience and robustness of repair joint. A strengthening solution can benefit from material ductility to hinder the influence of loading eccentricity.

Keywords

Bonded joints, Mixed-mode fracture, Cohesive zone modelling

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ID:124

Recent Trends in Novel Fe-based Shape Memory Alloys

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Abstract

Iron-based shape memory alloys such as Fe Ni Co Al X (Ti, Ta, Nb) and Fe Mn Al Ni-X (Ti, Cr), attracted considerable attention due to their unique material properties. Low costs for alloying elements and high reversible transformation strains qualify them for industrial mass applications. Both alloy systems feature unique functional material characteristics. One of the key features of the Fe-Mn-Al-Ni shape memory alloy system is the low temperature dependency of the critical stress for martensitic transformation over a wide temperature range, which is due to its low Clausius Clapeyron slope. The proposed application temperature range of the alloy is between -196°C and about 150°C. Fe-Ni-Co-Al-X (X=Ta,Ti,Nb) shows high reversible strains under a high superimposed stress up to 900 MPa. In both systems, polycrystalline material conditions can be seen as the main drawback in terms of structural stability. Furthermore, data on the thermomechanical pseudoelastic and actuation response are rare in open literature. Thus, thermal and thermomechanical processes need to be qualified in order to guarantee structural stability. The current study focuses on different material conditions following thermal and thermomechanical processing to improve the performance of these alloys for application, also in the polycrystalline state.

Keywords

Fe-based SMAs, Superelasticity, Actuation

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Susceptibility of a Fe-Mn-Al-Ni-Cr shape memory alloy to stress corrosion cracking

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Abstract

In recent years, iron-based shape memory alloys have become increasingly interesting for application in the construction industry. The reversible phase transformation between a high temperature austenitic phase and a low temperature martensitic phase opens up applications in many different areas, e.g. as damping elements in earthquake prone areas or as prestressing elements in concrete structures. Previous investigations on the electrochemical corrosion properties of a Fe-Mn-Al-Ni-Cr shape memory alloy revealed that the corrosion properties of iron-based shape memory alloys are strongly influenced by the prevailing phases. The martensite phase suffers from a severe selective corrosion attack due to the formation of dislocations at the martensite-to-austenite interfaces. In the present study, the corrosion properties of the above-named alloy are further elucidated by investigating the susceptibility to stress corrosion cracking. The simultaneous occurrence of tensile stresses and unfavourable environmental conditions can lead to spontaneous failure of a building structure. For these investigations tensile tests under constant load control in different chloride-containing solutions have been conducted. The pitting corrosion that occurred during immersion in the test solution has a decisive influence on the martensitic phase transformation and the crack evolution. The high density of dislocations at the phase boundaries promotes the formation of transgranular cracks on the fracture surface as well as stress-induced corrosion cracks between single pitting holes on the lateral surface. Further investigations of the fracture surfaces revealed the occurrence of intergranular crack growth. The detrimental mechanisms lead to failure of the specimens well before the targeted test time of 1000 hours.

Keywords

Iron-based shape memory alloy, martensitic phase transformation, stress corrosion cracking, civil engineering

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Modelling of Hybrid Steel-SMA Shear Walls with Local Stress and Reinforcement Considerations

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Abstract

The incorporation of Super-elastic (SE) Shape Memory Alloys (SMAs), such as Nitinol, presents a method of passively improving the damage resiliency of traditional reinforced concrete structural elements. This resiliency can be of particular use in seismic applications owing to the super-elastic behavior allowing for increased recentering. Currently available experimental data on hybrid slender shear walls incorporating both steel and SE-SMAs has demonstrated the recentering improvements while also highlighting that use of SE-SMAs tend to cause formation of a predominant crack that controls the response. The ability to more accurately predict this behaviour through numerical methods would allow for better understanding of nuances in hybrid slender shear wall design going forward. The paper herein presents a numerical modelling program that considered the impacts of local stress concentrations as a result of a singular predominant crack formation during reverse-cyclic loading. This modelling program was carried out in VecTor2, a non-linear two-dimensional finite element program, in conjecture with experimental data of a hybrid steel-SMA slender shear wall and a traditional reinforced concrete companion wall. The use of a strain-hardening reinforcement constitutive model which considered local fracture was found to improve the displacement prediction capabilities of models. Additional considerations which were investigated included increasing reinforcement properties to reflect conditions at the wall base and accounting for the impact strain gauge instrumentation may have on rupture of reinforcement. The results can provide insight into the creation of numerical models that better reflect the local stress and reinforcement conditions found in the presented hybrid steel-SMA and reinforced concrete slender shear walls.

Keywords

Finite Element Analysis, Super-elastic Shape Memory Alloy, Nitinol, Slender Shear Wall, Seismic Resilience

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Innovative hybrid CFRP composite and Fe-SMA bonded systems for structural glass flexural strengthening

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Abstract

In the last few decades, contemporary architecture has been pushing the use of structural glass in many applications. Thus, the glass industry has developed the thermal toughening to increase its tensile strength and lamination to prevent brittle failures. However, additional structural redundancy is required, since glass elements can still fail unexpectedly due to the growth of existing surface flaws. To overcome these issues, several solutions have been proposed based on glass composite systems, mainly using steel, fiber-reinforced polymers (FRP) or iron-based shape memory alloy (Fe-SMA), as reinforcement.

This work presents innovative hybrid CFRP composite and Fe-SMA bonded systems for structural glass flexural strengthening. These innovative systems consist of laminated glass beams simultaneously strengthened with near-surface mounted (NSM) and externally bonded reinforced (EBR) with CFRP composite and Fe-SMA reinforcements. The ability of such systems to (i) avoid premature debonding, (ii) improve post-cracking response and (iii) ensure ductile failure modes was assessed through flexural tests on large-scale laminated glass beams, where the effect of post-tensioning was also explored.

Keywords

Structural Glass, CFRP, Fe-SMA, Flexural Strengthening, Ductility

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Improving the Structural Performance of RC Beams with Openings using Iron-based Shape Memory Alloy (Fe-SMA) Reinforcement

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Abstract

Incorporating openings within cantilevered reinforced concrete (RC) beams significantly compromises their structural integrity and performance. This presents a critical challenge in structural engineering. Attempting to mitigate these adverse effects, this research employs comprehensive numerical simulations to investigate the efficacy of Iron-based Shape Memory Alloy (Fe-SMA) reinforcement. By examining the impact of two pivotal factors—the size of the opening and the level of prestress applied to the Fe-SMA reinforcements—this study demonstrates that the strategic incorporation of Fe-SMA bars around openings can markedly enhance the structural response of RC beams. This enhancement is manifested through increased stiffness, diminished crack propagation, and an improved load-carrying capacity, collectively contributing to a significantly more robust and durable structural system. Although elevating the prestress levels in the Fe-SMA reinforcements yields only a marginal increase in the initial cracking load and a modest improvement in the load-carrying capacity, the overall findings underscore the potential of Fe-SMA reinforcements to improve the resilience and performance of RC beams with openings. Thus, this research offers valuable insights into optimizing RC beam designs to overcome the challenges posed by including openings, paving the way for developing more resilient and efficient structural systems.

Keywords

Beam, Fe-SMA, Numerical, Opening

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Structural health monitoring

ID:013

Detection of internal defects in RC structures using GPR and ultrasonic methods

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Abstract

The ultrasonic research method for studying the structures and determining the possible presence of defects has been known for a long time and has been successfully used to solve various issues directly at construction sites. However, this method has a number of disadvantages, such as the low speed of work and the lack of visual visualization of research results. At the same time, the new technological GPR method is devoid of such disadvantages and, on the contrary, is characterized by high speed and visibility of research results.

This article presents the results of field studies of vertical reinforced concrete structures by comparing ultrasonic and GPR methods. As a result of the research, it has been shown that with using of modern non-destructive inspection methods of structures, such internal defects of concreting as pores, cavities, voids and disintegration can be detected efficiently and with high speed. The research results can be presented visually and allow you to more accurately position the location of defects, as well as build 2D and 3D maps of the location of defects.

Keywords

Concreting, Defect, Dielectrical constant, Flaw, GPR.

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ID:016

Full-scale load test of a PRC bridge beam after 60 years of service life.

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Abstract

The safety assessment of existing infrastructure is a matter of significant concern for infrastructure management authorities. Specifically, in Italy, numerous reinforced concrete (RC) and prestressed concrete (PRC) bridges were constructed during the 1960s and 1970s. Many of these bridges are still in operation, raising questions about their current load-bearing capacity given the long service time. This study focuses on the experimental examination of the ultimate performance of a PRC bridge beam taken from a bridge deck constructed in the 1960s. The bridge in question, known as the Mollere viaduct, was situated near the town of Ceva (Italy), along the Torino-Savona highway A6. The PRC beam was characterized by a simple supported static scheme with semi-articulated end connections having a total span of 34.60 meters. The beam had been prestressed using post-tensioning techniques. This paper presents an overview of the critical aspects related to the planning of the experimental campaign and, in conclusion, highlights the preliminary findings with respect to structural safety and monitoring.

Keywords

Full-scale, ultimate behavior, prestressing, existing bridge

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ID:018

Long-Term Indirect Monitoring System for Short and Medium Span Bridges

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Abstract

Bridge health monitoring has been widely discussed for establishing the rational maintenance strategies of existing bridges. Meanwhile, we need to provide discussions and recommendations on how to establish fully automatic data collection system and how to manage the big data for holistic bridge maintenance decisions.
The author has been developed a vehicle-based (coupling of a moving vehicle and a bridge) bridge health monitoring system by using public buses which is one practical solution to the problem for condition assessment of short and medium span bridges (called “bus-based monitoring system”). The proposed system has some new ideas about making use of the under rear-wheel spring acceleration sensors installed on an in-service fixed-route bus operating on the public transit system (long-term and indirect methods), define “characteristic deflection” as an indicator that may be useful in efficiently detecting a structural anomaly of a bridge, etc.
The main objectives of this paper are 1) to introduce the details of how to assess the bridge condition based on the results of long-term application (total more than 10 years) to actual bridges on Ube City bus network in Japan, as a specific example for verify the system, 2) to discuss what is possible steps in realizing practical application of the system to existing bridges for consideration systematically into the maintenance strategies in the future.

Keywords

Short and medium span bridge, Long-term and indirect monitoring, Public bus, Condition assessment, Characteristic deflection

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Structural monitoring, FEM updating and performance assessment of a wind turbine

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Abstract

In this study, long-term monitoring of a 900-kW onshore wind turbine with a tubular steel tower of 54 meters high and foundation with 26 reinforced concrete piles is performed based on vibration data. Modal properties such as frequency, mode shape and damping ratios were obtained by Enhanced Frequency Domain Decomposition method. Then, change in modal parameters due to environmental and operational conditions was determined. Modal parameters after cleansing such effects were obtained by multiple linear regression analyses.
Finite element model of the wind turbine was developed in ANSYS including piles. Soil-structure interaction was modeled by p-y, t-z and q-z soil springs. Finite element model of wind turbine was updated based on identified modal parameters.
Finally, nonlinear time histories were performed to obtain seismic fragility curves of the structure with limit states being the local buckling under different levels of wind speed. In the context of this study, it was observed that identified modal values had significant scattering and level of wind speed significantly changed the seismic fragility curve of the wind turbine.

Keywords

Wind turbine, Vibration-based monitoring, Environmental and operational effects, Performance assessment

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Measured Displacement Data Analysis and Modelling for Structural Health Monitoring

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Abstract

Non-physics-based modeling is gaining attention in the area of structural health monitoring due to underlying advantages e.g. finite-element or physics-based model might not exist at all. Therefore, in case of aforementioned scenario, it may be useful to have a model that is developed via the use of time-series data instead of underlying physics. Such model can be developed using parametric, non-parametric, and system identification approach, where later state-space based model quantities can be derived. In this study, experimentally measured time-series data (e.g. displacement) have been utilized to develop a representative model. Initially, the data has been passed through a screening and selection process including data cleaning and filtering. Subsequently, the filtered data has been validated with the original data to make sure that overall dynamics remain same. Later, cleaned data have been employed to have an illustrative model via employing autoregressive type models. The influence of the model orders have been investigated and a comparison of different results have been presented. Further, the least-squares approach has been adopted to minimizes the prediction errors to optimize overall performance. However, it needs to be mentioned as herein out-only measured data has been used therefore no transfer function can be derived also stabilization plot is not possible without having a transfer function. Finally, the developed models output have been validated in both time and frequency domain. In short, it has been observed that the model output may vary significantly depending on the model orders and noise contamination of the original signal. The investigated approach is beneficial for monitoring while physics-based models either not available or not possible to derive.

Keywords

Structural health monitoring, Least-squares approach, Autoregressive model, Data-based model, Time and frequency domain

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Vehicle Classification using BiLSTM for Predictive Maintenance and Digital Twins

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Abstract

The service life of infrastructure is directly related to the traffic load. In the past, this traffic load has often been underestimated, resulting in significant damage to structures, especially steel bridges. In order to establish the paradigm of predictive maintenance in bridge engineering, prediction models for the state of damage and service life are necessary. In particular, the proportion of heavy trucks leads to a significant decrease in remaining service life. Therefore, knowledge of the composition and frequency of traffic is important. New methods from communications technology based on recurrent neural networks allow rapid identification of specific signals in monitoring data.
A bidirectional Long Short-Term Memory Network (BiLSTM) is used to identify different up to six vehicle types from the drive-by vehicle signals. The method was applied to monitoring data of drive-by data from a German wide span steel bridge with an orthotropic deck (Rhine bridge Neuenkamp). Validation was performed based on weight-in-motion data in combination with a finite element analysis. The extracted data allows a detailed analysis of the classification of vehicle types, sequence effects and clustering of vehicles. The gained data can later be used in digital twin applications.

Keywords

Signal analysis, structural health monitoring, recurrent neural network, traffic loads

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ID:085

Drive-by modal identification of high-speed railway bridge via CP response identification

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Abstract

High-speed railway bridges are subjected to heavy operational loads and significant impact forces due to the moving trains. It is important to carry out an effective structural health monitoring to ensure the safe operation of railway bridges. Traditional online bridge monitoring methods require sensor installations on the structures that can be time-consuming and expensive making it very difficult to satisfy the huge needs of monitoring all the existing railway bridges. Therefore, this study proposes to use the drive-by method for the bridge modal identification using responses of in-service high-speed trains. The measuring sensors are installed on the train that can conduct the measurement in its normal operational states. To improve the feasibility and accuracy of drive-by bridge modal identification, the contact-point (CP) responses between the wheels and the rail track are identified first from the train responses. A novel method via Bayesian expectation-maximization based augmented Kalman filter is proposed to reconstruction the CP responses and unknown states of the train simultaneously. The method is robust to the measurement noise of the train responses and the CP responses can be identified accurately. The identified CP responses successfully eliminate the dynamic components related to the train and greatly enhance the bridge dynamic information. The proposed CP response reconstruction method has great potential for drive-by bridge modal identification using the responses of train that can be further used to assess the structural condition of high-speed railway bridges.

Keywords

Drive-by, Modal identification, high-speed railway bridge, AKF, BEM

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Machine-learning-driven automatic application of the stochastic subspace identification method

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Abstract

This contribution illustrates a new paradigm for the automatic output-only modal identification of linear structures under ambient vibrations, namely the intelligent automatic operational modal analysis (i-AOMA). The proposed approach relies on the covariance-based stochastic subspace identification (SSI-cov) method whereas a machine learning technique is implemented to automatically tune its control parameters. Two distinctive phases can be recognized in the proposed approach. First, quasi-random samples of the control parameters for the SSI-cov method are generated. Once the SSI-cov method is performed for each sample, the corresponding stabilization diagrams are processed to prepare a database that will be employed to train the intelligent core of the i-AOMA method. This is a random forest algorithm that predicts which combination of the control parameters for the SSI-cov method can provide good modal estimates. New quasi-random samples of the control parameters for the SSI-cov method are generated next, until a statistical convergence criterion is fulfilled. If the generic sample is classified as feasible by the intelligent core of the i-AOMA method, then the SSI-cov method is performed. Hence, stable modal results are carried out from the stabilization diagrams and relevant statistics are also calculated to evaluate the uncertainty due to the variability of the control parameters. Some applications are finally reported, and the links to freely download the corresponding Python code are provided.

Keywords

Machine learning, Operational modal analysis, Random Forest, Stochastic subspace identification

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Simulation of acoustic emission events in Reinforced Concrete structures for Structural Monitoring

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Abstract

Given the aging state of critical infrastructure, encompassing bridges, buildings, and pipelines, Structural Health Monitoring (SHM) techniques have assumed paramount significance in the evaluation of these assets' structural health without interrupting their operational functionality. The Acoustic Emission (AE) technique, renowned for its proficiency in detecting various types of structural damage, enjoys notable recognition. However, challenges persist in quantifying damage and estimating safety margins, primarily due to an overreliance on empirical observations. To address this crucial gap, this paper introduces a methodology for the numerical simulation of acoustic emission events in reinforced concrete structures. This approach relies on a finite element model that aims to replicate the mechanical behaviour of the structure, with stress and strain analysis forming the foundational elements for simulating and quantifying these events. After validation performed through comparison with experimental data, the model is applied to perform parametric analyses to define the EA parameters most representative of the damage classification. This study serves as the framework for research efforts aimed at harnessing acoustic emission data in a more quantitatively rigorous manner for structural assessment. Significantly, it establishes a direct linkage between mechanical models and acoustic observations, offering a promising pathway toward a more comprehensive and precise understanding of structural integrity and safety within critical infrastructure. Moreover, this research may contribute to the development of improved strategies for assessing and maintaining the health of these essential assets in the face of their aging and potential structural issues.

Keywords

Structural Health Monitoring, Acoustic Emission, Damages, Mechanical Model, Experimental test

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ID:128

Research on the Application of Intelligent Steel Strands in Prestressed Concrete Beams

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Abstract

Steel strands are extensively used in large-span buildings, roads, bridges, dams, and other prestressed reinforced concrete structures. Due to reasons such as design and construction, environmental corrosion, and fatigue accumulation, the service life of steel strands is often much shorter than initially designed. They usually only meet the structural requirements and lack long-term, effective monitoring of their stress state during the operation of bridges. This results in a significant increase in maintenance costs and places a considerable economic burden on bridge operating entities. To address this issue, this study focuses on the application of intelligent steel strands in prestressed concrete beams. First, a novel intelligent steel strand with self-sensing properties is proposed, which allows for easy monitoring of the stress conditions of steel strands during their service life, as well as controlling prestressing and guiding construction. The study also includes repetitive testing of the mechanical properties of intelligent steel strands. Second, an embedded pre-tensioned intelligent steel strand is designed, and its performance and stress transfer effects are analyzed. Finally, research is conducted on intelligent strands that combine steel strands with fiber optic sensors. This integration of structural and intelligent monitoring technology provides a basis for both load-bearing and sensing functions. The research demonstrates that intelligent steel strands possess excellent mechanical properties similar to conventional steel strands while enabling real-time health monitoring of bridge structures. This contributes to reliable support for the intelligent operation and maintenance of bridge structures.

Keywords

Intelligent steel strands, Prestressed reinforced concrete structure, Health monitorin, Prestress loss, Technological research

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Structural Health Monitoring of Cable Stays in Power Distribution Networks

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Abstract

Cable stays are widely used in power distribution and telecommunication sectors to support utility poles. A cable stay consists of a steel cable and rod system that ties the pole to the ground to provide lateral stability. The cable is normally tied to the pole using a number of different details and the other end it is tied to a rod which is embedded into the ground. As a steel structure where a part is buried under the ground, corrosion is inevitable. Corrosion degrades the structural capacity of cable stays over time by reducing the effective cross-sectional area in carrying the load. Failure of cable stays can lead to utility pole failures which can pose significant economic impacts and safety concerns. Therefore, reliable and accurate condition assessment of cable stays is crucial for safe and reliable performance of power distibution and telecommnication networks. This paper investigates the ground level and below ground corrosion of cable stays. 25 in-service cable stays in Victoria, Australia are uprooted to conduct corrosion assessment and the results of corrosion assessment are presented in this paper. Further, a condition assessment framework for cable stays is proposed to facilitate the asset management team in planning the replacement and strengthening schedule for cable stays.

Keywords

Cable stays, Corrosion, Deterioration, Condition assessment

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Tension Estimation Of Bridge Stay Cables Using Vision-Based Methods

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Abstract

In this study, it is aimed to estimate the cable tensions of the New Kömürhan Cable-stayed Bridge using a vision-based monitoring system. The number of structures where cables are used as main supports is increasing with the development of material properties, analysis, and construction processes. Structural Health Monitoring (SHM) is necessary to ensure operational and structural safety and integrity. The estimation of the cable tensions is one of the most important factors in early detection of deterioration and damage. Fatigue damage caused by cyclic traffic and wind loads, corrosion due to environmental factors, and sudden earthquake loads cause a decrease in cable tensions, which affects the overall performance of the structure. In this study, cable tensions were determined using the lift-off test and the vibration response under seismic events recorded by existing acceleration sensors on the bridge. Then, cable tensions were estimated by vision-based methods using video. In the first two methods, only 8 of 42 cables are continuously monitored; on the other hand, all cable forces were estimated with the vision-based monitoring system and gave consistent results compared to 8 cables. In the last part of the study, Finite Element Model (FEM) of the bridge was developed and verified by comparing cable tensions obtained from FEM and measurements. Additionally, pylon and deck frequencies of verified FEM match with those obtained from vibration records.

Keywords

Vision-based monitoring system, Image processing, Model verification, Tension estimation.

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ID:153

Self-Sensing Capacity of Calcium Aluminate Cement-Based Multi-Walled Carbon Nanotube and Nanocarbon Black Composites at Elevated Temperatures

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Abstract

Multiwalled carbon nanotubes (MWCNT) and nanocarbon black (NCB) possess intrinsic self-sensing capabilities and show promising potential for structural health monitoring. The self-sensing performance of MWCNT and NCB concrete at elevated temperatures has rarely been studied to assess its feasibility for long-term monitoring applications. In this study, the mechanical properties and piezoresistivity of MCNT/NCB nanocarbon material sensors based on calcium aluminate cement (CAC) was investigated at different temperatures (25, 100, 200, 300, and 500 °C) to develop an efficient MCNT/NCB sensor that experienced minimal degradation in piezoresistive sensitivity during stress/strain monitoring. The specimens were designed based on CAC cementitious materials, and MWCNT/NCB dosages (MWCNT:1.0% and NCB:0.80%) were used as the cementitious binder weights. The specimens were evaluated under monotonic compression loading to determine the ultimate strength and different cyclic compression stress amplitudes to evaluate piezoresistive sensitivity and repeatability. The results showed that the repeatability and sensitivity of the frictional changes in the resistivity (FCR) of the CAC-based sensors exhibited acceptable linearity and excellent reversibility at 25, 100, 200, and 300 °C. Moreover, there was no spalling after the heat treatment, which improved the piezoresistivity at elevated temperatures. For the specimen without heat treatment, the FCR reached 35% at 14MPa and 45% after heat treatment at 300 °C. However, after heat treatment at 500 °C, explosive spalling was observed in the CAC-based sensor, which was no longer conductive because of the explosive spalling of the nanocarbon carbon oxidation. The CAC-based MWCNT/NCB sensors exhibited good mechanical properties and high sensing performance at normal and elevated temperatures of 100, 200, and 300 °C compared with those at 500 °C, which demonstrates that they promote the application of smart CAC-MWCNT/NCB-based sensors for structural health monitoring at elevated temperatures and contribute to improved piezoresistivity.

Keywords

Calcium aluminate cement, Multi-walled carbon nanotubes, Nanocarbon black, Self-sensing, Elevated temperature

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ID:163

Development of generic AI models to predict the movement of vehicles on bridges

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Abstract

For civil, mechanical, and aerospace structures to extend operation times and to remain in service, structural health monitoring is vital. Structural health monitoring (SHM) system is a method to examining and monitoring the dynamic state of essential constructions. Because of its versatility in adapting to unfavorable structural changes and enhancing structural dependability and life cycle management, it has been extensively used in many engineering domains, especially in civil bridges. Due to the recent technical developments in sensors, high-speed internet, and cloud computing, data-driven approaches to structural health monitoring are gaining appeal. Since artificial intelligence (AI), especially in SHM, was introduced into civil engineering, this modern and promising methods has attracted significant research attention. In this project, a large dataset of acceleration time series using digital sensors was collected by installing structural health monitoring (SHM) system on Nibelungen Bridge located in Worms, Germany. A meta-data description for Artificial Intelligence (AI) models was defined and used to enable automated access to training AI models for deep transfer learning. The models are stored in a research data management in such a way that they can be versioned and uniquely referenced. This paper focuses on analyzing different classification models using deep learning approach to predict the vehicle movement on the bridge from the raw acceleration data obtained from sensors.

Keywords

Structural health monitoring (SHM), Artificial Intelligence (AI) and Machine Learning (ML).

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ID:167

Acoustic Event Detection for Prestressing Wire Breakage Monitoring in Concrete Bridges

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Abstract

Aging infrastructures, particularly concrete bridges, in most developed countries are growing, directly impacting their safety and longevity. Therefore, early detection of damages such as wire breakage is not only vital; it is urgent to prevent catastrophic structural failures such as the Polcevera bridge in Genova, Italy. Prestressing cable degradation in concrete bridges poses a significant risk to structural integrity. Therefore, effective monitoring and early detection of prestressing cable degradation are essential to securing the safety and stability of the bridges.
In response to this challenge, a novel approach for wire breakage detection, using Mel-frequency cepstrum coefficients (MFCCs) and a multilayer perceptron (MLP) is proposed. To validate the effectiveness of the proposed models, experimental data from two Italian bridges were collected. This dataset was used for training and testing the models. To address the limited real-world data, data augmentation techniques, including MixUp, time-shifting, and polarity inversion, were employed, leading to enhance the models' robustness and prevent overfitting. MFCCs extract features from acoustic emission signals and are classified by MLP.
The results demonstrate effective damage detection and classification, underscoring the MLP's potential for real-time bridge monitoring. The MFCCs-MLP combination advances wire breakage detection, while data augmentation addresses data scarcity challenges. This method holds promise as a robust, broadly applicable model for bridge monitoring, enhancing infrastructure safety and durability.

Keywords

Prestressed concrete beams, Wire breakage detection, Mel-frequency cepstrum coefficients, Multilayer perceptron, Data augmentation

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ID:194

Exploiting time-frequency analysis for damage detection using Generative Adversarial Networks

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Abstract

Structural Health Monitoring (SHM) is of utmost importance to ensure the safety and to enhance the safety and longevity of various engineering structures, from buildings and bridges to aircraft. Detecting the onset of damage within these structures is a challenging task that requires cutting-edge methodologies. Time-frequency analysis has proven its prowess in characterizing structural responses of nonlinear dynamical systems, facilitating the identification of subtle, yet critical, changes due to damage. This study delves deep into the use of the Generative Adversarial Network (GAN) for damage detection, with focus on the application to nonlinear dynamical systems through time-frequency analysis. GAN is an artificial intelligence technique that exhibits exceptional proficiency in data generation, synthesis, and detection of anomalies. By merging the valuable information provided by time-frequency analysis about nonlinear dynamical systems with the discriminative capability of the GAN, this works illustrates a novel approach towards a reliable damage detection in engineering structures and showcases its potential for SHM applications.

Keywords

Damage detection, Generative Adversarial Networks, Neural networks, Wavelet transform.

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ID:202

Application of Digital Image Correlation to Field Monitoring of Masonry Arch Bridges

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Abstract

A large number of masonry bridges constructed in Europe during the Industrial Revolution are still in service. Continuous operation for far more than a century and weathering effects have contributed to material degradation in the main bridge components. To ensure that old masonry bridges remain safe even under increasing traffic loading, it is important to identify potential deterioration in bridge performance before the development of critical irreversible damage. This task can be accomplished via periodic monitoring of the bridge response under traffic loading. Digital Image Correlation (DIC) is currently used as an effective non-contact method to measure displacements and strains in physical testing. Most of the applications are in laboratory settings, but DIC techniques have yet to be extensively applied to field monitoring. This paper showcases the potential of DIC monitoring for serviceability assessment of masonry bridges. Some results of an extensive monitoring program on railway viaducts in the UK are presented and critically discussed. Structures with different geometrical characteristics, including different pier heights, span lengths and span-to-rise ratios and made of different masonry materials have been investigated. The results obtained using specific targets attached to the monitored structures or using the actual masonry texture and bond characteristics as natural targets have been compared, and the effects of environmental effects (rain, wind) and monitoring sites (urban and rural environment) have been assessed considering also the influence of cameras characteristics and settings. In all scenarios, suitable monitoring data were mostly obtained. A significant influence of the camera depth of field has been established, especially when measuring deflections at different locations on the intrados of the arch barrel. Strategies to mitigate the detrimental effects of environmental noises, which are quite significant especially when monitoring in challenging environmental conditions, are also proposed.

Keywords

Masonry Bridges, Non-contact Monitoring, Digital Image Correlation

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ID:204

Satellite-derived Digital Surface Models for InSAR Deformation Measurements on Bridges

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Abstract

Canadian bridges need structural health monitoring (SHM) to ensure their safety and longevity. In-situ inspections are expensive and time-consuming, and climate change effects on river bridges may make previous legacy inspection schedules inadequate. Remote sensing can help supplement in-situ inspections or alert bridge operators to the need for a new inspection. Satellite-based Persistent Scatterer Interferometric Synthetic Aperture Radar (PS-InSAR) is an emerging approach for bridge deformation monitoring that requires accurate geolocation of the PS targets for best results. If the as-built elevations on bridges are insufficiently accurate, geolocation errors may limit the usefulness of the PS-InSAR data for bridge SHM. Satellite stereo imagery can be used to derive Digital Surface Models (DSMs), which give the elevation of the top surfaces of structures. It is unknown whether DSMs derived from satellite imagery are adequate as height sources for ensuring accurate positioning of PS-InSAR targets when bridge drawings or surveys are unavailable or unreliable. A study evaluating PS-InSAR elevation corrections using a DSM from satellite imagery was conducted on the Samuel de Champlain Bridge in Montreal (QC), Canada. A tri-stereo image triplet was used to create a 1 m resolution DSM, which was evaluated for height accuracy against a historical survey and used to correct PS-InSAR data points for elevation. The PS-InSAR dataset was georeferenced with DSM height corrections and evaluated for accuracy.

Keywords
DSM, PS-InSAR, Bridge Deformation Monitoring

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Damage Classification Using CNN-Based Model for Multi-Part Strengthening System

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Abstract

Strengthening and retrofitting systems, including FRCM (Fiber-Reinforced Cementitious Matrix), play a vital role in improving the durability and safety of structures facing challenges such as aging, increased loads, or seismic risks. To ensure the long-term integrity and performance of these structures, it's crucial to monitor the health of repaired structural components. Acoustic emission (AE) is a non-destructive and passive technique that involves the detection and analysis of stress waves emitted by various material components undergoing damage. In this particular research, the study focuses on the classification of damage in different material components of RC (Reinforced Concrete) beams strengthened with FRCM. This classification is achieved using a convolutional neural network (CNN) model that utilizes image-based waveform data from the AE testing. The study collected waveforms from four distinct failure modes: fabric-matrix debonding, fabric rupture, tensile cracking in the cementitious matrix, and yielding of steel. These waveforms were used to train the CNN model. Each waveform was converted into a Continuous Wavelet Transform (CWT) scalogram before being input into the model. The model demonstrated an overall prediction accuracy of approximately 92%. The pre-trained model was further employed to classify failure mechanisms in a full-scale RC beam that had been flexurally strengthened with FRCM. The overall test accuracy in this real-world field setting was found to be approximately 86%, which is considered a satisfactory level of accuracy.

Keywords

TRM, FRCM, AE, CNN, CWT

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ID:208

Accuracy of fib Bulletin 90 formulations for the bending capacity of FRP-strengthened RC beams

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Abstract

In the last two decades, fiber-reinforced polymer (FRP) composites have become a popular solution for flexural strengthening of existing reinforced concrete (RC) members. Their success is partly due to the extensive research performed to deeply understand the behavior of FRP-strengthened RC members, which resulted in the publication of various design codes and guidelines all over the world. Most of the design formulations employed to estimate the bending capacity of FRP-strengthened RC beams are based on a fracture mechanics approach that limits the composite axial stress due to the occurrence of composite debonding from the substrate. Different model parameters are provided by design codes and guidelines to account for the differences between intermediated crack-induced (IC) debonding and plate end (PE) debonding. Among available guidelines, the *fib* Bulletin 90 provides numerous approaches that promisingly allow for an accurate estimation of the FRP-strengthened RC beam bending strength.
In this paper, the accuracy of formulations provided by the *fib* Bulletin 90 to estimate the bending capacity of FRP-strengthened RC beams is assessed. A database comprising results of experimental bending tests of FRP-strengthened RC beams is collected. Comparison between experimental and corresponding analytical results obtained with *fib* Bulletin 90 bending strength models allows to identify accuracy, differences, and peculiarities of each approach considered.

Keywords

Externally bonded reinforcement, design formulations, bending strength, database

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ID:215

Field monitoring, BIM representation and FEM analysis of preheater towers in cement plants

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Abstract

The major goal of this paper is to use effective and accurate procedures to monitor, model and predict the evolution of the deterioration and safety conditions of highly complex structural systems such as preheater towers (PTs) in cement plants. The main structural elements of reinforced concrete PTs are exposed to severe conditions during their service life, which can trigger deterioration phenomena that significantly affect their structural safety. It is necessary to maintain them in operational and safe conditions, while taking into account the needs of permanent upgrading of the mechanical equipment they support. Digital survey techniques are used to obtain three-dimensional information about the towers. These are fast and accurate solutions for the development of BIM-oriented reverse-engineering procedures. The information provided by the implemented methodology is used to characterize the appropriate representation of the problem boundary conditions and to calibrate the computational models. The BIM-to-FEM approach is performed to obtain the elastic model of the structure in its as-built and degraded states. This information serves as a predictive model for the evaluation of different situations in their service life. This predictive model holds the potential to be applied for analyzing diverse scenarios that utilize the acquired information about the tower. Moreover, the outcomes from the elastic damage model of the tower align well with expectations. The proposed work is carried out for a comprehensive evaluation of the structural degradation of PTs and provides valuable information on possible maintenance needs and strategies to ensure its long-term reliability and safety conditions.

Keywords

Preheater Tower, BIM-to-FEM, Monitoring, Reinforcement Concrete, Degradation

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Evaluation of Historic Truss Bridges

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Abstract

The prioritization of the maintenance and rehabilitation of bridges based on their historic importance is challenging. While the AASHTO's Guidelines for Historic Bridge Rehabilitation and Replacement contain guidance on selecting bridges for preservation, there is currently no guidance on how to prioritize historic bridges selected for rehabilitation.

A ranking system for rehabilitation prioritization of historic truss bridges is developed based on two levels of prioritization. The first level, Historical Importance, is the primary and most important level of prioritization. A historical importance factor (HIF) is presented to account for the bridge's uniqueness, year of construction, and other factors. Bridges are sorted based on their HIF to identify the ones for rehabilitation prioritization. When several bridges have the same HIF, a second level of prioritization (P2F) is developed to account for the bridge condition and rehabilitation potential.

In cooperation with the Kentucky Transportation Cabinet (KYTC), the authors developed a truss bridge database listing the historic, geometric, and other key features of the bridges. 94 candidate bridges were selected as being historically significant for preservation. For the bridges under consideration, P2F was not deemed necessary at this stage, since the prioritization based on the HIF provided sufficient clarity for investigating the rehabilitation potential of the bridges.

The results generated from the HIF ranking provide the tools for the KYTC to maintain Kentucky's truss bridges based on their historical importance.

Keywords

Truss, Bridge, Rehabilitation, Prioritization, Preservation

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ID:223

Bus Network Based Fleet Monitoring Towards Net Zero Transport

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Abstract

Since its first invention in 2004, drive-by Structural Health Monitoring (SHM) has been widely adopted to assess ageing infrastructures worldwide. In 2019, the EU Joint Research Centre highlighted it as one of the most promising techniques for the bridge SHM. Recently, a fleet composed of different vehicles has been regarded to be more efficient in obtaining the bridge component in contrast with a sole vehicle, as fleet monitoring can mitigate the annoying impact caused by undesired road components. Conventional fleet monitoring of drive-by SHM builds on instrumented heavy trucks, whereas various mechanical properties of the tested trucks could make it challenging to derive the bridge information for some scenarios, i.e., both the dominant frequency of the vehicle and bridge located within the same range. Therefore, this paper proposes a novel fleet monitoring framework for drive-by SHM, where thousands of buses are generated by utilizing Monte Carlo simulations. Latterly, bridge frequencies are isolated by implemented vehicular transfer functions from the measured bus accelerations for bridge condition assessment. Compared to conventional fleet monitoring, the bus network-based approach has proved to be more efficient because most of the mechanical properties of buses are identical, which further contributes more benefits in bridge information extraction. The proposed bus network-based fleet monitoring of drive-by SHM is validated with laboratory experiments of a scaled highway bridge.

Keywords

Structural Health Monitoring, Vehicle Bridge Interaction, Intelligent Infrastructure, Drive-By Monitoring, Net Zero Emissions

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ID:238

Smart monitoring of RC T beams strengthened by external bonded FRP

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Abstract

This study aimed to investigate the cracking behaviour of RC beams strengthened by external bonded smart FRP. A smart CFRP consists of two texture fabrics inside which a distributed fibre-optic sensor (DFOS) is inserted. During the test, the sensor measured the mechanical strain distribution of the composite with a millimetric spatial resolution. Simultaneously crack openings along the beams were detected and measured using digital image correlation (DIC).
The results of the strengthened beams were compared with reference values, and the crack width was compared with the theoretical values predicted using the Eurocode 2 (EC2) formula, calibrated for non-strengthened RC elements. Subsequently, an empirical model was established as a modification of EC2, considering the presence of a CFRP system. The corresponding results were compared and discussed to validate the model.
A smart CFRP was described and implemented in the tested beams and was used to measure the bond stress at the interface and cracks location. Strain and shear bond stress profiles have been reconstructed for a reference beam showing consistent results. This proposed model constitutes a monitoring process for CFRP-reinforced beams. The measurement of strain profile allow then to obtain the level of beam damaged during a loading.

Keywords

EBR FRP, RC structures, crack, smart monitoring,

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ID:240

Preliminary ranges of critical vertical settlements of Italian masonry building stock for SHM applications

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Abstract

Structural health monitoring plays a crucial role in ensuring the safety and reliability of masonry structures, by providing continuous and real-time monitoring of their structural behavior and identifying any potential issues or anomalies before they become critical. The measurement of vertical displacements (by means of mechanical gauges, optical instruments or even satellite-based interferometry) in masonry structures due to settlements provide useful information for the assessment of the vulnerability of existing masonry buildings. This paper aims to define a preliminary range of critical vertical displacements that activate in-plane local damages in masonry walls in terms of flexural and shear failure, for monitorability. In particular, flexural, diagonal shear and sliding local mechanisms are analyzed in this paper. Large scale analyses have been performed assuming simplified models where materials, loads and geometrical information of masonry structures are based on main Italian databases. Building models are generated by means of Monte Carlo analyses in order to simulate the behavior of Italian masonry buildings. The analysis results allow to provide preliminary fragility curves based on maximum likelihood estimation method.

Keywords

Masonry structures, vertical displacement, fragility curves, settlements, structural health monitoring

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FEA for improved implementation of IRT for monitoring of concrete bridges

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Abstract

Infrared thermography (IRT) is a non-destructive technique (NDT) known for fast, contactless, and wide area monitoring of concrete structures like bridges in transportation networks. Dealing with practical challenges of IRT such as the determination of favourable timeframe for data collection, detection of defects of various types and geometry, differentiation of the true concrete defects from environmental and operational effects, and so on by laboratory experiments is time-consuming, arduous, and costly. Finite element analysis (FEA) is an indispensable tool for addressing the practical challenges facing the implementation of IRT for structural health monitoring of concrete structures. This paper presents the analysis of finite element models (FEM) of concrete slabs with subsurface defects in the LUSAS software. Initially, the models are validated based on surface temperatures of concrete slabs measured in the laboratory by IR camera. Then, they are used to estimate the variation of thermal contrast, time rate of thermal contrast, and distribution of temperature on the surface with depth of defect. In addition, the results and trends are compared with the experimental measurements. The validated FEMs are used to estimate the amount of energy required for the creation of minimum safe detectable thermal contrast recommended by ASTM D4788-03 standard and other criteria. Finally, after discussion of results, the conclusions, and recommendations for improved implementation of IRT based on FEA, especially for the detection of defects at rebar depth, are outlined.

Keywords

Concrete bridge, Subsurface defect, Infrared thermography (IRT), Structural health monitoring (SHM), Finite element analysis (FEA)

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ID:248

A sustainable monitoring approach to manage archaeological complex sites – The example of Pompeii

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Abstract

The climate-change effects are becoming ever more significant in the management of archaeological sites, which in itself are notoriously a particularly complex system within the heritage preservation matter. The decay trend can be heavily affected by extreme and/or fast changes of weather conditions. While short-term solutions are not always available to avoid disasters, pro-active maintenance actions can be instead carried out to successful control the effects of the weather conditions fast change and to mitigate the extremes effects. A reliable knowledge and prevision of the decay evolution represents in this within the key point to design a fruitful maintenance plan. To this scope, a detailed heritage condition assessment requires in-depth survey and analysis, which are not typically compatible with the economical and time resources generally available in complex archaeological sites. Otherwise, faster and cheaper surveys, even if carried out with innovative technologies, do not allow a detailed assessment. An innovative monitoring approach has been developed and applied in the Archaeological Park of Pompeii (Southern Italy). The methodology considers multi-scale (data and time resolution) and multi-level (assessment accuracy) approaches consistent with the master data and the informative system already developed in the Park. In particular, it consists of three assessment level: Local (LA), General (GA) and Detailed (DA) Screening. LA is multi-yearly provided to lead an extensive heritage condition knowledge, by means of expeditious on-site surveys carried out by expert teams. GA is monthly provided to lead a sufficient knowledge about the overall heritage conditions and it is carried out by means of drones and artificial intelligence (AI) applications. GA can be also feasibly achieved to quickly manage emergency conditions. DS is developed punctually to in deep assess and resolve recognized critical local conditions, also with the support of monitoring devices. The proposed approach makes use of WebGIS, IoT and Digital Twins to describe the heritage health conditions and to develop predictive models to support pro-active maintenance policies.

Keywords

Monitoring, Climate-Change, Decay Prevision

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ID:249

An Innovative Monitoring Strategy of Ancient Temples made of Rigid-Block Structures

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Abstract

The need to preserve ancient monumental architecture in conditions of high risk finds crucial support in innovative methods and technologies that can contribute to improve our knowledge of the buildings' structural health and its evolution for the purpose of proactive maintenance. In this respect, an innovative experimental monitoring strategy has recently been developed and applied to the Temple of Athena in Paestum (Southern Italy, ca. 500 BC), in the frame of a joint research project by the Department of Civil Engineering (DICIV) of the University of Salerno (UNISA), the Archaeological Park of Paestum and Velia (PAEVE) and Leica Geosystems S.p.A. (LGS).

The monitoring activities aim to support an in-depth assessment of the behaviour evolution of the columns on the temple's Est façade, where a crack pattern has been recognised on some drums struck by a thunderbolt in the 70s.

The monitoring strategy involves innovative wireless sensors that are able to record distance and tilts of abacus reference points, with a sampling time of one hour. The monitoring network also considers weather data and has been designed to be expandable and remotely managed. The monitoring strategy is meant to build a digital twin of the columns in order to reconstruct the evolution of the crack pattern and assess its causes. By employing statistical analyses and Fourier decomposition technique, the applied methodology assesses the structural ordinary behaviour and can identify potential critical conditions.

The paper describes the experimented monitoring strategy and discusses its preliminary results, highlighting the impact of climate variations in the structural response of ancient monumental architecture.

Keywords

Structural Health monitoring, Cultural Heritage, Climate Change

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ID:256

The A3 highway Monitoring Model for Bridges Surveillance – Results and Considerations

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Abstract

In the context of road infrastructures management, the development of an optimal and efficient maintenance plan is fundamental to guaranteeing a safety service for the users and an optimal use of the financial resources. For this purpose, an appropriate monitoring methodology becomes necessary to support the managing bodies in the network administration and to give priority on the interventions.

In 2020, CUGRI (Inter-University Consortium for the Prediction and Prevention of Major Risks) and SAM (Southern Highways Company) launched a project of applied research, currently ongoing with SiS-SPN (Stable Consortium SIS Scpa), for the development of a surveillance model to dynamically manage the A3 highway (southern Italy). In particular, this model is based on a multidisciplinary approach which involves expert judgments, periodically on-site inspections and instrumental monitoring, according to the Italian "Guidelines for risk classification and management, security assessment and monitoring of existing bridges", published in 2020 after the collapse of the Polcevera viaduct in Northern Italy.

The main aim of the activity is to develop a Building Management System (BMS) capable of integrating GIS, BIM, and each risk representations, involving on-site interdisciplinary inspections, multi-hazards and multi-risks approach, and monitoring data analysis, in a strong multidisciplinary context.

The paper describes the developed surveillance model and shows the preliminary results.

Keywords

Bridge Monitoring, Risk Analysis, Multidisciplinary Approach.

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ID:257

Assessing the Evolution of Structural Health Monitoring through Smart Sensor Integration

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Abstract

Structural Health Monitoring (SHM) is a vital, continuous, and real-time process for evaluating the physical and functional conditions of various structures, such as buildings, bridges, dams, tunnels, and infrastructures. The primary goal of SHM is to ensure the long-term safety and integrity of these structures by minimizing risks associated with unforeseen failures and extending their operational lifespan. This involves deploying specialized sensors and instruments to collect pertinent data, including stresses, deformations, vibrations, temperature, and other parameters that indicate the state of structural integrity. Especially critical for high-risk structures like bridges and skyscrapers, SHM plays a pivotal role in early problem identification, enabling more efficient scheduling of maintenance and interventions. This, in turn, leads to reduced maintenance costs, enhanced structural safety, and prolonged lifespans for constructions. This study aims to analyze the current state of development of smart sensors and their substitution for traditional methodologies in structural health monitoring through a comprehensive review of existing academic research. By emphasizing the importance of SHM in ensuring the safety and efficiency of structures, particularly in the context of bridges and viaducts, the research underscores the substantial contributions made by smart sensors as complementary enhancements to conventional monitoring methods. The findings highlight the fundamental role of SHM in early anomaly detection, structural performance evaluation, and maintenance optimization. The study stresses the ongoing necessity for research and development efforts to seamlessly integrate intelligent technologies with established monitoring methods, ultimately enhancing the accessibility and effectiveness of SHM in dynamically evolving environments.

Keywords

Structural Health Monitoring, Bridges, Smart Sensors, Traditional Methodologies.

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ID:270

Vibration-based novelty detection using autoencoders: application to KW51 bridge

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Abstract

In recent years an increasing attention has been given to the application of Artificial Intelligence techniques within the context of Structural Health Monitoring (SHM) of Civil Engineering structures. Multiple advantages compared to traditional OMA-based techniques are achieved, such as a relatively low computational efforts and a possible insensitivity to environmental and operational variability (EOV). The present paper proposes an Auto-Encoder-based approach to automatically handle EOVs and, at the same time, to detect structural changes. The proposed procedure is based on the adoption of an Auto-Encoder (AE) model to reconstruct the multivariate measurement data collected during continuous dynamic monitoring. In more details, an AE model is trained with data collected simultaneously from all the available channels during a reference period, in which the structure is supposed to be in healthy condition under normal EOVs. Through the training procedure, the internal bottleneck layer of AE is supposed to learn how the variation of measured data is affected by the normal EOV. Subsequently, the trained AE is used to reconstruct the data collected from unknown scenario, providing a mean reconstruction error (between the measured and the reconstructed signals) that increases as soon as the monitored system changes from its healthy condition. The application of the AE-based procedure is exemplified to the benchmark KW51 bridge (a steel bowstring railway bridge in Leuven, Belgium), showing that the AE model, trained simultaneously with all the available sensors, is capable of detecting the structural changes due to a retrofitting performed on the bridge, under changing environmental and operational conditions.

Keywords

SHM, Machine Learning, Environmental effects, railway bridge.

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Cointegration technique to account for environmental variability in a concrete dam

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Abstract

Within Operational Modal Analysis (OMA) and Structural Health Monitoring (SHM) frameworks, novelty analysis aims to detect structural anomalies by inspecting the time evolution of the modal parameters of a structure subjected to ambient (unknown) excitations. However, real structures are subjected not only to structural anomalies, but also to environmental and operational variability (EOV), so it is necessary to remove EOV effects from damage-sensitive features.

The paper presents an application of Cointegration technique to account for EOVs on natural frequencies by constructing a new time-series mostly sensitive to structural anomalies. In detail, given a set of non-stationary time-series, Cointegration builds a stationary linear combination of them, namely the *cointegration residual*, which is purged from the common trends mainly associated with EOV.

The coefficients of the linear combination are determined by a maximum-likelihood multivariate technique, employing the natural frequencies to construct a cointegrating relationship within a training period, in which the structure is supposed to be in healthy conditions, under normal EOV. Once trained, the computed coefficients are used to test natural frequencies from unknown scenarios. The obtained *cointegration residual* will maintain its stationarity, as long as the structure behaves in normal conditions. Compared to traditional minimization techniques, the Cointegration relies on more general operations, such as the construction of a linear combination given a set of modal parameters.

The application of the presented procedure is exemplified with data measured in Baixo Sabor dam (Portugal) during the first two years of monitoring, which include the first filling of the reservoir.

Keywords

SHM, OMA, Environmental effects, Cointegration, dam

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ID:275

Monitoring of historical monuments: 5 years dynamic monitoring of the Milan Cathedral

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Abstract

Vibration-based monitoring is receiving increasing attention in Civil Engineering but practical applications on heritage structures are still not frequent. Since October 2018, a dynamic monitoring system is active in the Milan Cathedral with the main objective of continuously extracting features which are representative of the current state of structural health.
The paper is aimed at presenting selected results from the monitoring of the Milan Cathedral by applying the statistical pattern recognition framework to the dynamic responses continuously collected during about 5 years.
After a concise historic background on the monument and a description of the implemented monitoring system, the paper focuses on the dynamic characteristics of the building. The evolution in time of the automatically identified modal parameters is presented and discussed, with special attention being given to the influence of environmental parameters on the variations observed in the dynamic characteristics of the building. Once the correlation between environmental changes and natural frequencies has been highlighted, various techniques are applied to remove the variance of natural frequencies that is associated to environmental factors and statistical health indicators are evaluated.
Finally, as the responses to a couple of significant seismic events were recorded in December 2020 and December 2021, comments are given on the seismic behavior of the cathedral.

Keywords

Environmental effects, Milan Cathedral, Natural frequencies, Seismic response, SHM

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Operation modal analysis on prestressed concrete beams with shear or flexural cracks

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Abstract

This study aimed to apply Operation Modal Analysis (OMA) techniques on prestressed concrete beams (PCBs) in order to identify early warning signs of structural damages, such as changes in natural frequencies and/or relevant mode shapes. The main novelty, compared to past similar investigations, is the employment of OMA to these particular damage-scenarios: (1) a PCB equipped with bonded strands affected by "almost pure" shear-cracks; (2) a PCB equipped with unbonded strands affected by small and reversible flexural-cracks. It was found that, especially in the second case, variations of the natural frequencies may not always be an effective index of damage. On the contrary, a qualitative comparison between undamaged and damaged identified mode shapes can be useful for the spatial location of the cracks. Although not among primary objectives, it was also ascertained that OMA techniques are not suitable to assess the actual residual PCB strands' tensile load within typical variation ranges during bridges' service life.

Keywords

Prestressed concrete beam, damage detection, shear cracks, operational modal analysis, frequency domain decomposition.

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ID:296

Advancing Smart Health Monitoring: A Review of Low-Cost Sensors for Structural Assessment

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Abstract

In response to the global demand for structural health monitoring (SHM), particularly in the context of expanding structural assets, this paper conducts a thorough exploration of the integration of low-cost sensors in SHM applications. The primary focus is to introduce various low-cost sensors commonly used in SHM applications for bridges, aiming to unveil their full potential as economical alternatives to expensive commercial sensors. This approach not only broadens accessibility, allowing structures with limited SHM resources to benefit but also enhances measurement points for more robust results. The study begins with the introduction of the NodeMCU, serving as the programmable logic controller equipped with a built-in WiFi module. This feature enables IoT functionality for the low-cost sensors under review. The exploration then delves into an array of digital sensors. Systematic ambient tests were conducted to uncover challenges during sensor installation and data acquisition. The paper not only introduces these low-cost electronic devices but also provides practical solutions to overcome identified issues, ensuring their effective utilization for SHM purposes.

Keywords

Structural Health Monitoring (SHM), Low-Cost Sensor, Bridge Monitoring,

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ID:299

Effective structural health monitoring (SHM) system for bridges: a case study

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Abstract

In the last few years, an increasing amount of resources have been invested in the maintenance of existing infrastructure systems in Italy because of the recent catastrophic collapses of structures. In fact, it is now clear that bridges require proper management by the administering entities, which foresee a detailed control of the health condition of the structure over time, as well as the execution of the required works for good maintenance.

Therefore, the assessment of the structural “health” state of such systems has a crucial role. The monitoring of vibration modes has proved to be an excellent tool for SHM systems since they are related to intrinsic properties of the structure (i.e., mass, stiffness, and damping) and, therefore, to possible damage on the structure.

In a much broader perspective, not only the monitoring of "old" infrastructures is considered but also of new construction so as to have data traceable to healthy structures that serve as a basis for comparison in the examination of the development of damage.

Therefore, in the present work the layout of the SHM system with the innovative sensors of a recently built steel bridge was designed. A preliminary numerical model based on the information from the design documents has been developed and used for the application of OSP (optimal sensor placement) techniques to identify the optimal positions of the sensors to be used for a future SHM system. Moreover, the preliminary acquired signals from the installed SHM system have been processed through techniques of Operational modal Analysis (OMA) and compared with the numerical results.

Keywords

Steel bridge, wireless sensors, optimal sensor placement, MAC, monitoring

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UAV Vision-Based Structural Beams for Real-Time Structural Health Monitoring

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Abstract

Real-time assessment presents a significant challenge in Structural Health Monitoring (SHM), where the timely detection of structural defects, assessment of actual loads, and determination of in-service strength are crucial. This paper introduces an innovative approach that utilizes Unmanned Aerial Vehicles (UAVs) and vision-based technology to revolutionize SHM. A laboratory test on reinforced concrete beams was conducted, employing UAV-mounted high-resolution cameras and image processing techniques to capture surface data in real time. Damage was simulated using a closed-form solution for the progression of flexural cracks, providing insight into the assessment of in-service strength. The integration of UAV-based vision data collection and monitoring with cracking simulation offers a data-driven, real-time solution for enhanced structural assessment. This approach advances timely structural health monitoring, maintenance planning, and infrastructure safety, with profound implications for the field. This novel integration signifies a major step forward in SHM especially if integrated with other technological advancements leading to a better understanding of structural health monitoring.

Keywords

Structural health monitoring, UAV, Drone, vision sensors, crack modelling

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Wavelet analysis to detect nonstationary and nonlinear behaviours in railway bridge

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Abstract

This research concerns Structural Health Monitoring (SHM), with the use of an advanced modal analysis. Using accelerometric measurements, the classical approaches are the study of correlation between damage and the frequencies, mode shapes or damping ratios of the structure, and the detection of cracks from modal curvatures. Moreover, without experimental reference solution, identification of local defects or non-linearities is challenging. This paper shows the potentialities of the proper use of the continuous wavelet transform (CWT) for an analysis of the dynamic responses of railway bridges under the passage of high-speed train. We analyzed the theoretical response; Firstly, the signal must be partitioned properly, as it is comprised of distinct time intervals containing specific modal information (especially bridge and bridge + train). An improper interval definition could lead to unexpected edge effects in the case of a CWT analysis, and if the Fourier transform is used, excessive leaking. Secondly, frequencies originating from the train excitation have to be clearly identified and separated from the natural frequencies of the whole system. A CWT-based procedure is then proposed to process the global signal with emphasis on the choice the wavelet function. An application using experimental accelerometric data collected during the passage of train on a real existing bridge is given. The dynamic response of the "bridge plus train" system is found to have a very distinct non-stationary shape dependent on the finite length of the train and the periodic spacing of its axles. It illustrates CWT capability to detect and characterize nonlinear behaviors.

Keywords

Structural Health Monitoring, Wavelet Analysis, Railway Bridge

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Structural health monitoring of bridge under road traffic: data-driven approach

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Abstract

For existing bridges, reassessment and prognostic on lifespan is a key issue, especially in Europe where bridge assets are over 40 years old. Structural Health Monitoring (SHM) systems using various type of sensors, optical fibers, strain gauges and accelerometers offer a significant tool for safety verification approaches. In most of the use cases, engineering expertise is necessary to completely traduce measures as mechanical indicators and then be useful for reassessment. Moreover, without experimental reference solution, or knowledge of threshold values not to be exceeded, modal parameters or the axial deformation given by strain gauges or the vertical oscillations, an approach only oriented on signal processing can be quite limited. Data Mining (DM) offers then an alternative tool for damage identification of structures and identification of extreme loading effects. Recently, new techniques emerged, making instrumentation much easier and inspections cheaper. Time-frequency analysis tools such as the continuous wavelet transform have been recognized for several years for their ability to process vibration response signals, and to precisely identify the modal parameters of a structure. The topic of this research concerns the proposition of indicators using all data collected from various sensors (accelerometers, strain gages, temperature sensors) during few months on an existing bridge. Such indicators should be representative enough to allow an automatic structural health monitoring to detect abnormal load, and to assess damage using data mining techniques.

Keywords

Structural Health Monitoring, Prestressed Concrete, Assessment, Bridge

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ID:314

Hybrid vibration testing for bridge modal system identification

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Abstract

Output-only system identification of a large post-tensioned concrete bridge using hybrid excitation was conducted. To boost ambient excitations, a dynamic force induced by two light-weight electro-dynamic shakers was adopted for hybrid testing. The bridge modal characteristics were identified using three output-only identification methods: auto-regressive (AR) time series model, eigensystem realization algorithm with observer/Kalman identification (ERA-OKID) and data-driven stochastic subspace identification method (SSI-data). The accuracy and efficacy of the system identification algorithms when applied to hybrid dynamic responses were investigated and benchmarked against the results obtained from pure ambient vibration testing. The study demonstrated that using output-only identification algorithms on vibration responses produced by hybrid excitations can be used for extracting more accurate and reliable modal parameters with enhanced accuracy and reliability for large-scale structures due to enhanced excitation energy and better coverage of relevant frequency bands. More modes were identified at a reduced computational cost from voluminous data of multi-channel measurements.

Keywords

Hybrid testing, operational modal analysis, bridges, system identification, full-scale dynamic testing

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Structural health monitoring of concrete constructions using BIM and non-destructive techniques.

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Abstract

Structural health monitoring of a concrete construction is addressed in order to make a damage assessment. Different methods are proposed to associate to the 3D model all the information collected on the structures, specially designed for the case of concrete structures and adapted to the type of information to be associated. The aim is to achieve a model with the information linked in a more visual and easily accessible way. Non-destructive techniques are used for the internal and external characterization of the construction. For the internal characterization, a pachometer is used to locate the reinforcing bars, a sclerometer test and an ultrasonic test are performed. For the external characterization, a 3D laser scanning is performed to obtain the geometry and an exhaustive visual inspection is carried out. From the point cloud, a 3D BIM model is obtained with all the associated information that graphically reflects the state of structural health of the building. The pathologies of the structure are identified by means of the point cloud and the visual inspection. By using and combining all these techniques together with the BIM methodology it is possible to have a damage control over time in this type of structures. The case study focuses on the stairs that give access to one of the buildings of the School of Industrial Engineering of the University of Vigo.

Keywords

Reinforced concrete, Structural health control, BIM, Non-destructive techniques.

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Multidisciplinary monitoring in continuous of the Cannavino bridge

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Abstract

The ground-based radar interferometry (T-InSAR) provides such high-precision, contactless measurement capabilities for structural deformations, achieving accuracy levels of 0.001 mm in real-time. Its capacity to measure main vibration frequencies up to 100 Hz and assess deformations across multiple points of a structure simultaneously, with a range resolution of at least 0.75 m, showcases its superiority over conventional contact sensors like accelerometers or optical targets.
Compared to conventional contact sensors, like accelerometers or optical targets, the use of non-contact radar-based techniques overcomes some limitations and drawbacks, especially in the activities on structures in operation where time and space are very restricted. This work focuses on a multidisciplinary monitoring activity carried on Cannavino bridge area located SS 107 Silana-Crotonese. After a preliminary study with the laser scanner and the total station on the of the structure, a short, medium and long-term monitoring protocol was developed. Continuous measurements utilizing static interferometry, displacement transducers, and temperature sensors, capturing data every 15 seconds per station, provided a rich dataset. Additionally, biweekly topographic verifications through the Total Station and dynamic interferometric measurements using the IBIS-FS system during bridge operations at a sampling frequency of 100 Hz ensured consistency in assessing the bridge's resonance frequencies.A special platform was developed that can receive and process data in real time verifying the congestion of the same. This platform was able to send alert messages, when definite thresholds were exceeded, interrupting automatically the traffic. The analysis of results generated detailed displacement time-histories and identified dominant frequencies along the bridge, offering invaluable insights into the structure's behavior.
In summary, this project reaffirms the immense potential and adaptability of terrestrial radar interferometry in rapidly evaluating the structural behavior of infrastructures. The monitoring process has facilitated a comprehensive understanding of the bridge's geometry, relative movements, and critical areas, enabling informed planning for restoration interventions.

Keywords

Monitoring 1, T-InSAR 2, Bridge 3, Restoration 4

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Monitoring internal swelling reactions in concrete dams and potential remedial measures

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Abstract

Internal swelling reactions (ISR) is a term used to refer to the chemical reactions that result in the expansion and, eventually, damage of the concrete elements in which they occur. Alkali-silica reaction (ASR) and delayed ettringite formation (DEF) are the most common reactions of this type, both of which are relatively frequent in concrete dams. The concrete deterioration caused by ISR can be observed in several forms at the level of the structure. The external manifestations include relative movements, displacements and deformations, cracking, surface discoloration around the cracks, scaling or spalling and surface pop-outs.
The detection and the assessment of these structural symptoms in large concrete dams is usually made through visual inspection and interpretation of the monitoring instruments data, such as stress-independent embedded strainmeters, geodedic levelling, plumb lines and internal or external jointmeters.
The Portuguese information system, designed to serve as a national database, has its own data structure and includes the results measured from large concrete dams of all types, including dams with more than 60 years. This information system is used by dam owners and the National Laboratory for Civil Engineering (LNEC) to assess the structural behaviour over the years and determine the need for an intervention.
In what concerns to the rehabilitation of these ISR-affected hydraulic structures, the historically most successful intervention types are presented as function of the respective anomaly.

Keywords

ASR, DEF, Concrete dams, Monitoring instruments, Rehabilitation (max 5 keywords)

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Structural performance of self-healing concrete by bacillus subtilis bacteria with addition of RHA

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Abstract

The spores of the bacillus bacteria release calcium carbonate (CaCo3) that fill-up the microcracks in the concrete, that is to say that this biological agent added in the concrete instead of deteriorating the material works as a self-healing agent, several investigations have studied the influence of this bacillus bacteria in the concrete mainly in the species baccilus genus showing its benefits for the concrete with respect to its increase of resistance in the concrete. On the other hand, a replacement for the cementitious material has also been studied, finding that rice husk ash (RHA) in a proportion of 10% not only works as a replacement but also contributes to an increase in the strength of the concrete. In the present work, the mechanical properties of fresh and hardened concrete were investigated with a 10% replacement of RHA and four concentrations of bacillus subtilus bacteria. The study presents the use of bacillus subtilus specie and its behaviour with the addition of rice husk ash. The results showed an increase in compressive strength of up to 25,83 % compared to conventional concrete and 44.80 % compared to concrete with RHA addition. This research aims to promote the use of bacteria in concrete, as they not only provide an increase in compressive strength but also enhance the concrete's service life by endowing it with self-healing capabilities.

Keywords

Bacillus subtilis, Rice Husk Ash, self-healing, concrete

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Reliability of closed-form damage quantification for material and measurement uncertainty

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Abstract

The application of any existing damage quantification techniques requires validation through several real case studies to ensure a higher level of reliability. Absence of such extensive studies presents a limitation to successful implementation of these methods in practical scenarios. A reliability study is hence performed in this work considering material and measurement uncertainties to bridge this gap. The novelty of this study lies in determining a confidence bound of modal parameter-based closed-form expressions of damage quantity in a shear building. To achieve this, at first, a 10-story shear building is numerically analyzed for three locations of damage considering a wide range of severity. Gaussian distribution is assumed to account for stiffness variation of each story at healthy and damaged states of the structure. For each sample of stiffness, damage quantity is evaluated with prevailing closed-form methods. Similarly, in presence of measurement uncertainty, computed modal displacements are varied assuming similar distribution parameters as material uncertainty. Subsequently, these modal values are employed in the formulations of damage quantification. The effect of material and measurement uncertainty propagation on the reliability of estimated damage value is then examined and correlated with the numerical observations. Experimental investigation and validation with real dataset may be considered as the future scope of this study.

Keywords

Reliability, Uncertainty, Modal response, Damage quantity, Eigenvalue

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Structural Response of Containment Structure of NPP to Internal Pressure and Thermal Gradients

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Abstract

As a final task for the life-extension program of the Embalse N.P.P. located in Córdoba, Argentina, the pre-stressed concrete Containment Structure (CS) has been subjected to a full-scale pressure-leak test after more than 30 years of service. The test was carried out at the start of the summer season, after completion of a general overhaul of main functional components; the CS had previously been inspected, and successfully passed a first evaluation before the implementation of its life extension process. This paper is concerned with the analysis of the structural response of the CS to internal pressure and comparison with test results. The purpose of the paper is focused on assessing the structural response of the CS through the measured displacements and strains caused by the prescribed pressurization sequence. Special attention is given to thermal changes caused by exposure to sun radiation and daily temperature changes over the course of almost one month duration of the test sequence. A numerical model of the CS developed for a preliminary assessment of the design requirements imposed on the CS was also used in order to filter out the associated uncontrolled thermal strains and displacements that occur simultaneously with those associated with the changes in the internal pressure. The numerical model was first used to evaluate the expected stresses and compliance with design requirements during the test, and was later used to calculate the thermally induced strains and displacements that occur during the pressure test in order to assess the displacements directly associated to the increase in internal pressure.

Keywords

Pressure test, Life extension, nuclear, power plant, thermal

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X-ray diffraction application for tensile evaluation of Post Tensioned Cables

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Abstract

X-ray diffraction (XRD) is an analytical technique that can provide reliable solutions to many issues related to material science and industrial application, as quality control and process parameter optimization of manufacturing processes as geology, chemistry, pharmaceuticals, mechanics, semiconductors, nano-materials, additive manufacturing etc. However, it remains a technique with several aspects of complexity mainly related to data interpretation and instrument standardization that limits its application to procedures dependent on sample dimension and preparation. In addition to traditional powder diffraction techniques that are already used in civil engineering, X-ray diffraction has been used for years in mechanical engineering to determine residual stresses. In the past, some attempts of application in the field of civil engineering have been reported, but size of the available instrumentation at that time, have to date prevented a real use, despite the fact that its potentiality and applicability had been amply demonstrated. Over the last 4 year, in Italy, thanks to an intense ongoing investigation campaign, the measure of the tensional state of the post-tensioned cables of pre-stressed concrete structures has been the subject of evaluation campaign. The purpose of this dissertation is to provide general information on the physical principles of X-Ray-diffraction and to illustrate what are its current potentialities applied to the measurement of the tensional state of post tensioned cables (PTC) in the light of the instrumental innovations available to date.

Keywords

Non-destructive tests, post tensioned concrete, prestress loss, X-Ray diffraction, structural assessment

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Virtual Sensing in Steel Bridges: Time Series Deep Learning for Stress Prediction

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Abstract

This study introduces an innovative approach for predicting stress responses in steel bridges, specifically focusing on a railway bridge in Vänersborg, Sweden. Four deep learning models have been evaluated: Multilayer Perceptron (MLP), Long Short-Term Memory (LSTM), Temporal Convolutional Network (TCN), and a hybrid LSTM-TCN. Training on stress history data from a multiscale Finite Element (FE) model and validation with real-world data from a bridge monitoring system revealed high prediction accuracy near sensor locations, surpassing an R-squared score of 0.9, comparable to the polynomial local response function method.

The results underscore the great potential of deep learning-based sequencing models in identifying complex, time-dependent stress correlations, including those at distant points. These models demonstrate a notable capability for capturing non-linear relationships within stress histories. While sequence-based models (LSTM, TCN, and hybrid LSTM-TCN) tended to provide conservative estimates impacting fatigue life predictions, the MLP model occasionally underestimated critical stress cycles. Notably, the TCN model exhibited high computational efficiency, which is beneficial for handling large datasets.

This research emphasizes the potential of deep learning techniques for time series to enhance bridge monitoring systems, improve virtual sensing, and enable real-time monitoring capabilities. Our proposed methodology provides a comprehensive understanding of stress responses in steel bridges, which is crucial for ensuring their maintenance and safety.

Keywords

Fatigue Life Prediction, Virtual Sensing, Time Series Modeling, Deep Learning

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Modal identification of existing concrete half-joint bridges through free vibration tests

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Abstract

Vibration-based tests are widely used for the assessment of existing structures. They allow the estimation of modal parameters, a possible deviation of which may be symptomatic of the onset of damage in the structure. Specifically, in the case of bridges, free vibration testing is a rapid, low-cost method that requires the installation of a limited number of sensors on the structure. This contribution presents the results of the dynamic identification for a series of existing concrete half-joint bridges based on free vibrations recorded after the transit of heavy trucks. The bridge deck modal characteristics (frequencies, damping ratios and mode shapes) are obtained via a recently developed identification framework based on the variation mode decomposition. These experimental estimates are also analyzed and used to calibrate a finite element model of the bridge deck, based on in-situ material characterization tests. Negligible fluctuations both in frequency and mode shapes are observed between experimental and numerical findings, which suggests that the analyzed overpasses do not present any relevant damage or cracking process under the service loads.

Keywords

Road overpass; half-joint; free vibration tests; modal identification; structural health assessment

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Deep Learning-Based Prediction Model of Temperature-Induced Deflection of a Multi-Span Continuous Box Girder Bridges: Case Study

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Abstract

The deflection of a bridge is a crucial factor in assessing its structural integrity and safety, serving as an indicator of the overall rigidity of the bridge. The deflections stemming from temperature variations may surpass those attributed to live loads. However, the monitoring data acquired from the sensors indicate a time-lag effect exists between temperature variations and resulting deflection. The time-lag effect poses challenges in precisely characterizing and modeling the temperature-induced deflection behavior. Therefore, this paper presents a deep learning-based prediction model to forecast the temperature-induced deflection of strengthened multi-span continuous box girder bridges. The Long-Short Term Memory (LSTM) model was adapted in this paper leveraging deep learning techniques which capable to learn complex patterns and non-linear relationships between temperature and temperature-induced deflection data to forecast the deflection under different temperature variations. To enhance the precision of the LSTM model, this paper proposed the Empirical Mode Decomposition (EMD) method to extract the temperature-induced deflection from the raw deflection data which induced by other various factors such as vehicles loads and wind loads. In the forecasting outputs obtained from the LSTM model, the root mean squared error (RMSE) and mean absolute error (MAE) were noteworthy achieved a low error value of 0.51mm and 0.39mm respectively. Lastly, residual analysis was conducted to analyze the forecast outputs from the LSTM model with the actual measurements obtained from sensors.

Keywords

Box girder bridge, Temperature induced-deflection, Prediction, Deep learning, Empirical Mode Decomposition

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ID:443

Experimental study on identification of rebar prestress based on acoustic elastic effect

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Abstract

As the core vertical prestressed force member of the bridge structure, the finish rolling rebar can not effectively control the stress loss in the whole process of anchoring and is affected by environmental corrosion and other factors during the actual construction, resulting in the vertical prestress can not meet the design requirements or even failure, which seriously threatens the durability and safety of the structure. In this paper, ultrasonic guided wave technology and acoustic elasticity theory are combined to detect the effective prestress of rebar, and the key problems such as guided wave propagation characteristics and acoustic elasticity effect under different stress states after bare rebar and rebar wrapped mortar are studied. Taking the center frequencies of 50 kHz, 75 kHz and 100 kHz as excitation signals and considering different excitation powers, the post-tensioning test and guided wave propagation test of rebar and outer mortar were carried out, and the variation law between the first wave velocity of guided wave and the tensile force was analyzed. The results show that the first wave velocity of the guided wave of the rebar decreases with the increase of the excitation frequency, which is consistent with the theoretical dispersion curve. With the gradual increase of the excitation power, the amplitude of the guided wave waveform received by the rebar only increases gradually in the time domain and frequency domain, while the shape and position of the waveform do not change, so the influence of the excitation power can be ignored in the experiment. The law between the first wave velocity and the tensile force of the rebar after outsourcing mortar is consistent with that of the bare rebar, but the first wave velocity and energy are significantly lower than those of the bare rebar. It is feasible to establish the identification method of rebar prestress based on acoustic elastic effect.

Keywords

Acoustoelastic effect, Finish rolling rebar, Outsourcing mortar, Experimental study, The first wave velocity

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Experimental and numerical bond behavior of PBO FRCM tested using a pull-out set-up

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Abstract

Fabric-reinforced cementitious matrix (FRCM) composites have become increasingly popular in the field of externally bonded (EB) reinforcement of existing concrete and masonry structures. They are used as flexural, shear, and torsional strengthening of reinforced concrete (RC) members. They are comprised of high strength textiles embedded in an inorganic-based matrix. FRCM tensile mechanical properties are characterized by clamping-grip or clevis-grip tensile tests, whereas their bond behavior by indirect or single- and double-lap direct shear tests. The eccentricity between the applied load and the restraint in single-lap direct shear tests entails for the presence of normal stresses that can affect the bond stress-transfer mechanism. Furthermore, direct shear tests require relatively large and heavy specimens. To overcome these issues, a new pull-out test set-up was proposed in the literature to investigate the bond behavior of FRCM composites that fail at the textile-matrix interface. In this paper, nine pull-out tests are performed on PBO FRCM composites. Bonded lengths shorter and longer than the textile-matrix interface effective bond length are considered. Six specimens have a short bonded length (i.e., 150 mm), whereas three have a long bonded length (i.e., 450 mm). Applied stress – global slip curves of the specimens tested highlight the presence of friction at the textile-matrix interface. The results of the pull-out tests are compared with those of corresponding single-lap direct shear tests presented in a previous work with the same PBO FRCM composite and the same bonded length and width. The applied stress – global slip curves obtained from the two sets of test show good agreement. Finally, the pull-out test set-up is validated by means of a three-dimensional finite element model.

Keywords

PBO, FRCM, pull-out, CML, numerical modelling

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Vibration-based fault Detection of a Hydraulic Pump Using a Convolutional Neural Network

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Abstract

This research presents a method for vibration-based fault detection in hydraulic pumps using a convolutional neural network (CNN). The reliability and efficiency of the hydraulic pump are crucial for the effectiveness of the hydraulic system. Hence, in order to ensure optimal performance of the hydraulic pump, it is imperative to implement problem detection and monitoring. Initially, by employing the piezoelectric sensors positioned in proximity to the pump, vibration signals were acquired from both the operational and faulty conditions of the pump. The MATLAB software is utilized to preprocess the time domain vibration data before its input into the CNN. There are two types of CNN models commonly utilized in deep learning for fault detection: 1D CNN and 2D CNN. The comparison is conducted on both the frequency domain and time series vibration data, utilizing a 1D CNN architecture. Subsequently, the data graphs in the time domain and frequency domain are compressed to a reduced resolution size prior to being inputted into a 2D CNN. In order to make comparisons, the vibration signals are further analyzed using principal component analysis (PCA), which is a method for reducing the dimensionality of the data. The results indicate that utilizing the frequency spectrum as the input for the CNN leads to the highest accuracy of 100% for both 1D and 2D CNN models. Using the time series as the input for the CNN results in a decrease in defect identification accuracy to 96%. These results also show that the accuracy drops even more when PCA is used to compress time series or frequency spectrum data before it is fed into the CNN model.

Keywords

Convolution Neural Network, Fault detection, Structural Health Monitoring, Frequency spectrum, PCA

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Structural strengthening and repair

ID:017

GA-based economic and environmental optimization procedure for seismic upgrading of RC frames

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Abstract

The seismic upgrading of existing RC structures has become a timely challenge that often civil engineers are meant to deal with. Although this particular design problem can be solved adopting an appropriate combination of member-level and structure-level techniques, it is really hard to find any design rule for supporting engineers in a similar choice. Thus, if such decision process is seen as an optimization problem, Genetic Algorithms (GAs) could be employed to search for the “fittest” upgrading solution, with respect to one predefined optimization criterion. The present paper outlines the latest advances in the implementation of a recently-formulated GA-based optimization procedure for the seismic upgrading of existing Reinforced Concrete (RC) structures, selecting a feasible and code compliant solution, obtained by combining FRP jacketing of RC columns (as member-level technique) with the introduction of steel braces (as structure-level technique). Recently, novel optimization criteria have been adopted, not only accounting for the initial intervention costs, but also for the environmental costs, accounting for Life-Cycle-Assessment (LCA) of all the operations required for of both member- and structure-level interventions. At each procedure iteration, the feasibility of a “population” of potential upgrading solutions is evaluated with respect to a previously-defined objective function and, then, some “genetic operators” are handled to generate new potential upgrading solutions with the aim of gradually increasing their cost-effectiveness. The paper focuses on the comparison between the “optimal” seismic upgrading solutions for an ideal RC existing building, suggested by the GA-based procedure, adopting different optimization objectives, accounting for both economic and environmental costs.

Keywords

Economic-Environmental Optimization, Genetic Algorithm, Seismic upgrading, existing RC structures, Steel braces

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ID:047

AE-based Health Monitoring of Full-scale RC Beams Strengthened with FRCM Composites

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Abstract

The use of fiber-reinforced cementitious matrix (FRCM) offers several advantages, making it a potential replacement for conventional fiber-reinforced polymers (FRP). The integration of mechanical anchorage enhances the robustness and cost-effectiveness of the FRCM system. This research study is primarily focused on the comprehensive flexural strengthening of reinforced concrete (RC) beams using FRCM. To achieve this, three RC beams were intentionally partially damaged, and subsequently, two layers of FRCM were applied with three distinct strengthening strategies, including options with and without mechanical anchorage. These beams were then subjected to a monotonic four-point bending loading test. Monitoring of the front face of the beam was carried out using the Digital Image Correlation (DIC) technique, while the bottom and back faces were equipped with three acoustic sensors, each with a frequency range of 0-1000 kHz. It was observed that the FRCM strengthening strategy involving mechanical anchorage proved highly effective in increasing the load capacity of the beam by approximately 20% when compared to other strategies using a similar percentage of fabric reinforcement. The analysis of acoustic emission (AE) data involved the assessment of parameters such as event rate, b-value, RA-AF, sentry function, historical index, and frequency content (partial power). These metrics helped in successfully identifying different phases of the test based on changing trends in event rate, and RA-AF over time. The sentry function and historical index revealed the patterns of major events, while the b-value indicated the occurrence of micro and macro cracking during the progression of damage. Frequency analysis was effectively employed to classify various damage mechanisms associated with different material components.

Keywords

TRM, FRCM, AE, parametric analysis, partial power

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ID:054

New bonding agents for the NSM FRP strengthening system for concrete structures

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Abstract

Over the past few decades, the implementation of near-surface mounted (NSM) FRP has become a promising strengthening method for improving the performance of concrete structures. Despite the common use of epoxy adhesives in NSM FRP systems, concerns have arisen due to their drawbacks, including the emission of toxic fumes and reduced mechanical strength when subjected to elevated temperatures and moisture. To address these issues, cement-based adhesives have been introduced as a substitute bonding agent with the goal of enhancing the performance of concrete structures in high-temperature settings and minimizing environmental and health hazards. In this paper, new modified cement-based adhesives have been developed for the NSM FRP system for concrete structures. The efficiency of these adhesives was assessed through an experimental investigation involving pull-out testing using a single-lap shear test setup to study the bond behaviour of the NSM CFRP laminate for concrete structures. The results of these tests demonstrate the effectiveness of the NSM technique when new cement-based adhesives are utilized, as highlighted in this paper.

Keywords

NSM FRP, Cement-based adhesives, Concrete structures, Bond Behaviour

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ID:081

Experimental assessment of the flexural/shear strengthening effectiveness of new CFRP bars

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Abstract

The potential of a new carbon fibre reinforced polymer (CFRP) bar is explored for the simultaneous flexural and shear strengthening of reinforced concrete (RC) beams. This bar has a stick geometric configuration, with a part applied according to the near surface mounted (NSM) technique and the other according to the embedded through section (ETS) technique, both connected with a smooth transition zone. The NSM part aims to increase the flexural capacity of the RC element, while the ETS part, inclined at 45-degrees relative to the RC beam's axis, provides shear strengthening and avoids premature end debonding and rip-off failures modes to the NSM part. To avoid premature rupture of the transition zone of this bar, CFRP anchor are applied in the critical regions of the beam. An experimental program with almost real scale RC beams, subjected to a four-point bending test configuration, was executed to demonstrate the efficiency of this strengthening technique. The experimental results reveal that the RC beam strengthened using this innovative CFRP bar and technique exhibited an impressive threefold increase in load carrying capacity when compared to a reference RC beam, and ensured high deflection performance.

Keywords

RC beams, Flexural and shear strengthening, New CFRP bar, CFRP anchor, Experimental tests.

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ID:082

Seismic Retrofitting of a 7-storey Hospital Building

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Abstract

In this work, two main structural solutions have been proposed to retrofit an existing Italian hospital building located within the National Cancer Institute “G. Pascale Foundation” in Naples. The structure under consideration is composed by nine reinforced concrete cores connected by means of steel structural members.
Preliminarily, the seismic vulnerability has been evaluated according to the linear dynamic analysis with reference to both for the Life Safety (SLV) limit state and the Operational (SLO) limit state according to the current Italian code. The analyses have been performed using the SAP2000 program, post-processor VIS15 and plugin SPF. Subsequently, in order to improve the structural performance of the building, two solutions have been developed both based on the reinforcement of the RC cores but by adopting two different approaches: the first one characterized by the use of the added RC walls; the second one based on the using of steel plates. Then, the attention is focused on the pile foundation. In particular, the structural vulnerability has been evaluated by adopting a static linear analysis and, consequently, a retrofitting intervention has been provided. Finally, the proposed interventions have been evaluated from the economic and environmental points of view.

Keywords

Existing structures, Structural retrofitting, RC walls, steel structures, pile foundation

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ID:090

Experimental Response of Headed Stud Shear Connectors in Steel-UHPC Composite Slabs

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Abstract

Ultra High Performance Concrete (UHPC) is widely used nowadays with the aim to obtain more resilient and sustainable structures. In particular, interest is rising on the use of UHPC for replacing existing slabs in steel-concrete bridge decks, which generally leads to a possible reduction in thickness and, consequently, results in a lower material demand.

As the possibility of substituting existing slabs with UHPC ones is strictly related to the effectiveness of beam-to-slab connection, nine push-out tests have been carried out at the Structural Engineering Testing Hall (Str.Eng.T.H.) of the University of Salerno with the aim to characterize the mechanical behaviour of the shear connection between concrete slab and steel joist. Three groups of specimens were realized, each of which characterized by a slab made of a different concrete and with different thickness. More specifically, i) a 150-mm-thick slab conventional RC slab, ii) a 120-mm-thick medium-strength RC slab and iii) a 75-mm-thick unreinforced UHPC slab were considered for the push-out specimens tested as part of this study. However, Nelson-type headed stud shear connectors, 16 mm in diameter and 64 mm in height, were employed in all those specimens.

This paper reports the results of the push-out tests and compares the different force-slip curves obtained for the three groups of tested steel-concrete stubs, in view of future developments intended at understanding their influence of global behaviour of steel-concrete composite bridge decks.

Keywords

UHPC, Push-Out Test, Shear Connectors, Steel-Concrete slabs

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ID:096

Seismic Performance of Damaged RC Column Repaired with Structural Mortar

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Abstract

Knowledge on the seismic performance of damaged reinforced concrete (RC) structures after repair is essential for an effective post-earthquake disaster management policy. However, the number of experimental studies investigating the seismic behavior of repaired RC members are insufficient, especially for structural members that have suffered damages of slight or moderate levels. In this study, three identical large-scale code-conforming RC columns were tested under combined effects of axial load and reversed cyclic lateral displacements. The reference column was tested until failure, while the remaining two columns were tested after the formation of damage at different levels and repair with structural repair mortar contains recycled raw materials. The primary objectives of the experimental program are to enhance the knowledge on the post-EQ performance of damaged RC columns and to investigate the effects of repair at slight and moderate damage levels. This paper provides details on the degradation of seismic performance of code-complying RC columns due to damages and the effectiveness of the mentioned repair technique. In addition, plastic hinge modification factors that can be used for numerical representation of the structural characteristics (such as stiffness, ductility, and lateral load capacity) of the damaged and repaired members are also discussed.

Keywords

Columns, Seismic, Reparability, Damage, Repair, Plastic Hinge

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ID:106

An integrated approach for seismic design and modelling of plywood-retrofitted timber floors

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Abstract

The application of timber-based strengthening solutions to existing wooden and masonry structures, combines several benefits, such as reversibility, compatibility, lightness, sustainability, affordability, and effectiveness. With specific reference to existing timber floors, the superposition of plywood panels fastened to the sheathing has proved to be an excellent method to enhance the seismic response of such structural components, combining a great improvement of in-plane strength and stiffness, with a considerable increase in their hysteretic energy dissipation.
In order to promote the use of this retrofitting method in practice, this work firstly presents the implementation of calculation tools supporting the design and advanced numerical modelling of timber diaphragms strengthened with plywood panels. The suite of tools allows to first estimate the full nonlinear, cyclic in-plane response of the strengthened diaphragms, starting from the geometrical and material properties of the existing sheathing and the plywood overlay, as well as the mechanical characteristics of the fasteners. In a second step, it is possible to transform such estimated in-plane response into a constitutive law for finite element modelling and perform advanced numerical simulations, by means of a user-supplied subroutine developed for DIANA FEA software. Relevant calculation examples show the accuracy and potential of this integrated approach, which also found application in an ongoing research study on the evaluation of the influence of retrofitted diaphragms' stiffness on the seismic out-of-plane response of masonry gables, as part of the ERIES-SUPREME project, supported by the Engineering Research Infrastructures for European Synergies (ERIES).

Keywords

Timber floors, Plywood, Numerical modelling, Architectural conservation, Seismic retrofitting

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ID:107

Design and modelling tools for timber-based seismic retrofitting: from research to practice

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Abstract

Reversible retrofitting techniques for protecting existing or historical buildings against seismic events have found increasing application in in the recent years. In particular, the use of wood-based strengthening solutions for both timber and masonry structures has shown promising results in terms of reversibility, compatibility, lightness, sustainability, and effectiveness. With reference to existing timber floors, an excellent method to enhance their seismic response is the fastening of an overlay of plywood panels to the existing sheathing, an intervention that greatly improves in-plane strength, stiffness, and energy dissipation. In order to promote the use of this retrofitting method in practice, calculation tools supporting the design and modelling of timber diaphragms strengthened with plywood panels, have been developed. As a result of a fruitful synergy between academic research and professional engineering, this work presents relevant recent examples of application of the developed calculation tools in the seismic retrofitting of timber diaphragms in existing buildings. Three significant case-study buildings are examined: two masonry churches with monumental timber roofs, and an ancient sawmill with a mixed timber-masonry structure, all located in the province of Brescia (Italy). The developed tools allowed to conduct parametric analyses to calibrate the best retrofitting strategy, and to analyze the additional benefits of the plywood-based retrofitting interventions, especially in terms of hysteretic energy dissipation, affordability, and cost- and execution-effectiveness. This work can contribute to the promotion of timber-based techniques in the combined structural, seismic, and conservation upgrading of existing buildings belonging to the architectural heritage of seismic-prone countries.

Keywords

Timber floors, Plywood, Existing buildings, Architectural conservation, Seismic retrofitting

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ID:114

Seismic retrofitting of an existing hospital with external steel lattice

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Abstract

Earthquakes cause serious damage to buildings and result in heavy losses to society, therefore, it is necessary to enhance the seismic capacity of existing buildings via structural retrofitting. The traditional retrofitting approaches are based on the component-level, but their improvement effect for the overall structure is not obvious.
Up till now, the seismic retrofitting technology can be generally divided into three types. The first is strength-improving type, the second is ductility-improving type, and the third is seismic dissipation/isolation type. Most of them are focused on member-based or component-level improvements of strength or ductility applied to poorly reinforced concrete walls or columns and masonry walls.
Meanwhile, the weak layer of the existing structure can be strengthened by external sub-structures as steel lattice or frames to make the overall structural capacity or stiffness more uniform. In addition, because the construction is an external operation, it can achieve non-disturbing retrofitting without affecting the normal use of the inner structure, which is of great practical significance and social benefits for lifeline projects such as schools and hospitals that cannot be interrupted.
In the present case study, the efficiency of a seismic retrofitting with external steel lattice of the university hospital Zurich (USZ) will be discussed. The original 3-story reinforced concrete building with a floor area of 44m/24m was built in 1966. Subsequently, in 1970, the building was extended by 4 floors with a composite steel structure. On the roof floor there is a helipad for emergencies. The first results of a response spectrum analysis showed major deficiencies in terms of horizontal and torsional stiffness, so that a strengthening measure became necessary.
The results were verified by means of a push-over analysis, which showed that the measure applied was very effective. Finally, the structural design and the connection details to the existing concrete structure are shown.

Keywords

existing buildings, seismic retrofitting, external steel lattice, push-over analysis

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Use of equivalent interface samples during fracture mechanics investigations

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Abstract

During an international project called SBO (Strength Bond Offshore), a design strategy of adhesively bonded composite reinforcements for steel structures was developed and assessed. It relied on the use of a large number of fracture mechanics tests in mode I, mode II and mixed-mode. To reduce the number of samples while remaining representative of the studied reinforcement a new methodology called “equivalent interface samples” is proposed.
This paper aims at presenting the adaptation of fracture mechanics tests implied by this new methodology for all tested modes (mode I, mode II and mixed mode), and its use during the design strategy. First, the geometry of the samples will be presented. Then, the obtained results during the fracture mechanics experimental campaign will be introduced. Those investigations relied on the use of optical fiber to monitor the crack propagation during the tests. The obtained toughness characterizations allowed to propose a design strategy that was assessed in regards with experimental tests led on real size steel samples reinforced with adhesively bonded composite. The comparison allowed a validation of the new methodology for the design strategy of bonded composite reinforcements for steel structures.

Keywords

Adhesively bonded composite reinforcement, Steel structures, Fracture mechanics, Equivalent interface

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ID:168

3D-printing technology for integrating the monitoring and rehabilitation of civil structures

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Abstract

In the last decade, 3D-printing technologies are widely spreading also in the field of architectural restoration of historic structures, buildings and monuments, thanks to the possibility to simply and precisely reproduce complex shapes with different materials. Nowadays, 3D printing technologies, in the aforementioned field, are generally employed for the physical reproduction of decorative/architectural components, while the reproduction of structural elements is still in a primordial stage. In this context, the paper presents an experimental study on 3D-printed samples made of PLA (Polylactic Acid Material), equipped with fiber optic sensors introduced inside the samples during the printing process. Then, considering different printing processes and the effect of aging artificially induced, experimental tests were performed with the twofold aim of investigating the mechanical response of samples and the reliability of fiber optic sensors. Regarding the latter, the comparison between the data provided by the universal machine employed for carrying out the tests and the ones deduced from the fiber optic sensors allowed for examining the interaction between the samples and the fiber optic: a paramount issue for the design of monitoring systems integrated with 3D-printed components.

Keywords

3D-printing, cultural heritage, monitoring, fiber optic, PLA

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ID:170

Structural assessment and numerical analysis of existing reinforced concrete frame structure

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Abstract

On March 20, 2020, Zagreb was hit by a strong earthquake with a magnitude of 5.5 on the Richter scale, with the epicenter located 7 km away from the city center. A large number of buildings in the city center were damaged, as they were dating back to the late 19th and early 20th centuries. After the earthquake in Zagreb, the area of Petrinja, which is approximately 40 km away from Zagreb, was struck by a 6.2 magnitude earthquake on the Richter scale, further damaging buildings in Zagreb. The subject of this study is the presentation of in situ tests on the existing structure and structural strenghtening of the existing structure of the Faculty of Political Sciences building at the University of Zagreb. The building is consisted of 3 blocks connected into one unit. The load-bearing structure of the building is a reinforced concrete frame system (column- beam). Filling between frames is masonry made of solid bricks. The floor structure is reinforced concrete ribbed slabs, which is characteristic for the construction period around the mid-20th century from which building dates. Structure has six floors above ground. This paper presents the initial condition and categorization of damage after the earthquake, as well as the in situ tests on the existing load-bearing structure. Through input parameters of the data provided from existing structural properties, an numerical analysis of the existing condition and the current capacity of the load-bearing structure under seismic action was performed. Based on the results, a retrofitted numerical model was developed and analyzed. Result of analysis is achieved capacity under seismic action. Finally, the implemented retrofitting interventions on the load-bearing structure in the construction phase is given along with the description

Keywords

Earthquake, in situ tests, structural strenghtening, static analysis

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Welding under service conditions – Monitoring, repair strategy and rehabilitation

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Abstract

Steel structures, such as bridges, must be continuously maintained. Due to increasing traffic loads, design and execution shortcomings, many steel bridges are subject to various types of damage, such as cracks. To address these problems, it is necessary to perform maintenance, typically by removing these cracks by re-welding. During this repair process, the affected bridge needs to be closed to traffic in order to prevent crack movement during the welding. Due to this closure, traffic is diverted to alternate routes, increasing the traffic loads on those routes, which, unfortunately leads to additional damage and subsequent welding work and costs for these alternate structures. Therefore, the primary goal is to establish a method that allows welding work on steel structures while traffic is flowing. In order to achieve this, measurements were first conducted at a representative steel bridge to derive gap opening parameters of amplitude and frequency for welding tests under cyclic loading. Subsequently the weld quality and the fatigue performance were quantified. The weld quality and the fatigue strength were comparable to standard requirements, so that welding under service conditions is possible under certain aspects.
In this paper, it will be presented which crack monitoring techniques can be used to quantify the gap opening. A repair strategy for butt joints is presented, along with data on the fatigue strengths achieved. It is also shown how this repair process can be documented in a digital twin framework.

Keywords

Repair of bridges, retrofitting, fatigue, structural health monitoring, digital twin

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Static strength in adhesive joints with different patch plate end subjected to bending force

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Abstract

Adhesively debonding from the end of patch plates is one of the major concerns in the application of externally bonded joint methods for repairing or strengthening steel structures. This paper focuses on enhancing the adhesive strength of adhesively bonded joints by investigating different patch plate end configurations. The target specimen model was the adhesively bonded joints of the single patch plate adhered to the base plate subjected to the bending force. The epoxy resin Konishi E258R was used as the adhesive in this study. Five different patch plate end types of specimen models were analytically and experimentally investigated. The analysis was conducted by modeling using MSC Marc Student Edition 2022, and the static tests of the single patch plate bonded joints were conducted under bending force (cantilever beam). The result shows that the static strength of the adhesively bonded joint is significantly increased for each tapered design of the patch plate end.

Keywords

Adhesive joint, Adhesive debonding, Static strength, Patch plate end, Bending force

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Structural Rehabilitation using C-FRP: A Two-Decade Evaluation of Durability and Guidelines

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Abstract

This paper focuses on a strengthening intervention carried out in 1996 on reinforced concrete (RC) portal frame structures using Carbon Fiber Reinforced Polymers (C-FRP). In that period, there were no standards or guidelines (both national and international) governing the design procedure, which also lacked specific details, thereby requiring that the design of the intervention be based on a careful analysis of data obtained by suitable experimental tests. Today, nearly two decades after the execution of the intervention, the C-FRP-strengthened structure has maintained its structural integrity. This result not only validates the adopted design procedure but also confirms the significant advantages in terms of durability and lower maintenance costs associated with the use of C-FRP materials compared to traditional solutions such as concrete and steel. In this context, the effectiveness of the structural rehabilitation design, based on the experimental data, was then compared with current design procedures given by national and/or international guidelines. Through a comparative assessment of the two procedures and their respective results, it was possible to highlight the relevance of experimental studies for design purposes and to provide comprehensive data about the long-term durability of FRP-strengthened RC structures.

Keywords

Structural rehabilitation, FRP, Experimental study, Durability.

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Effectiveness of FRP bar anchors for prestressed concrete members

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Abstract

Prestressed concrete members are widely used around the word for making different types of structures, from bridges to tall buildings. Steel strands are generally employed to apply a compression force into the concrete. Recently, fiber-reinforced polymer (FRP) composite bars have been considered for replacing traditional steel strands in specific applications. The main advantage of FRP bars is their resistance to corrosion. Furthermore, they have a higher tensile strength-to-weight ratio and fatigue resistance compared to steel strands. Although using prestress FRP bars may entail for advantages over traditional steel solutions, the anchorage system is an open issue for this technology. Indeed, the anchorage should guarantee a high level of tensile stress into the bar and, at the same time, avoid local ruptures.
In this paper, the results of an experimental campaign comprising tensile tests of FRP bars with different anchors are reported and discussed. The experimental campaign was conducted to investigate the effect of wedges on the tensile behavior and on the type of rupture of FRP bars. Tensile test results and the modes of failure are discussed, shedding light on the main parameters that affect the mechanical behavior of the bars considered.

Keywords

FRP bars, Prestress concrete, Anchor systems, Tensile test, Wedges

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ID:212

Open issues on the use of composite bars as prestressed reinforcement of concrete members

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Abstract

In the last decades, fiber-reinforced polymer (FRP) composites gained popularity in the field of structural engineering thanks to their high strength-to-weight ratio, limited corrosion in harsh environments, and permeability to electromagnetic fields. These composites are used as reinforcement of new concrete members as well as for strengthening of existing structures. For existing reinforced concrete (RC) buildings, different techniques are available to increase the strength and the stiffness of the existing elements. Among them, a promising technology consists in applying a compression force to the elements by using external prestressed FRP bars. This technique may provide concrete crack closure, thus reducing the exposure of steel bars to the environment.

In this paper, a thorough literature review is carried out to investigate the open issues that hinders the diffusion of this innovative technique. According to the literature, the main issue is the anchor systems that should guarantee high stress level into the composite material avoiding, at the same time, local ruptures. Another open issue is the percentage of ultimate tensile strength to apply to the composite bars. In fact, a high level of prestress tension may lead to premature failure. Finally, the exposure of FRP bars to the environmental conditions (e.g., high moisture level, presence of chemical agents, and high temperature) may lead to a decrease of the compression force applied to the RC element.

Keywords

FRP bars, Prestressing, Anchor, Strengthening, SOTA

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How much code-based shear models affect seismic assessment of pre-code RC buildings?

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Abstract

Existing Reinforced Concrete (RC) building stock often have exhibited a significant vulnerability under seismic shaking after the most recent earthquakes worldwide. They were often designed without capacity design principles, even where seismic hazard is very high, such as in Italy. Two-third of Italian existing RC buildings have been designed to sustain gravity loads only (GLD). Almost all of them lack stirrups in beam-column joints and have a minimum amount of transverse reinforcement in columns. These features make such buildings extremely prone to shear failures under seismic actions. Additionally, the same physical phenomenon, i.e., the shear failure of beams/columns or joints, is assessed differently worldwide, with the result that the same building has (even great) different seismic capacity depending on the code adopted for its assessment. The main aim of this work is quantifying such a difference with reference to RC GLD Italian case-study buildings with different number of stories located in sites with different seismic hazard, based on nonlinear static analyses. Code-based safety checks according to European (Eurocode 8-part 3, 2005; Italian D.M. 2018) or American (ASCE-SEI 41, 2017) approaches are carried out. The results show that capacity at Severe Damage (SD) Limit State (LS) is always limited by joints failures. Nevertheless, European codes strongly limit the building capacity due to the first shear cracking (tensile failure) of beam-column joint. On the contrary, ASCE-SEI 41 (2017), considering just a compressive shear failure for joints, lead to significantly higher capacity at SD LS for the shortest buildings. Relevant design of seismic strengthening, thus, strongly depend on the adopted code approach, leading to generally higher strengthening costs when joints failures are (very conservatively) detected by means of the current European approach.

Keywords

RC existing buildings, shear failures, seismic codes, beam-column joints, failure type

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ID:227

Comparative analysis of seismic performance enhancement in irregular RC buildings using friction and fluid viscous dampers

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Abstract

The purpose of this study is to demonstrate the impacts of friction dampers (FD) or fluid viscous dampers (FVD) in irregular in plan and in elevation reinforced concrete buildings. The buildings (a four-story building, a nine-story building, and a twenty-story skyscraper) were analyzed using nonlinear dynamic time-history analysis on earthquake recorded accelerograms, three of which were real while the other four were artificial. For this purpose, 70 nonlinear dynamic analyses were carried out. This paper describes the optimal design of fluid viscous and friction dampers, with a focus on minimizing the following parameters: (i) maximum displacement (top of the structures), (ii) building torsion, (iii) maximum horizontal interstory drift. Two different placement of the dampers have been studied in each building. The consequences of each strengthening method are shown, and other relevant results were obtained from this creative comparison (optimal design, two passive energy systems, and three different story numbers). The comparable results show that in low-rise structures, FD were more successful than FVD for reducing torsional moment; however, in medium and high-rise buildings, VDF were more effective at improving the seismic performance of the structures.

Keywords

FD, FVD, Irregularity in plan, Irregularity in elevation

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ID:229

RC beams externally strengthened by steel plates: Experimental database and preliminary analysis

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Abstract

External steel plating is a popular technique for the flexural strengthening of RC beams thanks to the ease of application which does not require skilled labor, the relatively low-cost and the optimal mechanical properties of the steel material.
Research on externally plated RC beams is much older than the literature related to the strengthening methods employing fiber reinforced (FRP) materials which were more recently developed. Despite this, the number of FRP applications is far greater than those available for steel applications, as also corroborated by the widespread of several international guidelines for the FRP strengthening design of RC structures. Conversely, the *in-situ* applications with steel plates are still very common and often preferred to FRPs, but they are not well supported by clear design indications.
This paper contributes to filling this knowledge gap by presenting the results of a preliminary theoretical study on the flexural performance of steel-plated RC beams. To this purpose, a large experimental database was compiled from the literature, which includes three/four- point bending tests performed on rectangular or T-shape RC members variably reinforced with external steel plates. Then, the study focused on the theoretical estimate of the bending moment capacity of the beams under considerations. The analysis was performed by accurately accounting for the failure modes experienced during the tests which were also linked to the strengthening layout, such as: thickness, width and number of steel plates, presence of steel anchors along the plate or at its ends. Preliminary design indications are also provided.

Keywords

Flexural strengthening, Steel plate, Anchors, Debonding, Analysis

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ID:230

Seismic retrofit strategy for nonconforming existing steel buildings with CBFs

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Abstract

Recent advancements in materials engineering have introduced new possibilities in the field of Civil Engineering. A noteworthy example is the development of metal foam, an innovative material with a favourable weight-to-stiffness ratio and excellent damping and energy dissipation properties. The increasing interest in the characteristics of metal foam has motivated researchers to explore innovative solutions for dissipative dampers. Researchers from the University of Salerno, the University of Naples Federico II, and the Nagoya Institute of Technology have proposed and examined dissipative aluminium foam dampers for use in steel Concentrically-Braced-Frames (CBFs). In this bracing system, a steel rod or tube is connected to an aluminium foam damper which provides the structure with energy dissipation capacity when subjected to compression forces. A wedge device is employed to absorb the permanent deformations of the aluminium foam, preventing any pinching behaviour in the overall response. These studies have also incorporated analytical equations governing the global behaviour of the bracing system.
This research offers an opportunity to assess the effectiveness of such a solution by studying an existing two-storey steel structure. The structural design includes pinned frames that support gravity loads, while concentrically braced frames are responsible for resisting horizontal forces generated by wind and seismic actions. However, as this structure was built in the early '80s, predating the availability of seismic design rules, it requires retrofitting interventions to improve its seismic performance.This manuscript presents the application of dissipative aluminium foam dampers for the seismic retrofitting of the analysed building.

Keywords

Seismic retrofitting, metal foam, energy dissipation capacity

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ID:233

Flexural Buckling Strength of Steel Angle with Reinforcement in Electric Transmission Towers

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Abstract

In Japan, mid-size electric transmission towers are composed of steel angle members connected with snug-tightened high-strength bolts. The dominant load for these structures is wind load; specific *Ministerial Ordinances* are used for structural design. Seismic design was omitted due to the small seismic effective mass. However, collapses have occurred recently due to the increasing wind intensity caused by drastic climate change. Consequently, there is a high demand to reinforce conventional towers currently in operation.
Typically, lap joints are used to connect the steel angle members in the construction field. This is done for workability purposes, and minimizing components is recommended for safety reasons. The lap joint employs snug-tightened high-strength bolts, accommodating slippage and introducing an eccentricity that generates a secondary bending moment. The design guideline explains how to evaluate the amount of eccentricity at the joints. However, the evaluation method when reinforcing the main members was not shown in the past due to its perceived unnecessary nature.
This paper reports the flexural buckling strength evaluation method of reinforced steel angle members under eccentric load. A theoretical approach is used to derive the evaluation formula, considering the effect of eccentric load and the amount of reinforcement. Finally, small-scale experiments are conducted to validate the proposed design formula. The test results confirm that the proposed formula can reasonably evaluate the strength of reinforced steel angle members.

Keywords

Flexural buckling strength, Steel Angle, Electric transmission tower, Eccentric joint, Reinforcement

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ID:246

Comparative Study of Design Models for Shear Strengthening of RC Beams with NSM FRP

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Abstract

This study investigates the accuracy and reliability of the existing design models for shears-strengthened reinforced concrete (RC) beams with near-surface mounted (NSM) fibre-reinforce polymer (FRP) rods and laminates. Separate statistical and reliability-based studies have been conducted on the predicted shear contributions of NSM FRP materials in the strengthened beams using seven existing design models. To assess the accuracy and reliability of these models, the predictions were compared with the experimental results on 112 test specimens from 24 studies. A special attention is paid to the available NSM bond models employed in developing the shear strength. The results of this study can be used for standard committees to choose the most precise and reliable models for their corresponding design standard code or guidelines.

Keywords

Near-surface mounted method, Shear strengthening, Design models, Reliability, Statistical assessment.

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Exploring the Influence of Strain Rate on BTRM Tensile Behaviour

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Abstract

Extensive research has been conducted on textile-reinforced mortars (TRM); however, a significant gap exists in understanding how strain rate influences their mechanical performance. TRM composites reinforced with basalt textiles (BTRM) have become increasingly popular due to the remarkable sustainable profile of basalt fibres. However, there is limited knowledge regarding the tensile response of this composite under intermediate strain rates.

The present study examined a BTRM composite consisting of a bi-directional basalt fibre textile and a commercially available mortar strengthened with short glass fibres. Coupon specimens with aluminium tabs were tested with a high-speed servo-hydraulic equipment, with loading rates ranging from 1mm/s to 1000mm/s. Strain and failure propagation were captured with a high-speed camera and analysed by the digital image correlation technique. Tests were also performed under quasi-static conditions for comparison.

The mechanical characteristics of the BTRM composite were assessed based on its tensile strength, ultimate strain, toughness, stress-strain behaviour, and failure mode. The findings demonstrated that the BTRM composite exhibited sensitivity to changes in strain rate. Increasing strain rates enhanced tensile strength, ultimate strain, and toughness. Furthermore, the specimens examined under dynamic conditions displayed distinct stress-strain characteristics and failure mechanisms compared to similar specimens subjected to quasi-static loadings.

Keywords

Basalt, textile-reinforced mortar, dynamic, digital image correlation technique, structural strengthening

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ID:278

Influence of torsional effects in seismic retrofit of RC buildings

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Abstract

The nonlinear static procedures are very popular for the design and assessment of buildings subjected to earthquake ground motion in current structural engineering practice. Their application and relative accuracy are very relevant issues, especially in the case of seismic retrofit of irregular and/or high-rise buildings. Many retrofit design procedures are valid for low-rise buildings and/or neglect torsional effects and higher modes contribution. The vibration properties are considered unchanged after retrofit, and the higher modes are often neglected. Other ones are based on the proportional stiffness criterion (i.e., lateral story stiffness due to the additive structures is considered proportional to that of the original main structure). Still others rely on the hypothesis that the main structure remains elastic. Often, they neglect the interaction between the main structure and the additive structures used for retrofit. These are very significant drawbacks in the case of plan-asymmetric buildings, where torsional effects are important. In this case, the seismic response is dominated by harmful torsional effects and, thus, the retrofit strategy should significantly modify the dynamic response. To overcome such drawbacks but still keep the simplicity of using equivalent pushover analysis, this paper develops a "two-step" pushover procedure for seismic retrofit of plan-asymmetric buildings using buckling restrained braces. To this aim, a real case-study school building has been considered in the analyses. A design method has been implemented to size buckling restrained braces to be placed on selected spans and stories of the building. The effectiveness of the retrofit strategy has been finally demonstrated by nonlinear time-history analyses under different sets of earthquake-strong ground motions.

Keywords

Seismic Retrofit, Reinforced concrete building, Torsional effects.

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ID:279

Dissipative exoskeletons for seismic rehabilitation of RC buildings

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Abstract

A large number of highly seismically vulnerable buildings includes several relevant and strategic buildings. Relevant buildings like schools, assembly halls, public offices, and cultural institutions should retain their structural integrity since their collapse could cause major human losses and significant economic impact. Moreover, it would be appropriate for such buildings to remain fully operational even during seismic retrofit work. This has stimulated the development of seismic retrofit solutions based on rapid, low-impact, and reversible interventions that offer many advantages. First, they can be done while the building is operational. Second, they can be removed and rapidly replaced if damaged due to earthquake shaking. Third, they can be integrated to combine seismic resilience and energy efficiency, thus reducing the time and costs of two separate interventions. This situation has stimulated the use of external additive structures, commonly called exoskeletons, as a feasible solution for seismic retrofit of existing RC buildings. Typically, the research and applications deal with non-dissipative steel exoskeletons involving the application of diagonal grids (diagrids) or external steel concentric braces from the outside of existing RC buildings. This paper presents the design and assessment of dissipative exoskeletons based on steel slit dampers for the seismic retrofit of RC buildings. To this aim, a real case-study school building has been considered. The dissipative exoskeletons have been designed using a displacement-based design procedure. The geometry of the dumbbell-shaped steel strip dampers has been selected to avoid stress concentration, accumulation of plastic strain, and premature buckling failures. The effectiveness of the retrofit strategy has been finally demonstrated by nonlinear time-history analyses under different sets of earthquake-strong ground motions.

Keywords

Dissipative exoskeletons, Steel strip dampers, RC buildings.

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ID:301

Shear strengthening of RC beams with U-wrapped FRCM composites: assessment of current design guidelines

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Abstract

Fabric-reinforced cementitious matrix (FRCM) composites have been widely used in the past two decades as externally bonded (EB) reinforcement of existing concrete structures. They represent an effective solution for the flexural, shear, and torsional strengthening of reinforced concrete (RC) members. Shear strengthening with EB FRCM can be performed by either side bonding, U-wrapping, or full-wrapping the reinforcement around the cross-section of beams and columns. The FRCM can have a continuous or discontinuous layout, and the textile can be applied with different inclination angles with respect to the beam longitudinal axis. The contribution provided by the EB FRCM to the member shear strength is usually computed by an extension of the Mörsch truss model, which assumes the formation of a main diagonal shear crack. This approach is followed by both the Italian CNR-DT 215 (2018) and the American ACI 549.4R (2020) design guidelines, which provide similar formulations but rely on different hypotheses. In this paper, the accuracy of these formulations to determine the shear strength of U-wrapped FRCM-strengthened RC beams is assessed against a database of RC beams collected from the literature. Comparison between experimental results and analytical predictions allowed to identify the main features of the design models considered.

Keywords

PBO, FRCM, design models, shear strength, numerical modelling

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ID:303

Seismic strengthening of existing structures by External steel exoskeletons

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Abstract

The evaluation of the structural safety of existing schools and the planning of their retrofit measures are vital and top priority tasks. This research intends (i) to assess the structural safety of a steel school building in Italy and (ii) to suggest retrofitting measures to improve its seismic resilience. The first section describes and discusses the data collection and the numerical model developed, representative of the existing building. Pushover analyses are then conducted to evaluate the seismic performance of the completed structure. Based on the identified shortcomings, a novel strengthening intervention using 2D parallel steel exoskeletons was developed following a displacement-based step-by-step method. The exoskeleton systems were designed considering the architectural and functional needs of the school building, with the goal of maintaining structural safety while preserving the building's aesthetics and usability. Lastly, the efficacy of the chosen retrofitting method was verified through non-linear static analysis conducted on the reinforced structure.

Keywords

Existing structures, assessment and retrofit, steel bracing, parallel exoskeleton, non-linear analysis.

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ID:317

Numerical study on inelastic cyclic behavior of CFRP wrapped substandard RC columns

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Abstract

Few numerical investigations have been carried out on fiber-reinforced polymer (FRP)-jacketed substandard RC columns with characteristics not normally met in properly designed structural members. Three columns were modeled through finite element method (FEM) by means of ATENA and OpenSees considering their cyclic lateral-load displacement hysteretic responses, where i) the first column (S) represents the typical characteristics of substandard columns violating rules of their construction time (i.e. 1975 Turkish Seismic Design Code) in terms of compressive strength of concrete ($f_c \approx 10$ MPa) and transverse reinforcement detailing ($s = 250$ mm, where s is stirrups spacing), ii) the second column (C) represents the columns of buildings thoroughly complying with the requirements of their construction time (i.e. 1975 Turkish Seismic Design Code) ($f_c \approx 19.5$ MPa and $s = 80$ mm), and iii) the third column (RS) is identical to substandard column (S), but retrofitted with a CFRP jacket of 1 ply thickness. High axial load-to-axial capacity ratio ($0.75 f_c bh$) together with high shear demand (ratio of shear force corresponding to the moment capacity (V_e) to shear strength (V_r) of 0.55) were among main features of the substandard column (S). In OpenSees, fiber-discretized sections along the column height are modeled, allowing to account for distributed plasticity. Both the slip of longitudinal bars at the column-foundation interface and buckling of these bars in compression were considered. Furthermore, cyclic stiffness and strength degradations were captured as well. In ATENA, the columns were modeled as a single macro element and discretized by fine meshes capturing both flexure and shear deformations. The results obtained through the numerical modeling were in a good agreement with the experimental ones. The ductility of column C was much enhanced with respect to Column S. Results also showed that the brittle/undesired failure mode of Column S was improved significantly after the seismic retrofit using CFRP jacketing.

Keywords

FRP, Reinforced Concrete Column, Seismic, Retrofit, Substandard

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ID:349

Characterization of Interlaminar Durability of Fiber Anchors Used with FRP Strengthening Systems

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Abstract

To mitigate debonding, FRP anchors such as U-wraps and fiber splay anchors, are typically employed. Fiber splay anchors are often preferred because they are efficient in terms of materials usage and can be applied in locations with geometric constraints or limited space. Given that FRP strengthening systems aim to prolong the service life of structures, ensuring their durability is paramount under harsh environmental conditions. The authors recently conducted a durability study on FRP-strengthened notched concrete beams, involving water immersion at 50 °C for 3,000 hours (per ACI 440.9R) to assess the durability of the fiber splay anchors. The study concluded that specimens experiencing anchor rupture in the bend region exhibited a nearly 25% reduction in capacity following accelerated conditioning. In CFRP composites, carbon fibers are inert to the environment, and therefore do not exhibit deterioration. However, given the complex stress state (i.e., both normal and shear stress components) in the bend region of the anchor, the durability of the fiber anchor is influenced by the degradation of the fiber-matrix interface and polymer matrix. This study evaluates the effects of FRP material-level design parameters (manufacturing method and carbon fiber sizing) on the interlaminar durability of fiber anchors via the short-beam test. The accelerated conditioning protocols employed include hygrothermal, alkali, saltwater and freeze-thaw exposure. The mechanical testing is completed with scanning electron microscopy and atomic force microscopy to identify relevant degradation mechanisms. The study is underway, and results will be reported at SMAR 2024.

Keywords

Anchors, FRP, durability, sizing, accelerated conditioning

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ID:386

Statics of Masonry Walls With Openings: a Singular Stress Approach

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Abstract

A large portion of current structures, including historical monuments (churches, mosques, temples, etc.) and ordinary buildings, is made of masonry. Masonry consists of blocks joined by mortar, assembled with a texture to prevent sliding through methods like Friction/Interlocking/Confinement. It is inherently heterogeneous, and the mechanical properties of the blocks, mortar, and their bond largely influence the overall masonry response. Experimental characterization remains a challenging task. The structural analysis of masonry is almost always focused on determining stress in an existing structure. Their deformation is primarily associated with fractures, it means that an elastic analysis cannot fully capture the deformation of a masonry structure. Even without considering the elastic properties of the masonry, a static analysis alone can provide dependable values for essential structural parameters. We employ a basic model for masonry known as the Rigid No-Tension Model, relying on the following Heyman's assumptions: (i) masonry cannot endure tensions; (ii) masonry possesses infinite compressive strength; (iii) elastic strains are zero; (iv) sliding is prevented by the infinite shear strength of masonry. In addition to the hypotheses described above, we assume that stress can be decomposed additively into a regular (Cauchy) part and a singular part. Specifically, we assume that the regular part is zero. In this context, the static analysis of a wall is reduced, given the forces along the boundary, to the finding of a 'truss structure' of compressed members within the domain (the wall itself). In two-dimensions, and with forces at the vertices of a convex polygon, the use of polytope Airy stress functions shows that this 'truss structure' supporting the given forces will be derived from the folds of the polyhedral function. Among all the equilibrated solutions, the envelope of tangent planes to the boundary will be chosen.

Keywords

Masonry structures, Strut Net, Singular Stress, Airy Stress Function, Limit Analysis

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ID:394

Simulation of Two-way Slabs Strengthened in Punching with CFRP Strips

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Abstract

Two-way slabs are vulnerable to two-way punching shear which may cause catastrophic failures. Furthermore, over the recent past, the trend has been set to use construction waste as recycled aggregates in structural concrete. Therefore, the work presented herein, numerically investigates in detail, the behaviour of the two-way reinforced concrete slabs, cast with both natural aggregate concrete and recycled aggregate concrete, under punching shear. The work also focuses on simulating the behaviour of such slabs strengthened and/or retrofitted with carbon fibre reinforced polymers strips. Based on the detailed numerical investigation, it was observed that the use of carbon fibre reinforced polymers increased the overall stiffness of slabs strengthened with carbon fibre reinforced polymers strips compared to the slabs without carbon fibre reinforced polymers strips for both natural aggregate concrete and recycled aggregate concrete slabs. Spacing of the carbon fibre reinforced polymers strips from the face of the column was also found to be effective in reducing the deflections of the slabs at similar load levels. For both natural aggregate concrete and recycled aggregate concrete specimens, the influence of slab thickness and concrete compressive strength was observed to be significant on the behaviour of the slabs.

Keywords

Recycled aggregate concrete, Two-way slabs, carbon fiber reinforced polymers, Punching Shear, Retrofitting

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ID:395

Behaviour of Full Scale Shear Critical RC Beams Strengthened with Textile Reinforced Mortar

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Abstract

Textile reinforced mortars (TRM) have recently used for strengthening of Reinforced Concrete (RC) beams by researchers. The use of Carbon, glass, aramid and PBO fibres have extensively caught the eyes of the scientists and research enthusiasts, basalt fibre has been mostly explored for strengthening of masonry. For beams, a narrow band of data is available TRM using basalt fibres as strengthening material, most of which comprises of small-scale tests. The following paper presents an experimental study of six full scale beams tested within the shear critical region, i.e. a varying shear span to depth (a/d) ratio between 1 through 2.5, where three beams are acting as control beams for various a/d ratios while the remaining three TRM strengthened full scale beams with basalt fibres provided at the tension face and wrapped in U-shaped arrangement for corresponding a/d ratios. The results showed that TRM using basalt fibres is effective in improving the performance of RC beams in terms serviceability, both crack and deflection control. The use of TRM also improved load carrying capacity of beams in flexure and delayed the appearance of first crack, and the post cracking stiffness of the flexural members and better performance in terms of ductility.

Keywords

Reinforced concrete, Shear Critical beams, Strengthening, Textile Reinforced Mortar, Performance

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ID:403

Numerical characterisation of FRP curved reinforcement produced by filament winding

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Abstract

Previous studies have demonstrated that an automated filament winding process can be conveniently used to produce shear reinforcement for concrete structures. The method allows the creation of geometrically complex elements suitable for materials optimisation. This is in addition to the advantages of non-metallic reinforcement. On the contrary, the biggest drawback is the anisotropy properties of fibrous materials. Concentrations of stresses and material defects characterise the reinforcement's curved portions; thus, material efficiency reduction is expected. Generally, the strength of pultruded FRP stirrups is estimated at about 30-40% of the tensile strength in the direction of the fibres. Still, experimental studies have shown that efficiency can be increased due to the manufacturing process and cross-section aspect ratio. This study aims to identify a mechanical model for predicting the bent strength of FRP stirrups fabricated by the filament winding technique. This is here formalised as a non-linear equilibrium problem of a curved Timoshenko beam on an elastic foundation. Numerical results show good agreement with the experimental data available from previous studies, assessing the model's suitability.

Keywords

Filament winding, Stirrup, Concrete, Beam, Shear, Numerical modelling.

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ID:406

Sustainable system with non-intrusive anchors for the preservation of historic steel structures

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Abstract

Historic steel constructions, such as riveted bridges, are valuable heritage assets that require preservation without invasive interventions such as welding or drilling. Auxiliary structures installed on these constructions to carry out structural strengthening or structural repairs must be easily removable. The difficulty of access to these structures makes it difficult to carry out structural inspections using traditional methods. To tackle this issue, an innovative, non-invasive, removable anchorage system has been developed and tested. In this context, clamp-based connections represent a method for constructing removable systems that enable anchoring to pre-existing structures without the need for intrusive procedures. This system allows the installation of temporary elements for the inspection and maintenance of historic steel structures without invasive operations. Also, this system allows the assembly of new elements to structural strengthening and repair of historic steel structures. Finite Element Model (FEM) simulations and laboratory experiments are carried out in order to verify the necessary load-bearing capacity for the loads involved in the works performed on the structure. In addition, the installation of elements with these anchors is being carried out on riveted steel bridges, showcasing the practical application of the developed technology.

Keywords

Steel trusses bridge, Non-invasive removable connections, Historic steel bridge maintenance, FEM simulation.

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ID:429

Possible Approaches to the Reconstruction of the Vyšehrad Bridge in Prague

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Abstract

Prague has two iconic views. The first is Charles Bridge with the silhouette of Prague Castle in the background, the second is the Vyšehrad Railway Bridge framed by the imposing structure of Vyšehrad. It has been a listed cultural monument since 2004. The Vyšehrad Railway Bridge was opened in its first form on 15 August 1872, its current appearance dates back to 1901. It is a riveted structure with three parabolic arches spanning about 70 m with verticals and diagonals in the shape of segmented cross-sections. The structure is an important technical cultural monument, which is also located in an exposed part of the Prague Monument Reserve. However, due to long neglected basic maintenance, the structure deteriorated to such an extent that the Railway Administration decided to demolish it. Having carried out an inspection and structural assessment of the bridge we are confident that it can be repaired, refurbished and modified to provide a long and satisfactory additional service life for future operation of the railway and footways. In particular, localised corrosion defects resulting from inadequate maintenance over many years can be repaired and the structural components which fail to meet the assessment criteria in their current condition can be repaired or replaced. Expressed in weight, only 15% of the structure by mass needs structural repair or improvement; the rest is satisfactory without further intervention, other than renewing the corrosion protection system. The paper wil be focused on a detailed examination of the condition of the bridge and the possibilities of its reconstruction for railway transport. It describes the reconstruction system, replacement of individual elements and contactors.

Keywords

Vyšehrad Railway Bridge, reconstruction, assessment of condition

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Available measurement methods to evaluate the fiber and matrix bond performance of FRCM composites

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Abstract

Measuring the bond between Fiber-Reinforced Cementitious Matrix (FRCM) composites and the substrate onto which they are applied is crucial for assessing the performance of these materials when used for the strengthening of existing structures. Experimentally, this parameter has been investigated by conducting single/double lap shear tests. However, as the bond failure is usually reached at the fiber-matrix interface, it is hard to obtained reliable date of the local phenomena occurring at such location. This is caused by the impracticality of observe the behavior due to the presence of an exterior matrix layer. In this paper, a detailed review of methods used to measure the bond between the fibers and the matrix is presented. Methods studied include traditional instrumentation such as strain gauges, and more recently developed digital image correlation (DIC). In addition, due to the increase in use of new sensing technologies such as wavelength- or frequency-based fiber optic sensors (FOS), these techniques are also evaluated. The research presented in this paper emphasize the applicability of these techniques and offer a comprehensive analysis of their respective advantages and limitations, ultimately providing valuable insights into their utility for characterizing the bond behavior of FRCM composites.

Keywords

FRCM, bond, DIC, fiber optic sensors, testing

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Experimental investigation of Carbon FRCM confinement effect on 3 concrete cylinders under monotonic loading

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Abstract

In recent years, fabric reinforced cementitious matrix (FRCM) became a desirable material in the rehabilitation of concrete structures. The FRCM system features some advantages such as compatibility with the substrate, easier and non-expensive installation on a wet concrete, and ultraviolet degradation resistance. As FRCM is a new material, the existing literature provides limited knowledge on the behavior of FRCM in concrete structures. In particular, the mechanism of FRCM to confine concrete is still not fully understood. This paper incorporated an experimental program where plain concrete cylinders were confined with FRCM and tested under uniaxial compressive loading. The experimental testing parameters included concrete grade, number of FRCM layers, and fibers direction using micro-fibre reinforced mortar. The test results showed that FRCM was effective in confining plain concrete as the compressive strength increased and a ductile behavior was developed. Providing more FRCM layers did not enhance the confining action. The application of longitudinally oriented fabric had an insignificant effect on concrete compressive behavior.

Keywords

Textile reinforced mortar (TRM/FRCM), design guidelines, Concrete Confinement Characterization

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Three-point bending tests of concrete notched beams with different contents of PVA fibers

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Abstract

During the last few decades, fiber-reinforced concrete (FRC) has been widely used in the construction industry to increase strength and toughness of concrete structural members. Different types of fiber have been used in FRC, with different dimensions, shape, and mechanical properties. The addition of short, dispersed steel fibers in concrete gained large popularity in recent years and steel FRC (SFRC) is commonly used in specific structural applications (e.g., precast tunnel segments) and to partially substitute conventional reinforcement bars. Nowadays, the addition of synthetic fibers in concrete is becoming increasingly popular, thanks to the ability of these fibers to delay the occurrence of microcrack and/or provide post-cracking tensile residual strength. Furthermore, synthetic fibers have better durability than steel fibers. Among different synthetic fibers, polyvinyl alcohol (PVA) fibers have shown promising results. In this paper, a preliminary experimental campaign is carried out to investigate the effect of micro and macro PVA fibers on concrete tensile strength and toughness. To this aim, three-point bending (TPB) tests are performed on concrete notched beams with different contents of PVA fibers. Results obtained with PVA-FRC are evaluated with respect to a corresponding plain concrete specimen, and the possible synergy between micro and macro PVA fibers embedded in concrete is assessed. Results show that PVA macrofibers increase the concrete post-cracking tensile residual strength.

Keywords

FRC, PVA fibers, residual strength, three-point bending tests

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Mini Symposium 1: Multifunctional materials for sustainable constructions: integrated thermal, structural and sensing systems

Organizers:

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ID:032

Multifunctional prefabricated textile capillary tube panels for integrated renovation of buildings

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Abstract

In this paper, a novel seismic-plus-energy retrofit solution for building envelopes is presented. The intervention aims to simultaneously improve the thermal efficiency and seismic safety of buildings with a light, cost-effective, and sustainable approach. The so-called TCP system consists of prefabricated textile capillary-tube panels, which at the same time improve the seismic performance and energy efficiency of existing buildings. The seismic behaviour of the proposed system is tested on three 3/5-scaled masonry-infilled RC frames through quasi-static in-plane cyclic loading. A comparison with a non-retrofitted control frame and a frame retrofitted with textile-reinforced mortar and extruded polystyrene boards is offered, highlighting the effectiveness of the TCP retrofit. A significant increase in strength, stiffness and displacement capacity was demonstrated for the retrofitted specimens compared to the control specimen. The potential of using TCP panels for integrated building retrofitting was demonstrated, with similar seismic performance improvements compared to the more typical TRM-retrofit. Finally, the thermal performance of the proposed integrated retrofitting system was assessed through in-situ experimentation on a real residential masonry building wall, exhibiting high efficiency.

Keywords

Textile reinforced mortar (TRM), Textile capillary tube panel (TCP), Integrated seismic and energy retrofit, masonry envelopes

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Bond performance of a multifunctional strengthening system for concrete structures

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Abstract

The combined application of two baseline technologies (i- strengthening of concrete structures using fibre-reinforced polymers (FRP) reinforcement and, ii- monolithic Al/Na2.99Ba0.005OCl/Cu batteries synergistically embedded into a FRP material) leads to a multifunctional retrofitting system for concrete structures, where the reinforcement is a FRP structural battery. On the one hand, the multifunctional reinforcement upgrades the mechanical capacity, and so the safety, of the structure. On the other hand, it can store electric energy from renewable sources. Unlike separate batteries, when the multifunctional reinforcement is integrated into the structure, it is protected against environmental exposure and vandalism, and does not take up habitable space. The two baseline technologies have not yet been combined for application to the construction sector. In this work, the design of the multifunctional retrofitting system is presented. Moreover, the application of the multifunctional retrofitting system in concrete structures is assessed. Failure of concrete structures strengthened with FRP almost always is expected to occur by debonding of the FRP from the concrete substrate. Thus, tests have been done on the FRP-concrete joint behaviour and failure modes have been analysed. Moreover, the battery electrical response has been monitored to investigate the influence of the stress level and/or the loss of adherence between the concrete and the multifunctional reinforcement system on the electric performance. The results are compared against the behaviour observed in the characterization campaign on the separate FRP structural batteries.

Keywords

Energy storage, Structural integration of devices, Structural batteries, Multifunctional reinforcement, FRP strengthening.

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Eco-friendly alternative to autoclaved aerated concrete with heat storage/release function

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Abstract

The European climate law imposes a legal obligation to meet the EU's climate target of reducing EU emissions by at least 55% by 2030. Consequently, numerous endeavours are underway to achieve this objective and ensure climate neutrality by 2050. Special efforts are being made to reduce the energy consumption associated with heating and cooling in buildings, as this need consumes a significant amount of energy. One of the emerging trends in these activities is the development of new materials with a reduced carbon footprint and new functionality related to the storage and release of heat, which can improve the energy efficiency of buildings.
The article presents the results of tests on cementitious foam enriched with microencapsulated Phase Change Materials (MPCMs) in the amount of 10% and 20% of the paste volume. The capacity of MPCMs to absorb and release substantial amounts of latent heat at a constant temperature offers the potential to decrease daily energy requirements for heating and cooling, thereby positively impacting global warming and climate change. Consequently, the incorporation of MPCMs in materials can significantly enhance the thermal functionality of the material. The densities of the tested cementitious foams were selected in relation to typical autoclaved aerated concrete products, i.e., 350 kg/m^3, 500 kg/m^3 and 700 kg/m^3. The basic thermal and mechanical properties were examined. The obtained results indicate that the tested composites may be a promising alternative to commonly used autoclaved aerated concrete. The research used some results of the NRG-STORAGE project (H2020).

Keywords

Foam concrete, Microencapsulated phase change materials (MPCMs), thermal properties, mechanical properties, heat storage/release

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Geopolymers as adhesive for sustainable NSM CFRP strengthening of RC structures

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Abstract

Carbon fiber reinforced polymer (CFRP) composites are known to be a very effective material for strengthening and rehabilitation of reinforced concrete (RC) structures. Near surface mounted (NSM) technique, has been used as an effective method for this purpose, over the past two decades. The conventional technique benefits from the superb properties of polymeric adhesives as the matrix, e.g., epoxy resins, to ensure a successful transfer of stresses between the CFRP and concrete substrate. However, the vulnerability of polymeric matrices to high temperatures motivated researchers to focus on developing cement-based adhesives for NSM CFRP systems for the special applications where fire safety is an issue. Recently, efforts led to promising outcomes for the future of these novel systems. This upgrade not only fulfills the fire safety measures, but also is necessary from the environmental point of view, due to the pollution and health problems associated with the usage of epoxy resins as conventional adhesives for FRP systems. While improvements occurred in the bond performance of the NSM CFRP systems with cement-based adhesives, using innovative sand-coated CFRP strips, the alternative sustainable approaches could be also investigated. This paper is dedicated to adoption of geopolymer adhesive, to serve as a matrix for NSM strengthening techniques, using special sand-coated CFRP strips. Bond tests have been performed in ambient and thermo-mechanical conditions and results showed promising performance of adoption of geopolymer in this technique. A life cycle analysis (LCA) was also performed to compare geopolymer as a sustainable matrix, with epoxy resin and cement-based adhesive as its competitors, for eco-friendly strengthening systems for RC structures.

Keywords

Strengthening, Near Surface Mounted technique, CFRP, Geopolymer, sustainability.

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Toward optimized carbon fiber cementitious sensors

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Abstract

With physical and mechanical properties comparable to those of concrete, piezoresistive cementitious composites are poised to enable seamless strain and defect monitoring in civil infrastructure. Many research projects have demonstrated the sensing properties of cementitious sensors. The sensitivity, repeatability, and stability of their response are heavily dependent on mix design and fiber dispersion. This paper presents a preliminary framework using microscopy and the Taguchi method for identifying best practices in fabricating cement paste sensors containing carbon fibers. Higher fiber content, the use of a centrifugal mixer, and supplementary cementitious materials significantly improved repeatability, while mixing order and speed had minimal impact. Further research should examine the effects of mixing duration, additional conductive fillers, and environmental factors on the sensitivity, repeatability, durability, and stability of the sensors under both compression and tension at different loading rates.

Keywords

Cementitious sensors, Piezoresistivity, Carbon fibers, Fiber breakage and dispersion, Sensitivity, Repeatability

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A novel structural and energy cementitious materials for nearly-zero energy buildings

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Abstract

A novel material with tunable dynamic insulations, thermal energy storage skills, and structural properties is presented in this work. The so-presented NRG&STRUCT concrete is a porous concrete made of microencapsulated phase-change materials (mPCM) embedded within the cement-based mix. A strength-based theory accounting for the porosity together with a quality-based index, and the mPCM content are the most relevant parameters to control the structural and energy performance in an NRG&STRUCT concrete. The work thus presents the energy performance of a demo-building made of this material. Particularly, layer-wise graded NRG&STRUCT concrete are used in external walls. At each layer, the material is characterized by its strength index and mPCM content, which both play the role of design variables to be determined by solving an optimization problem where the objective function is the energy consumption for keeping the indoor thermal comfort, computed by EnergyPlus. These design variables are continuous, allowing the use of gradient-based optimization solvers. The structural stability of the energetically optimal solutions is forced via constraints on minimal density.

Keywords

Structural, energy, cementitious materials, nearly-zero energy buildings.

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Stress monitoring of mineral-impregnated carbon fibre reinforcements (MCF) for smart concrete structures

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Abstract

Due to its high corrosion resistance, high-temperature endurance, cost-effectiveness, and sustainable utilization, mineral-impregnated carbon fiber (MCF) composites have been introduced as a replacement for traditional steel or fiber-reinforced polymer reinforcements. MCF produced by impregnating carbon fibre with cementitious matrices have excellent electrical conductivity and piezoresistivity, which enables MCF to function as a sensor for concrete structural health monitoring. In this study, the stress-sensing performance of MCF was investigated, from cyclic to monotonic compression and bending tests. The electrical resistance measurement is conducted by two-probe and four-probe methods, and the effect of different electrode configurations is explored as well. The results demonstrate that the MCF exhibits a significant stress self-sensing capacity, with fractional changes of resistivity (FCR) changing correspondingly with applied forces within an elastic regime. For the single MCF, it will be different to study the compressive stress self-sensing. However, by embedding MCF into concrete, the compressed load can be transferred from concrete to MCF which illustrates the compressive stress sensing capacity of MCF. The electrode configuration methods affect the piezoresistivity, due to the interface between electrodes to the cross-sectional MCF. This study explores the stress sensing capacity of MCF as reinforcement and sensors, which promotes its future smart application of structural health monitoring for concrete infrastructures

Keywords

Mineral-impregnated carbon fiber, Piezoresistivity, Stress self-sensing, Electrode configuration, Embedded sensors.

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Multifunctional sensing mortar for masonry structures: first development and characterization

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Abstract

This study delves into the potential of self-monitoring masonry components constructed with specialized mortars containing conductive carbon-based fillers. The primary objective is to assess their ability to autonomously evaluate their structural integrity. These innovative masonry elements are designed to produce an integrated monitoring system within a structure. This system can effectively identify and respond to changes in structural performance, such as partial damage, crack propagation due to structural anomalies, or significant events. The key to this self-monitoring capacity lies in the application of sensing mortars. These mortars can be used as the bedding material for masonry blocks. Through this approach, the study aims to characterize and determine the feasibility of these intelligent masonry structures, offering the unique ability to diagnose their own condition. Electromechanical tests on single components and more complex masonry structures allowed to optimize the materials and the building procedure, and to characterize the mechanical, electrical and sensing behaviour. In particular, compressive and bending tests have been coupled to electrical measurements through electrodes applied in the samples. The results of the work demonstrate the feasibility of the technology to be scaled to higher-scale structures.

Keywords

Carbon-based fillers, Smart masonry, Self-sensing mortar, Structural health monitoring, Cementitious multifunctional composites

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Dynamic and static thermal performance of foam concrete with phase change materials via Hot Box

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Abstract

Human population is constantly growing, and with it, the consumption of energy which is provoking in recent times a severe shortage of fossil fuels. In particular, energy efficiency of buildings plays a preponderant role, being the core of multiple research projects around the globe. Within the European Union, half of the energy consumption is dedicated to heating and cooling in buildings and industry. It represents the main energy end-use sector. Considering the EU's target of becoming carbon-neutral by the year 2050, the heating and cooling sector direly calls for major advances in energy efficiency, building sustainability and a cut back of fossil fuels consumption. Among the activities in this field of research, there is the endeavor of enriching cementitious foam with microencapsulated phase change materials (mPCM), in order to combine latent and sensible heat storage capacity in the building's insulation layer, thereby, decreasing daily energy consumption for heating and cooling.
The work presents the results of static and dynamic measurements of concrete wall elements with an insulation layer of reference cementitious foam (without mPCM) and a foam concrete insulation including 10% and, respectively, 20% mPCM by paste volume. The measurements were carried out in a Hot Box Test Bench and temperatures were monitored both on the surfaces and in the intersections of the wall elements. The research was carried out in the frame of the NRG-STORAGE project (H2020).

Keywords

Foam concrete, Microencapsulated phase change materials (MPCMs), thermal properties, dynamic measurements, heat storage/release, Hot Box

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Mini Symposium 2: Research and development of Iron-based Shape Memory alloys and their engineering application technology in China

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ID:364

Experimental investigation on load carrying capacity of UHPC shell reinforced with iron-based shape memory alloys (Fe-SMA)

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Abstract

The utilization of iron-based shape memory alloys (Fe-SMA) can significantly enhance the mechanical properties and durability of civil engineering structures as prestressing tendons. The martensitic transformation-induced self-prestressing force, resulting from temperature changes, offers a more convenient approach to generate prestress compared to traditional method, which is suitable for applying prestress in thin-walled curved components. The present study involves the design of a novel type of ultra-high-performance concrete (UHPC) shell structure reinforced with Fe-SMA to enhance its load carrying capacity, while an UHPC shell strengthened with conventional steel is employed as reference. The shape memory effect of Fe-SMA is activated through the utilization of high-temperature steaming curing. The load carrying capacity and anti-cracking ability of the UHPC shell are investigated through four-point bending tests and 3D digital image correlation (DIC) measurements. The findings demonstrate that UHPC shells reinforced with Fe-SMA exhibit enhanced load carrying capacity, superior energy absorption, and improved deformability in comparison to the reference group. Increasing the steaming curing temperature within a certain range can increase the recovery stress, resulting in improvement in the cracking load. However, this temperature effect diminishes with further increases in the curing temperature. Importantly, the utilization of Fe-SMA also modifies the failure mode of UHPC shells by decelerating crack propagation compared to those reinforced with conventional steel. The incorporation of Fe-SMA presents promising prospects for enhancing both load-bearing capacity and resistance to cracking in UHPC shells.

Keywords

Iron-based shape memory alloys (Fe-SMA), UHPC, Shape memory effect, Martensitic transformation, Prestressing

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Improving the fire performance of concrete beams with iron-based shape memory alloys

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Abstract

The traditional method for satisfying fire resistance requirements of reinforced concrete (RC) structures is to provide adequate concrete cover depth. However, excessive concrete cover depth may increase the risk of concrete spalling during a fire and result in a wider crack width. The structure will be difficult to repair due to the large residual deformation after fire. Iron-based shape memory alloys (Fe-SMA) can be activated and produce recovery stress when exposed to fire, a natural heat source. The recovery stress can reduce the deformation and improve the mechanical properties of concrete structures. Therefore, a novel active approach based on the Fe-SMA is proposed in this study to investigate the feasibility of improving the fire performance of RC structures through the recovery stress generated by Fe-SMA under fire. The fire test of Fe-SMA RC beams was conducted. The mid-span deflection of the Fe-SMA RC beams was significantly reduced. The fire resistance of the Fe-SMA RC beams was 35%-49% higher than the conventional RC beams. The residual deformation was reduced by about 20%-40%, and the crack width was decreased by about 30%-90%. In addition, Fe-SMA can develop permanent prestress after cooling to room temperature, improving the mechanical properties after the fire. The residual bearing capacity of the Fe-SMA RC beams was 21% higher than the conventional RC beams. The residual stiffness of Fe-SMA RC beams was approximately 86%-121% higher than the conventional RC beams. The experimental results show that the Fe-SMA has great potential in improving the fire performance of RC structures.

Keywords

Fire performance, Iron-based shape memory alloys (Fe-SMA), Reinforced concrete beam, Recovery stress, Fire test

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Monitoring and Strengthening of PCCP utilizing DAS and iron-based shape memory alloy

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Abstract

This investigation proposes an integrated technology for monitoring and strengthening the prestressed concrete cylinder pipe (PCCP) with broken wires, which is based on distributed acoustic sensing (DAS) and self-prestressing iron-based shape memory alloy (Fe-SMA). The technology was evaluated in a full-scale study on two PCCPs with an inner diameter of 1400 mm and a length of 6000 mm. A single optical fiber was pasted/embedded on the surface of the PCCP mortar coating along the length direction, and the signals generated by wire breakage were monitored by the DAS system. After the monitoring, the Fe-SMA bars were externally wrapped outside the surface of the PCCP with a wire breakage ratio of 10%, and heated to 200 ℃ through electrical resistance heating, to generate the circumferential prestress. Following this, the wire breakage ratio was increased to 15%, and the Fe-SMA bars were heated secondary to a higher temperature of 300 ℃ to increase the circumferential prestress, further limiting the negative effect caused by wire breakage development. The results show that the DAS system can identify the time and location of wire breakage, where the wire breakage signal is characterized by a high amplitude and short duration. Following prestress strengthening with Fe-SMA bars, there was a discernible reduction in both the width and length of the principal crack. Moreover, significant decreases were observed in the strains of concrete, mortar coating, and prestressed steel wires. Additionally, the higher activation temperature of Fe-SMA bars can effectively offset the negative impact caused by the wire breakage development of PCCP. Combined Fe-SMA with the DAS monitoring system, it enables precise positioning and efficient strengthening of in-service PCCP with broken wires.

Keywords

Iron-based shape memory alloy, Prestressed concrete cylinder pipe, Distributed acoustic sensing, Wire breakage monitoring, Actively prestressed strengthening

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Compression performance of FRP externally wrapped Fe-SMA strips confined concrete columns under large load eccentricity

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Abstract

Due to the shape memory effect of iron-based shape memory alloy (Fe-SMA), it can be utilized to rapidly apply the active confinement on concrete columns. Therefore, this study presented an innovative strengthening method, which can emergency repair damaged columns. The eccentric compression test was used to investigate the relative compressive behavior of concrete columns that were individually confined by passive confinement, active confinement, and hybrid confinement. Also, the different net-spacing strips (30 mm, 40 mm, and 75 mm) and different layers of FRP strips (1 layer and 3 layers) were considered as the experimental variables. The results show that these three forms of confinement, hybrid confinement in particular, can significantly increase the load carrying capacity and lateral deformation of concrete columns. In order to choose the best ways to strengthen concrete columns, a verification calculation was lastly suggested to estimate the specimens' peak compressive stress.

Keywords

Active confinement; Passive confinement; Fe-SMA strips; Strengthening method; Eccentric compression test.

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Study on the flexural behaviour of T-shaped RC beams strengthened with NSM Fe-SMA bars

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Abstract

Iron-based shape memory alloys (Fe-SMAs) have gradually become a research hotspot in the field of structural strengthening due to their convenient application of prestress. However, unlike traditional prestressing methods, it is challenging to intuitively determine the effective prestress of Fe-SMAs using instrumentation. This study conducted bending tests on eight concrete T-beams near-surface mounted (NSM) with Fe-SMA bars to elucidate the effects of Fe-SMA reinforcement ratios (0%, 1.6%, 2.5%) and activation temperatures (non-activated, 200 ℃, 300 ℃) on flexural performance. The effect of zero preload on the recovery stress was investigated, leading to the proposal of a formula for calculating effective prestress. The results indicate that increasing the Fe-SMA reinforcement ratio positively influences load at service limit state, ultimate load, and post-cracking stiffness. The enhancement in post-yield stiffness is particularly notable due to the stress-strain hardening effect of Fe-SMAs. The effective prestress of Fe-SMAs is influenced by both the preload of Fe-SMA and crack closure of specimens; as the preload increases, the recovery deformation capacity of the Fe-SMAs decreases. The theoretical values of anti-arch calculated using the proposed model closely match the measured values. Fe-SMA achieved rapid prestressed NSM strengthening and demonstrated favourable strengthening effects.

Keywords

Flexural behaviour; near-surface mounted (NSM) strengthening; iron-based shape memory alloy (Fe-SMA) bar; effective prestress.

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Study on the shear properties of I-shaped concrete beams reinforced with Fe-SMA rebar

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Abstract

The cracking of the prestressed box girder bridge web is one of the difficult problems in the engineering field. The vertical prestressed loss is one of the reasons for the cracking of the box girder bridge web. Fe-SMA rebar, as a new type of prestressed material, can be used as vertical prestressed rebar in box girder bridge web to supplement the vertical prestressed loss and inhibit the cracking of web. Therefore, taking the I-shape beam with simplified concrete box girder bridge web as an example, the shear experiment of I-shape beams with Fe-SMA rebars in shear span area was carried out. The effects of Fe-SMA activation state, layout spacing and reinforcement diameter on shear performance of I-beam were studied. The variation laws of cracking load, ultimate load and main tensile strain were analyzed. The results show that the failure mode of the specimen changed from brittle shear failure to ductile flexural shear failure, and the ultimate deflection of the specimen increased significantly after the Fe-SMA rebar was activated. The activation of Fe-SMA rebar had a significant effect on reducing the main tensile stress of the section in shear span area and delaying the cracking of beam body. In addition, a method for calculating shear capacity of I-beam with Fe-SMA rebar was proposed. The calculated shear capacity was in good agreement with the experimental data, which provided reference for the subsequent research.

Keywords

Fe-SMA rebar, I-shaped concrete beam, Shear property, Self-prestressing, Cracking load

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Mini Symposium 3:
Digital Manufacturing in Construction

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ID:255

Applications of digital twins in reinforced and prestressed concrete bridge infrastructure

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Abstract

This study investigates into the innovative application of Digital Twins to monitor the structural health of reinforced and prestressed concrete bridges. Digital Twins, precise digital representations of real structures, emerge as an advanced solution, integrating data collected through drones and sensors to simulate and analyze structural behavior. This approach is decisive for anticipating pathological manifestations, optimizing maintenance, and preventing failures, holding significant implications for the future of structural engineering. The research investigates the application of Digital Twins in monitoring the structural health of concrete bridges, emphasizing their potential in early identification of pathologies, efficient maintenance, and prevention of structural failures. Two case studies exemplify the practical application of this technology, highlighting challenges such as complex data integration and associated costs. Digital Twins, capable of simulating structural behavior, have proven effective in monitoring the health of concrete bridges, addressing pathological manifestations, and optimizing maintenance. Despite technological challenges and associated costs, their application is necessary to ensure structural safety, reducing both human and economic impacts.

Keywords

Digital Twins, Structural Monitoring, Reinforced Concrete Bridges, Structural Health, Construction Technologies

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Energy absorption and dissipation in negative stiffness metallic architected materials

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Abstract

With the recent advancements in additive manufacturing, engineers now have the capability to tailor the geometry in harmony with the base material in order to achieve superior performance. This allows for the production of metamaterials with extraordinary properties, such as negative stiffness, negative Poisson's ratio, and enhanced energy absorption capacity, surpassing the capabilities of traditional materials and structures. The adoption of such structures not only aligns with the principles of sustainable development but also promotes multifunctionality and substantial waste reduction. In this study, we evaluated negative stiffness architected materials using Ti6Al4V alloy, employing powder bed fusion 3D printers for manufacturing. Through experimental analysis, the results demonstrate the potential of architected materials for energy absorption and shape recovery. Moreover, by utilizing finite element analysis the tradeoffs between energy absorption, dissipation and shape recovery with respect to the elastic, elastic-plastic, and superelastic base materials are explored.

Keywords

Architected materials, Additive manufacturing, snap-through, buckling-induced

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ID:276

Digital Fabrication of Segmental Concrete Columns for Accelerated Bridge Construction

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Abstract

The combination of digital fabrication technology and pre-stressed segmental column construction holds great promise for the accelerated construction of bridges while optimizing material usage. This study aims to explore this potential by introducing a innovative pre-stressed segmental column system that utilizes permanent formwork made from 3D printed concrete (3DPC) and partially bonded iron-based shape memory alloy (Fe-SMA) reinforcement for pre-stressing. To evaluate the system's seismic performance, large-scale experiments were conducted on two columns subjected to both gravity and lateral loads. The experimental findings demonstrated that the columns were capable of withstanding lateral drifts of up to 5% without collapsing, and the permanent 3DPC formwork exhibited no signs of premature failure or de-lamination. Additionally, the columns displayed self-centering characteristics, maintaining a residual drift of 1% up to a target drift of 4% when the reinforcement ratio of steel to Fe-SMA rebars was 0.3. These results showcase the potential of the proposed prefabrication concept, which enables the design of bridge columns that are both material-efficient and resilient to seismic actions

Keywords

Digital fabrication, 3D concrete printing, segmental column construction

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Innovations to Improve 3D Concrete Printing of Portland Cement-Steel Slag Blended Mortars

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Abstract

Concrete has the potential to sequester CO_2. However, the extent of carbonation is proportional to the degree of hydration of cement. On the other hand, steel slag, a by-product from the steel-making industry, can react with CO_2 directly due to its reactive gamma–C_2S morph. Introducing steel slag by partially replacing cement and taking advantage of more CO_2 exposure surface area by 3D printing can help improve the sequestration capability of the steel slag-based 3D printable material. This study evaluates the CO_2 uptake potential of steel slag-based 3D printable concrete using different quantification methods. CO_2 uptake efficiency is analyzed by calculating the mass gain after carbonation, using a phenolphthalein indicator and thermal analysis. The results of 3D printed specimens are compared with casted specimens of steel slag-based concrete and conventional concrete. Further, steel slag's potential to uptake CO_2 in comparison with conventional concrete is investigated.

Keywords

CO_2 uptake, 3D concrete printing, steel slag, thermal analysis

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Direct energy deposition for lifetime extension of cracked steel components

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Abstract

Wire and arc additive manufacturing (WAAM) is a versatile technology with applications ranging from manufacturing to the strengthening and repair of aging components. This paper investigates the effectiveness of strengthening techniques using WAAM through both numerical simulations and experimental observations. A thermo-mechanical analysis is employed to predict the temperature and stress fields in repaired specimens. The results show that original cracks in the plate are arrested due to compressive residual stresses generated at the crack tip due to the WAAM process, as well as the increased stiffness around the cracked region. However, new cracks initiate at the edge of the plate/WAAM-material interface which corresponds to the high-stress state in the region. This issue is mitigated significantly by machining the WAAM sample into a pyramid shape, resulting in infinite life for the strengthened plate under fatigue loading. Fractography analysis aids in better understanding the mechanism of sample failure. In conclusion, the results underscore the potential of WAAM repair, offering a hopeful outlook for the future of steel structure maintenance by presenting it as a promising method for mitigating fatigue-induced damage in steel structures.

Keywords

Metal 3D-printing, Hybrid manufacturing, Fatigue repair, Fatigue life extension, Crack arrest

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Load Transfer Mechanism in 3DPC Formwork under End Anchorage Post-tensioning

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Abstract

The application of 3D printed concrete (3DPC) as a permanent stay-in-place formwork for casting reinforced concrete structures has gained attention over the past few years. This is mainly due to the advantages offered by 3DPC formwork, including design freedom and the ability to act as a permanent part of the structure, unlike traditional timber formworks, which are temporary and are often discarded after a few times usage. Currently, 3DPC formwork is not considered as a load-bearing part of the structure mainly because it is unreinforced. Post-tensioning of the 3DPC formwork could be a promising solution to improve its load-carrying capacity and cracking behavior. However, it is important to understand the load transfer mechanism in the 3DPC formwork on post-tensioning to avoid any premature failures. The aim of this study is to investigate the load transfer mechanism in 3DPC formwork under end anchorage post-tensioning. For this purpose, load transfer experiments were conducted on four 30mm thick 3DPC formwork specimens designed for one-way ribbed slabs. To simulate the post-tensioning load with an end anchorage, steel plates were provided at the specimen ends and axial load was applied to the specimens at different eccentricities from the neutral axis. The results showed that the specimens failed due to the development of high shear stress concentrations at the corners of the flanges of 3DPC formwork.

Keywords

3D concrete printing, stay-in-place formwork, post-tensioning, load transfer mechanism

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Mini Symposium 4: Intelligent digitalization in structural health monitoring and lifetime maintenance of complex structures

Organizers:

Steffen Marx (Technische Universität Dresden, Germany)

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ID:020

Monitoring heavy vehicle braking events using smartphones to improve the braking force model

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Abstract

Despite the high quality of available traffic data, there is a significant gap in the understanding of heavy vehicle deceleration and the frequency of braking events involving these large vehicles. This paper presents a practical and scalable approach based on the use of smartphones to collect braking event data. Dedicated Android applications were developed to collect essential data, including accelerations, angular velocities (gyroscope), and GPS information. To optimize file sizes, acceleration data, sampled at a rate of 10 Hz, was only recorded when a threshold of 2 m/s² was exceeded. A parallel strategy was used for the gyroscope data. The geographic data, sampled at a rate of 1 Hz, provided invaluable insight into the location and causes of braking events. To complete the analysis, classification algorithms were used to estimate braking frequency rates on different road categories. Over approximately nine months, 22 heavy-duty vehicles of different types were equipped with smartphones, and their operation was monitored along the Swiss road infrastructure. The comprehensive dataset of collected braking events provides an in-depth understanding of braking behavior as well as a good basis to improve the braking forces estimation. Information such as deceleration profiles and braking rates (braking events per km driven) were therefore used to improve the braking force model developed in research project AGB 2011/003. The preliminary simulation results based on the updated model are presented in this paper.

Keywords

Braking forces, Smartphone monitoring, Monte Carlo, Dynamic

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Distributed fiber optic sensing for early-age monitoring of concrete structures

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Abstract

Rayleigh based fiber optic sensing enables quasi-continuous strain measurements with high spatial resolution over extended ranges up to 100 m per sensor. The dense strain readings provide valuable insights into the structure, both locally and globally. On the global scale, deformation and load redistribution within a structure can be observed. On the local scale, even the smallest cracks, with widths below the human perception range can be detected. The durability of concrete structures depends to a large extent on the existing crack widths. Hence, early age monitoring of structures can have a decisive influence on the long-term infrastructure maintenance costs. The distributed nature of distributed fiber optic sensors (DFOS) enables monitoring of concrete structures from the beginning of their existence, where the precise locations of future damages are not known. Deployment of DFOS into the formwork enables monitoring the (precast) concrete structure through all production stages, from pouring, its curing phase, through stripping the formwork, prestressing, transport, up to its montage on site. Used for quality control, manufacturers can harness this early age monitoring for internal quality control or even proof the agreed quality to the owner by issuing birth certificates.
As part of the IDA-KI research project, a large-scale demonstrator bridge – the openLAB – is built with precast girders. These are equipped with an extensive monitoring system, including cast-in DFOS. Preliminary tests are carried out on 15 m long prestressed precast elements, before the final assembly of the bridge. In this contribution, we present some results of experiments on these large-scale specimens.

Keywords

Structural health monitoring, fiber optic sensing, distributed strain sensing, early age monitoring, large-scale experiments

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Interaction between BIM and FE models in structural health monitoring

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Abstract

Building Information Modeling (BIM) is already widely used in civil engineering projects. Digital building models that contain geometric as well as semantic information are generated and could be managed throughout a structural life cycle. A BIM model could generally serve as a primary source of any required information on building construction, including the finite element (FE) models or monitoring systems as well. The interaction between BIM and FE models is of great importance for structural engineering as it helps increase productivity and minimize mistakes due to human factors. Moreover, with the help of structural health monitoring (SHM), it should be possible to update BIM and FE models to the current state of the structure and to predict the remaining service life. Obviously, FE models of different complexity and dimensionality are required for the same structure in view of various structural or material limit states considered during the structural design phase and the service life as well. The present contribution describes the development of a method that allows FE models of different complexity and dimensionality to be consistently extracted from the same BIM model. It focuses on openBIM technology incorporating the Industry Foundation Classes (IFC) format. The corresponding IFC file is enriched with FEM and SHM relevant information, for example, dimensionality of the FE model, FE size as well as positions and conditions of the sensors. Using such information in the BIM model, the FE model for ANSYS APDL can be created. The simulation or monitoring results can be subsequently introduced back into the original BIM model, thus describing the actual structural state. The contribution will be illustrated by examples of representative laboratory structures.

Keywords

Building Information Modeling, Industry Foundation Classes, finite element model, structural health monitoring

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Modifying the dead load safety factor of the Nibelungen Bridge based on 3D measurements

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Abstract

The calculation, verification and assessment of structures in Europe shall follow Eurocode 0, which employs a semi-probabilistic safety concept with partial safety factors to account for scattering uncertainties in materials and actions. However, in the case of existing structures, the features like materials and actions are already determined and can be in many cases measured. Hence, a rigorous application of this safety concept for existing structures may yield conservative results and potentially lead to unnecessary rehabilitation, strengthening and replacements procedures. To address this issue, the fib Bulletin 80 provides two approaches to modify partial safety factors for materials and actions: the design value method (DVM) and the adjusted partial factor method (APFM). This paper investigates how DVM and APFM can be used to specify the partial safety factors for the dead load of existing structures based on precise geometry measurements. For this purpose, the Nibelungen Bridge in Worms, which serves as the validation structure of the German Research Foundation-funded priority programme SPP 100+, is used as an example. As a part of this programme, an as-designed 3D-geometry model based on inventory technical drawing as well as an as-built 3D-geometry model based on point clouds, which was generated using laser scanning technology, of the bridge are developed. As a result, the deviations between these two models are determined and analyzed. Subsequently, object-based partial safety factors are derived. In the end, new safety factors are proposed for the German recalculation guideline.

Keywords

Existing bridges, Partial safety factors, Nibelungen Bridge Worms, Assessment, Dead load

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A data-driven approach for linking models of large-scale bridges and monitoring data

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Abstract

Predictive maintenance of large-scale structures such as bridges requires precise numerical models to describe their current condition. Typically, solving an inverse problem is necessary to determine model parameters from Structural Health Monitoring (SHM) data. However, conventional methods such as Finite Element Updating through optimization algorithms demand substantial computational ressources, as numerous parameter combinations need to be assessed to identify the optimal model state in each calibration step. Consequently, these methods are only partially suitable for creating digital twins of bridges.
This paper introduces an alternative approach by treating the inverse problem as a model parameter classification problem. This involves establishing a model database that covers a wide range of damage states. Notably, this method eliminates the need for multiple simulations during the application phase, as simulations are performed only once in an offline context. Subsequently, a classification algorithm is trained based on this database, enabling real-time selection of the best-fit model for practical applications using SHM data, without the necessity for additional simulations. Transparency in algorithm decisions is crucial for infrastructure maintenance, therefore, optimal classification trees from the field of interpretable machine learning are employed. Decision trees offer a balance between high accuracy and interpretability while providing additional advantages, such as sensor placement evaluation. In summary, this approach demonstrates the potential for linking numerical models with SHM data through the application of interpretable machine learning techniques, facilitating real-time decision-making for the preservation and management of critical infrastructure.

Keywords

Digital Twins, SHM data, interpretable machine learning, optimal classification trees, large-scale bridges

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Advances of Digital Twins in Bridge Structures Maintenance

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Abstract

The conception and development of digital twins (DT) are increasingly under investigation within the civil engineering sector. They exhibit significant potential in nearly all phases of construction, including design, construction, operation, and maintenance. However, the precise function and implementation of DT lack a clear definition and continue to be the subject of research. This paper focuses on the implementation and the latest developments of DT concerning the maintenance of complex structures. To achieve this, first, we conducted a comprehensive review of papers published within the last five years related to DT in the maintenance of civil engineering structures. These papers were selected based on co-occurrence analysis of keywords in journal papers, which rank within the top quartile (Q1 and Q2) of the Scimago Journal Rank. As a result, we summarize and analyze the concepts, methods, and application cases. Then, the application of DT on the Nibelungen Bridge Worms in Germany will be introduced as a case study. Finally, we provide a discussion on the implementation of DT in the maintenance of civil engineering structures

Keywords

Existing bridges, digital twin, maintenance

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ID:108

Vibration monitoring of structures with indirect load identification and Kalman update

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Abstract

In September 2022 the German Research Foundation (DFG) has launched the priority program SPP 2388 100+ to develop new methods for digital representation, SHM and lifetime management of complex structures, due to the continuously increasing amount of old infrastructure buildings. The present contribution is prepared within the LEMOTRA project as a part of SPP 2388 100+.

Among various SHM methods, the approach based on the Kalman update for data assimilation between model and measurement is applied and further developed to create a kind of functional digital twin for SHM. For this, a sound numerical model and a measurement system with a continuous data flow are necessary to provide online predictions of the state and response parameters of the structure. System changes resulting from damage or aging processes can be detected and localized, provided the measurement and the model prediction share the same cause. Thus, the load identification is a necessary prerequisite for reliable data assimilation techniques. A two-step update procedure is proposed and applied in this context.

At first, one part of the measurement system is used for load identification. Therefore, a cluster structure of Convolutional Neural Networks (CNNs) was developed, trained and calibrated to extract load characteristics such as load magnitudes, load velocities or the number of vehicles on the bridge from multiple acceleration sensors. Given this information, the actual load can be reconstructed.

In the second step, a different set of sensors is used for the data assimilation. In contrast to the first measurement locations, the measurement data from these sensors should be sensitive to potential system changes or damage. Here, the identified load is used as input for the model predictions which are then compared to the measurement data. A combination of different ensemble based Kalman Filters provides a sequential update of the state parameters (e.g. displacement, velocity, acceleration) and the model parameters (e.g. stiffness, mass, damping).

The proposed approach is implemented in MATLAB and tested on both numerical examples and a laboratory structure.

Keywords

Kalman Filter, Neural Network, Load Identification, Model Update, Damage Detection

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System identification and monitoring of bridge structures

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Abstract

The research presented is part of the SPP100+ of the German Research Foundation. Subject of the research is the early detection of damage, especially on large bridge structures. For this purpose, investigations carried out at the technical centre of the I4S, in particular to take into account the environmental conditions (EOC) in the context of system identification of mechanical structures. The lifetime of the considered structures is divided into macro and micro time domains. In the micro time domain, state space models serve as a basis for damage localisation. The parameters of the models are estimated based on output-only methods and $H2/H\infty$ optimization. The damage location is done by SP2E, a projected state and estimation error method in conjunction with a machine learning method, for the categorization of the EOC. This paper presents the monitoring method in micro time domain of lifetime and first results of experimental investigation and vibration-based output-only measurements at the technical centre.

Keywords

System identification, subspace method, H_2/H_∞ optimization, innovation model

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Damages Detection combining Modal Analysis and Acoustic Emission in Concrete Structures

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Abstract

To ensure the structural stability of large infrastructure systems like concrete bridges, a range of measurement techniques are needed to identify and detect various types of damage or decay, including rebar corrosion, cracking, tendon failure, or alkali-silica reactions.

In an experimental study, a progressively increasing point load was applied at the centre of a flipped-T-shaped concrete sample, inducing a reduction in mechanical stiffness. During the loading process, structural deformation and acoustic emission resulting from concrete crack formation were measured. Between the load steps, the unloaded structure was excited with an impulse hammer for a modal analysis. Therefore, accelerometers were attached at 24 sensor locations.

At first, we assess the suitability of the individual methods in detecting, localizing and quantifying possible damage. As a second step we show correlations in the number and intensity of identified crack events, the change in eigenfrequencies of correlating mode shapes of the specimen and the size and location of optically identified cracks on the concrete surface.

We conclude that the combination of different methods increases the reliability and quality of damage detection and localisation required for real-world application.

Keywords

Modal analysis, Acoustic Emission, Damage Detection, Concrete, Cracks

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BIM-oriented approach for the setting up of a Bridge Management ECO-System

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Abstract

When it comes to risk management of the very diverse Italian infrastructures – notably concerning bridges, viaducts, and overpasses, most of which were built between the end of the Second World War and 1980, with only 15% less than 20 years old – the national scenario is quite heterogeneous, since ownership, if verified, pertains to different managing bodies and each of them employs its own maintenance procedures. Therefore, this paper presents an approach for the systematization of highway bridges, viaducts, and overpasses and the related inspection data by conjugating the requirements of the Italian reference framework consisting of LG2020 (the guidelines for risk classification and management, safety assessment, and monitoring of existing bridges), the ASPI (Autostrade per l'Italia) Handbook, and AINOP (National Information Archive of Public Facilities).

In particular, a procedural workflow has been developed and tested on the infrastructure artworks on the A3 section connecting Naples, Pompeii and Salerno, included in the C.U.G.RI. ("Centro Universitario per la Previsione e Prevenzione Grandi Rischi") – S.A.M. ("Società Autostrade Meridionali"). Working on the pilot case of the Olivieri Viaduct, dedicated descriptors were developed and subsequently implemented as custom "parameters" in the BIM environment to meet the cataloging requirements for each structural component into which the infrastructure has to be decomposed following the specifications of the regulations.

In addition, the digitization procedure involving two types of operators – modelers/inspectors and supervisors – has been further optimized by developing ad hoc VPL (Visual Programming Language) scripts for the automatic assignment of classification data and inspection forms, and to establish a direct link between the information model developed in the editable BIM environment and the monitoring platform designed by C.U.G.RI's IT engineers.

Keywords

BrIM, BMS, Monitoring ECO-System, Italian Regulations, Olivieri Viaduct

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Detection of strain and crack development in RC under tensile fatigue loading using 2D FOS

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Abstract

For reliable service life prediction of reinforced concrete (RC) structures, a fundamental knowledge of the damage development under repeated subcritical loading is essential. Even though computational models are becoming increasingly capable of performing numerical analysis of the structural behavior, the calculation of the entire structure involves an immense computational effort, especially in the case of fatigue loading. Moreover, for existing structures, both the loading history and the material properties are uncertain, leaving the actual strains and stresses within the structure unknown. Therefore, assessment of remaining service life is in practice mostly performed by elaborate visual inspection of the concrete surface.

To overcome this time-consuming process, it is crucial to consider continuously gained information on the damage state of the existing structure by comprehensive strain measurement. Combining them with accelerated physical service life prediction models leads to an improved assessment of structural safety.

Based on this premise, the authors have developed a monitoring concept that involves a two-dimensional application of distributed fiber optic sensors (FOS) on the concrete surface for high-resolution strain measurement. This paper presents the first studies using this general concept and shows how strain and crack development under monotonic and fatigue tensile loading can be accurately monitored using the FOS grid employed. The results clearly demonstrate that crack initiation can be predicted based on strain measurements long before the actual crack formation, and that even after crack initiation, the gradual crack opening can be reliably measured.

Keywords

Reinforced Concrete (RC), Fatigue, Tensile Loading, Fiber Optic Sensors (FOS), Monitoring

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Influence of the re-anchoring behaviour on the detection of internal tendon rupture by fibre-optic measurements

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Abstract

Unannounced tendon rupture is a dreaded failure mechanism in pre-stressed concrete bridges. Failure of single wires or tendons does not necessarily lead to concrete cracking. Then, damage cannot be detected by visual inspection. In the case of tendons bonded in concrete, re-anchoring after cracking causes characteristic local strain fields: tensile strains occur between the crack edges, while compressive strains develop around the tendons, until the initial prestressing strain is again reached. On the surface, these strains are small and depend on multiple factors, e.g., the depth of the tendon, the new anchorage length and the concrete stiffness. Such strain fields can be detected by fibre-optic sensors attached to the surface in two-dimensional grids. By evaluating the backscatter of emitted light beams, minimal strain changes (uncertainty: ±2 με) can be detected in quasi-continuous resolution (2.6 mm pitch). An experimental investigation of pre-tensioned concrete beams with three bars of 10.5 mm diameter is presented. These bars were mechanically cut to simulate failure, while longitudinal and transverse strains were measured on two opposing concrete faces. The location of rupture can be narrowed down towards a few centimetres. The shape and peak of the measured strain fields indicate the depth of the crack, as well as the anchoring length and the remaining pre-stressing force.
The effect of the bonding between tendon and concrete on the detected strain is investigated by varying the type of concrete as well as the surface conditions of the tendon (indented or smooth). Increased concrete stiffness (C40/50 to C 60/75) results in lower expansion of the strain field (less than 10 cm on the concrete surface), but higher strain peaks. The surface condition yields comparable results. For smooth tendon surfaces the anchoring length is increased and the strain field on the concrete surface is dispersed over a length of around 20 cm with smaller strain peaks. Both influences interact with the tendons' depth. The results are used to develop a monitoring system to detect the position and quantity of ruptured tendons, just from the strain signal on the concrete surface.

Keywords

fibre-optic sensors, pre-stressed concrete, tendon rupture, monitoring, re-anchoring

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Satellite monitoring of reinforced concrete buildings in areas affected by slow-moving landslides

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Abstract

Slow-moving landslides are very spread phenomena in Italy and worldwide. The study of their impact on the existing structures is of great interest, since they can provoke more or less serious consequences for structures, facilities and human lives safety. Traditional monitoring techniques on site are usually adopted for landslides. The innovative Differential Interferometry Synthetic Aperture Radar (DInSAR) techniques, based on the use of data derived from satellite images, constitute an advanced technology that allows to remotely monitor the deformation of large portions of land over long periods of time, with lower costs. These techniques are able to well capture displacements slowly evolving in time; they fit very well with slow-moving landslides. This work follows a previous study by some of the authors, where the structural health monitoring of a reinforced concrete infilled building within a landslide-affected area was made. A finite element model of the structure was created, assuming a non-linear behavior for the structural elements, focusing on the elastic part up to the yielding, while infills were modeled as diagonal struts. DInSAR data derived from the processing of COSMO-SkyMed images in the period 2012-2016 were used in order to investigate the evolution of the infills damage over the years. In this work, the monitoring period has been extended by processing new COSMO-SkyMed images, up to 2023. The prediction of the future expected displacements, shown in the previous study, has been now compared to the real displacements detected. According to them, the analysis of the expected damage on the infills has been checked.

Keywords

DInSAR, Landslides, Structural Health Monitoring, Reinforced Concrete Buildings, Infills.

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Simulation workflow for fault detection and localization in sandwich panels

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Abstract

Sandwich panels in civil engineering have the advantage of a high flexural strength and thermal insulation while providing a very low density. They are made of two steel sheets and a core of polyurethane or polyisocyanurate foam. Caused by the production process, the panels occasionally have defects, that are not visible from the outside. These can cause larger visible damages after installation in building facades. This paper presents a workflow for the detection and localization of the defects exploiting the influence of these on especially the response to a dynamic excitation. It uses an experimentally validated finite element model, feature engineering, and a neural network. The workflow initiates with the development and validation of a mechanical finite element model, using experimental data. The model serves as the foundation for a simulation campaign, examining both fault-free and models with faults. The simulation process incorporates variations in material parameters based on experimentally obtained standard deviations, ensuring a robust representation of real-world uncertainties. The resultant simulation dataset is subjected to a feature engineering process, encompassing time-, frequency-, and wavelet-domain features. This multi-domain feature extraction enhances the dataset's informativeness. The feature dataset is employed to train a neural network for two primary use-cases: Firstly, to discern between fault and fault-free models, providing an accurate fault detection mechanism. The second use-case involves the localization of faults within the model. The effectiveness is demonstrated using various testing datasets. The proposed methodology represents a combination of a synthetically created database from a validated finite element model, multi-domain feature engineering, and neural network capabilities. It offers a reliable methodology for fault detection and localization in sandwich panels. In practical use, this can lead to significant reduction of customer complaints and savings in replacement costs and hence carbon footprint.

Keywords

Sandwich structures, detection, localization, feature engineering, neural network

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ID:295

Development of a Low-Cost IoT-based Sensor for Early-Stage Concrete Monitoring

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Abstract

Concrete is an essential construction component that needs to be examined carefully for an early strength assessment in order to guarantee structural integrity and long-term durability. This paper delves into the viability of utilizing low-cost sensors, interfaced with an Arduino-based microcontroller, for real-time data acquisition in concrete structures. The study focuses on their application in the early stages to investigate the thermal cycles due to hydration reaction, particularly within macro-synthetic fibre reinforced concrete. DHT22 sensors are used to measure the concrete sample's temperature and humidity parameters. These sensors are linked to a NodeMCU microcontroller that has an integrated WiFi module to provide real-time data updates on the cloud. The programming code is created using the Arduino IDE platform and then loaded into the NodeMCU microcontroller to control sensor functions. The validation process consists of an early laboratory test and the placement of an additional DHT22 sensor outside the concrete sample to monitor the surrounding temperature and humidity to evaluate the system's operation and sensor´s accuracy. The collected data reveal promising insights, particularly in investigating corrosion within embedded reinforced rebar for future researches.

Keywords

Low-Cost Sensor, Concrete Monitoring, Early-Stage Assessment, Structural Health Monitoring.

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ID:410

Experiments on mechanical and physical properties of self-sensing concrete

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Abstract

This paper deals with the preliminary results of an experimental investigation carried out at the Structural Engineering Testing Hall (STRENGTH) of the Department of Civil Engineering of the University of Salerno (Italy) on the mechanical and physical properties of self-sensing concrete (SSC) incorporating Industrial Grade Multi-Walled Carbon Nanotubes (MWCNTs). It has been recently demonstrated that the use of self-sensing material in the Civil engineering field may provide a cost-effective solution for the structural health monitoring (SHM) of reinforced concrete structures. One of the weak points of these smart composite materials is related to the difficulty of ensuring homogeneous dispersion of the functional filler in the matrix. Therefore, the preparation technique must be thoroughly investigated. On the other hand, there is no unified standard or specification for CNT dispersion, which limits the standardized use of CNT in building materials. The experimental investigation was performed at the STRENGTH LAB with a dual purpose: (*i*) to analyse the effects of nano-additives dispersion on the microstructure of the mixtures and (*ii*) to determine the influence of MWCNTs on their compressive behavior. A total of sixty samples were casted, considering (*a*) five concentrations of MWCNTs, ranging from 0% to 0.1% by weight of cement, each with an increment of 0.025%, (*b*) two different matrices, Portland cement (42.5R) and high-performance cement (Geolite Magma), and (*c*) two different surfactants, along with sonication, used for the dispersion of carbon nanotube in the water, Sodium Dodecyl Sulfate (SDS) and Polyvinylpyrrolidone (PVP). The main results, in terms of compressive strength after 28 days of curing and physical properties, obtained through a qualitative analysis of the surface morphology and microstructure of cementious composites, carried out using Scanning Electron Microscopy (SEM) images, are presented and discussed.

Keywords

Self-sensing concrete, Structural Health Monitoring, Carbon nanotube, Experimental investigations, Dispersion techniques

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Mini Symposium 5:
Smart FRP and steel structures

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ID:043

A Graphical Solution to Bond Capacity

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Abstract

This study proposes an analytical model, referred to as the "Wine Glass model", offering an elegant graphical solution to the bond capacity. It is built on the basis of two key assumptions: (i) the bond length is sufficiently long (longer than an effective bond length) and (ii) the stress-strain behavior of the adherent monotonically increases, which is typically met by the majority of engineering materials. The tensile stress-strain ($\sigma - \varepsilon$) curve of the adherent can be visualized as a wine glass when plotted against the vertical axis (σ-axis). In this analogy, the fracture energy of the adhesive bond divided by the thickness of the adherent strip (G_f/t) represents the wine poured into the glass. The height of the wine within the glass corresponds to the level of adherent tensile stress, with respect to the bond capacity (F_b). This Wine Glass model, which suits lap-shear joints with both linear and nonlinear adherents, is validated on experimentally measured bond capacities of various types of lap-shear joints, including carbon fiber reinforced polymer (CFRP)-to-steel joints and iron-based shape memory alloy (Fe-SMA)-to-steel joints. It unveils the mechanism of bond capacity.

Keywords

Bond capacity, nonlinear adherent, analytical solution, graphical solution

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ID:064

Bond Behavior of CFRP-Strengthened Steel Structures and Its Environmental Influence Factors: State-of-the-Art Review

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Abstract

Bonded carbon fiber-reinforced polymers (CFRP) strengthened damaged steel structures show good application prospects in improving the load-bearing capacity and service life of steel structures. The insufficient performance of the bond interface is a core issue affecting the stability and durability of the CFRP-steel bond system. Firstly, this study discussed the influence of the mechanical properties of CFRP and adhesives on the bond behavior of the bond system. Then, the application prospects of nano-modification and novel film adhesives were reviewed. Next, the influence of bond length and film thickness on the bond behavior and failure mode of the CFRP-steel bond system was analyzed. Subsequently, the influence of the geometric configuration of the CFRP-steel lap joint on bond performance was summarized. Finally, the influence of environmental factors, including high temperature, moisture and relative humidity, ultraviolet rays, freeze-thaw cycles, subzero temperature, hygrothermal, and dry/wet cycles, on the bond behavior was analyzed. The results show that it can improve the bond and high-temperature resistance performance of the bond system using nano-modified or novel film adhesives. By setting a reasonable bonding length and adhesive thickness, the bond strength of the bond joint can be effectively improved. In adverse environments, protecting the adhesive layer from erosion was important. By collecting sufficient tested data, an empirical model for normalized bonding strength degradation at elevated temperature environments was proposed. This study can be used as a reference for CFRP-strengthening steel structures.

Keywords

Carbon fiber-reinforced polymer, Strengthened Steel structures, Bond behavior, Environmental influence factors

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An Attention-Based Detection Method of Displacement Field on Steel Surfaces

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Abstract

Steel structures are prone to fatigue cracks when subjected to cyclic loading, which may lead to catastrophic failure. Generally, the width of fatigue cracks in steel structures is below 0.1 mm at the early stage of crack propagation. Although high-resolution images can be obtained by consumer-grade cameras at low cost, these tiny cracks are difficult to detect by images alone. This paper proposed a crack detection method based on the displacement field on the surface of the structure obtained from images. Video or continuous images of the target structure under loading was first took and input into an improved LoFTR model, which was capable of densely matching the feature points on two pairs of images without distinct visual features. The surface displacement field of the structure was then performed inversely by the coordinate difference of a large number of matched feature points. Eventually, location of the cracks was extracted according to the discontinuities in the displacement field. A case study was conducted on a cracked steel plate. Results demonstrated a tiny crack with the maximum width of 0.1 mm was detected, which was more effective and accurate in comparison with image-based semantic segmentation methods.

Keywords

Steel crack detection, displacement field, computer vision, image feature matching

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Fatigue durability of adhesively bonded joints between steel plates and patch plates

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Abstract

In the adhesive bonding method of steel plates or FRP plates to restore the performance of steel members, the evaluation of delamination of adhesive joints in design and verification is an important concern. In particular, there are few data on debonding strength under cyclic loading, and standards for fatigue design have not yet been established. In this study, specimens were prepared by bonding a patch plate to a steel plate using epoxy resin adhesive, and repeated bending loads were applied to them to measure the occurrence and propagation of debonding. The types of the patch plates and adhesives were parametrically examined. As a result, S-N diagrams were organized by the ratio of the principal stress range in the fatigue test to the principal stress in the debonding in the static test, the bending fatigue durability of the debonding could be evaluated with high accuracy. Comparisons with experimental cases under tensile loading showed a similar tendency, indicating that the fatigue lives of debonding can be evaluated regardless of the type of applied force.

Keywords

Patch plate, Debonding, Fatigue durability, Bending action, Tensile force

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Fatigue behavior of CFRP strengthened ultra-high strength steel

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Abstract

Ultra-high strength steel (UHSS) with exceptional mechanical properties is gaining widespread use across various industries. However, research on strengthening UHSS with surface cracks using Carbon Fiber Reinforced Polymer (CFRP) is limited. Accordingly, a series of CFRP strengthening UHSS Q890 and Q960 experiments with surface cracks are carried out under fatigue loading. Two loading programs, the maximum stress equal to half yield strength fy and 200 MPa, are designed. Surface cracks at the weld root were pre-cracked, and a single layer of CFRP was applied adhesively to both sides of the butt-welded UHSS. First, the results show that when subjected to a maximum stress of 0.5fy, the fatigue life decreases as the steel grade increases. The strengthening effect is 1.07 and 1.34 times for Q890 and Q960, respectively. Second, when subjected to a maximum stress of 200 MPa, the fatigue life decreases as the steel grade decreases. Excellent strengthening effects of 1.89 and 2.60 times were obtained for Q890 and Q960, respectively. Finally, it is observed that CFRP delamination and rupture are the main fracture modes.

Keywords

Ultra-high strength steel, CFRP, fatigue, surface crack, butt-weld

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Adaptation of the pipeline supporting structure into a footbridge using FRP deck with SHM

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Abstract

In order to create a convenient pedestrian and bicycle crossing along the existing road bridge, the city authorities decided to adapt the existing heat pipeline supporting structure, located next to the road bridge, for this purpose. The three-span supporting structure with a total length of 109 m was built in 1975 from two steel plate girders, braced with crossbeams, on which a heat pipeline with a diameter of 100 cm was placed. In order to adapt the existing steel structure to the new live loads, the steel girders were strengthened by increasing their cross-section (bottom flange) and depth. Moreover, to minimize the dead load of the structure after the reconstruction, the lightweight FRP composite panels were used as a deck slab for the footbridge. The panels were connected to the steel girders by means of special connectors, but without the composite action between the steel girders and the deck slab. Due to the use of new material for the deck slab, the city administration required the implementation of a system for monitoring the technical condition of the panels. Therefore the monitoring system based on distributed fibre optic sensing (DFOS) technology has been implemented into the FRP panels. DFOS enables continuous measurements to be acquired along the entire length of the structure, which is particularly crucial for these types of bridge decks. Before the new footbridge was put into use, a proof load test of the superstructure was carried out to verify its load-bearing capacity and to check the operation of the monitoring system. The paper presents the method of strengthening of the steel structure, its final reconstruction method, the monitoring system of FRP panels, as well as the results of the proof load test and controlling of the monitoring system.

Keywords

Steel strengthening, FRP panel, distributed fiber optic sensing, SHM

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Mini Symposium 6:
Innovative Methods in Strengthening of Concrete Bridges using FRP

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Re-use of 25 year old CFRP pultrusions for bridge strengthening via post-tensioning cables

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Abstract

Kleine Emme bridge was a truss bridge built in 1998 for pedestrians and bicycles with a span of 46.8 m in the city of Lucerne - Central Switzerland. The bridge structure was a space truss made of steel pipes in composite action with a reinforced concrete deck. The bottom chord consisted of a steel tube that was post-tensioned with 2 parallel-wire CFRP cables inside the channel, a world premiere 25 year ago. Each cable consisted of 91 pultruded CFRP wires of 5 mm diameter which were prestressed to 1'350 MPa each, corresponding to 45% of the CFRP design tensile strength. The CFRP cable anchorages were obtained by casting the CFRP wire ends in steel sleeves with a special epoxy grout, a gradient stiffness load transfer media patented by Prof. Urs Meier of Empa in 1998. In spring 2016 the bridge was dismantled due to a new concept for flooding protection for the city of Lucerne which made it obsolete. 8.7 km of CFRP pultruded wires (market value 45'000 Euro) came back to Empa after decommissioning of the bridge. The 47.8 m long CFRP cables were stored outdoors for 7 years while Empa was looking for re-use options of these valuable materials, their residual tensile strength was assessed to be more than 90% after 25 years. This paper presents the development of a new filament wound CFRP sleeve and resin grout at Carbo-Link and Empa for the efficient anchorage of the 25 years old re-used CFRP wires. The new anchorage and cables were tested to tensile capacity (1.833 MN) in two full scale instrumented experiments using distributed fiber optic sensors, laser and strain gauges before two new 28.4-32.4 m long post-tensioning cables were produced by Carbo-Link with each 37 of the regained CFRP wires. Both CFRP parallel wire cables were finally successfully prestressed to 1 MN (55% of their UTS) in order to strengthen an existing bridge in the Swiss Alps over the river Ilfis in summer 2023. This strengthening project is thoroughly described: The re-use of valuable CFRP pultrusions for post-tensioning confirms the durability and shows the sustainability potential for CFRP.

Keywords

CFRP, re-use, pultruded wires, post-tensioning, bridge strengthening

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Reusing aircraft CFRP fragments to strengthen concrete structures: bond behaviour assessment

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Abstract

Carbon Fibre Reinforced Polymer (CFRP) composites are used for strengthening existing structures with different techniques such as Externally Bonded Reinforcement (EBR) and Near-Surface Mounted (NSM). While the use of CFRPs enhances the flexural response of Reinforced Concrete (RC) constructions, their high cost and environmental impact of manufacturing remain a substantial barrier to spread their use. Thus, reusing CFRP materials from other sectors might provide a solution.

Because of globalisation and transportation needs, the aeronautic sector anticipates substantial growth, resulting in a growing fleet with a bigger proportion of CFRP components due to their high specific properties. Therefore, the aeronautic industry will soon confront the challenge of handling End-Of-Life (EOL) carbon composites from decommissioned aircraft, with any clear sustainable alternative to landfilling. This work, aligned with the Sustainable Development Goals, proposes reusing EOL aircraft CFRP components for strengthening concrete structures.

This contribution is part of a broader project aiming to explore the feasibility to use CFRP segments from the aeronautic sector to strengthen RC elements. In particular, this work describes an experimental study to assess the bond behaviour between concrete and reused aircraft CFRP parts. It includes a series of single-shear tests with different cross-section areas and surface preparation methods for the CFRP materials. The results, in terms of load-slip response, bond capacity and failure modes are presented and compared to results from conventional benchmark CFRP materials.

Keywords

Strengthening concrete structures, reusing, bond, CFRP, aircraft.

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ID:232

Fly ash-activated geopolymer adhesives in strengthening of concrete structures using CFRP

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Abstract

Strengthening of RC structures using NSM CFRP technique is exhibited as effective and promising technology. However, having epoxy adhesive as the binding agent between the CFRP laminate and concrete substrate presents a serious drawback due to its low glass transient temperature which once exceeded, the Epoxy adhesive loses its mechanical strength. This study investigates the potential of employing geopolymer-based adhesives as an alternative to epoxy. Several mixes with different constituents proportioning, additives and alkali activators have been investigated for their residual thermomechanical strength, volume change, mass loss and density change at different firing periods. XRF, XRD and SEM analysis have been employed to help with assessing the thermal performance of geopolymer mixes. The results demonstrate that K-activated FA geopolymers have a better overall thermal performance over NA-activated FA geopolymers. Furthermore, the study indicates that incorporating additives has a true potential in advancing the geopolymer thermal performance in terms of residual strength, volume change and mass loss.

Keywords

Epoxy Resin, Geopolymer Adhesive, NSM FRP Strengthening, Alkali-activated fly ash/slag, Alkali-activated fly ash/slag.

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A convolutional autoencoder for damage assessment of FRP strengthened RC beams

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Abstract

The use of fibre reinforced polymer (FRP) in civil construction applications has gained considerable popularity worldwide as suitable method for strengthening existing concrete structures. However, there is very little experience in the implementation of methods able to give a reliable prediction about the health of this type of structures even although sudden and brittle failure modes are likely to happen. Electromechanical impedance (EMI) method formulated from measurements obtained from PZT patches gives the ability for monitoring the performance and changes experienced by these strengthened beams at a local level, which is a key aspect considering their possible premature debonding failure modes.

In this work, a deep learning approach using convolutional variational auto-encoders for exploiting the raw impedance signatures is implemented to automatically detect anomalies in an unsupervised manner for this type of structures. To validate the effectiveness of the method, an experimental test campaign was performed. A concrete specimen strengthened with FRP and instrumented with PZT transducers in different location was subjected to different loading stages which provided different levels of damage. The results showed the potential of the method for EMI data-driven minor damage identification for real-life concrete infrastructures.

Keywords

Convolutional autoencoder, Unsupervised methods, FRP strengthening, Concrete.

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Flexural strengthening of a bridge deck slab using near surface mounted CFRP rods

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Abstract

Swanley I/C East and West form part of the M25 Junction 3 interchange roundabout at Swanley in the UK. They are similar three span reinforced concrete beam and slab bridges with integral inclined piers. The soffits of the side spans of the structure started cracking soon after it opened in 1977 due to insufficient reinforcement in the deck. To remedy this, steel strengthening plates were bonded to the soffit of the side spans and to the top surface of the deck over the piers in the hogging regions.

The bridges have, in recent years been subject to Interim Measures Management following concerns over potential debonding to the steel plates bonded to the deck surface. When reflecting cracking has occurred in the surfacing, investigations have been undertaken including hammer tapping of exposed plates to map the debonding and manage the operation of the structure against a sensitivity study to plate debonding based on structural assessment.

During the management regime a strengthening rehabilitation / replacement scheme has been developed to replace the existing steel plates in the hogging regions with a new CFRP strengthening system composed on Near Surface Mounted Rods.

An extensive Early Contractor Involvement (ECI) and design development process has been undertaken to determine a solution that can be built in a sequence of existing plate removal that allows the existing structure to remain open to a lane of traffic during the works. This ECI included both procedural and laboratory trials on different materials and their properties to ensure buildability with the scheme constraints.

This paper presents the design, challenges and lessons learnt of Swanley I/C East bridge rehabilitation, which completed construction in November 2023.

Keywords

Bridge, Concrete, Strengthening, FRP, NSM

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Influence of Geogrid on the Flexural Behavior of Cracked Concrete Pavements

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Abstract

This paper investigates the influence of geogrid reinforcement on the flexural behavior of concrete pavements after the initiation of cracks up to failure. Two groups of notched concrete beam specimens with the dimensions of 150 × 150 × 550 mm were tested. The concrete specimens of the first group were tested under static loads. The concrete specimens of the second group were tested under cyclic loads. The geogrid was placed at a depth of 55 mm from the bottom of the concrete specimens. Test results illustrate that, when cracks are visible in the concrete specimens, the geogrid could maintain the flexural behavior of the concrete pavements within the acceptable service level. The geogrid significantly prolonged the fatigue life of the cracked concrete pavements reinforced with the geogrid. The geogrid increased the maximum cyclic loads of the concrete specimens reinforced with geogrid before eventually failing. The number of geogrid layers used as a flexural resisting material under cyclic loads acts a significant role in improving the behavior of the concrete pavements compared with the specimens reinforced with one layer of geogrid.

Keywords

Geosynthetic materials, Geogrid, Concrete pavements, Cyclic loads, Fatigue behavior

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ID:360

Effect of Glass Fibre on Slag-Fly Ash Based Geopolymer Concrete

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Abstract

Geopolymer concrete is a durable and environment friendly construction material. However, less ductility and high brittleness are the major challenges of the geopolymer concrete. The addition of fibres in concrete impedes the fracture propagation and improves the overall mechanical properties of the concrete. This study investigates the fresh and the hardened properties of ambient cured plain and glass fibre reinforced slag-fly ash based geopolymer concrete (SFGC). All the mixes were prepared using an alkaline activator, composed of 14 molar sodium hydroxide (NaOH) solution, and liquid sodium silicate (Na_2SiO_3) with a modulus (SiO_2/Na_2O) ratio of 2. Alkali resistant glass fibres at the dosage of 1.5% by volume of the concrete were added to the mix to evaluate the workability, density, compressive and flexural strengths of glass fibre reinforced slag-fly ash based geopolymer concrete (GF-SFGC). The experimental results indicated that the addition of glass fibres in SFGC mix reduced workability but improved the density of concrete. The average compressive strength of SFGC determined at 7, 28 and 56 days was decreased by approximately 2-4% by adding the glass fibres in the mix. However, the average 28-day flexural strength of GF-SFGC was about 24% higher than the plain SFGC mix. Overall, the fresh mix of GF-SFGC was cohesive and the hardened specimens remained intact even after the failure.

Keywords

Glass fibre, Slag-fly ash based geopolymer concrete, Ambient curing, Workability, Mechanical properties

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ID:363

Comparative Assessment of FRP Composite Materials in Structural Applications under Low-Velocity Impact Loads: A Review

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Abstract

Structural members can undergo various types of loading during their lifetime, including impact loads. Fiber-reinforced polymer materials (FRPs) have been investigated as enhancing materials for various structural members against impact loading. This study reviews and highlights the impact resistance properties of different composite strengthening materials with a specific focus on vehicle collisions with bridge elements.

While the majority of existing research concentrates on the effectiveness of carbon fiber-reinforced polymer (CFRP) against impact loads, this study explores the performance of alternative materials. Comparative studies, including an assessment of aramid fiber-reinforced polymer (AFRP) versus CFRP, suggest that AFRP exhibits superior anti-impact mechanical properties, including enhanced energy-absorbing capacity. However, contradictory findings necessitate further investigation. Moreover, Dyneema® fiber-reinforced polymer (DFRP) emerges as a promising alternative with superior anti-impact mechanical properties compared to CFRP. Despite this potential, DFRP has not yet found widespread application in structural contexts. Remarkably, there is a lack of research evaluating the performance of axially loaded strengthened structural members. This research aims to bridge existing gaps in understanding practical applications for strengthening materials against impact loading. The presentation will include quantitative insights into the comparative performance of different materials and discuss the potential implications of the findings for future applications in structural engineering.

Keywords

FRPs materials, impact loads, vehicle collisions, CFRP, AFRP, DFRP.

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Mini Symposium 7:
Bio-based composites for rehabilitation and retrofitting of buildings and structures

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ID:023

Earth-based materials reinforced with flax fibers: an experimental investigation

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Abstract

Climate change and global warming have recently led to a notable shift towards sustainable design practices within the civil engineering community. Earthen construction materials are sustainable due to their local character with reduced transportation needs, low embodied and operational energy, and ease of recyclability. In this context, this work presents an experimental investigation of compressed earth materials enhanced with natural flax fibers. The primary objective is to investigate the influence of fibers on both the mechanical and thermal properties of the material with the ultimate aim of developing a novel type of masonry earth brick. Samples from two soil types (namely the clayey silt Bouisset and the sandy silt Nagen), incorporating distinct percentages of fibers, were statically compacted at a target dry density of 1900 kg/m^3 inside a metallic mould with inner dimension of 40x40x160 mm^3. The samples have then been subjected to 3-point bending and compression tests, as well as thermal conductivity tests. Results indicate that the addition of fibers improves the compressive and bending strengths of the samples, especially for the Nagen earth. Instead, the inclusion of fibers has a negligible effect on thermal conductivity and volumetric heat capacity. Only for the Bouisset earth, the thermal diffusivity improves with increasing fiber content, thus resulting in faster heat transfer.

Keywords

Rammed earth, Flax fibers, Mechanical Properties, Thermal Properties, Sustainable Materias, Strengths, Thermal Conductivity.

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Tensile behavior of Textile Reinforced Mortars made with either Jute or Flax fabrics

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Abstract

Nowadays, several industrial sectors are more and more motivated to develop and adopt sustainable solution. In this context, the civil engineering sector is not an exception: new materials, possibly obtained from renewable and locally available sources, are being worldwide developed and explored. As part of this common effort, special attention is being paid to an emerging class of materials generally referred to as bio-based composite systems. This study investigates the mechanical properties of a Textile-Reinforced Mortar (TRM) system produced with 2 layers of Flax and Jute textile embedded within a hydraulic lime-based mortar. The research also aims at analysing the cracking patterns exhibited by the Natural TRM systems as well as the bond behaviour of the natural textile embedded in the produced mortar. The proposed analyses highlight the relevant mechanical response observed in both cases and allows to have a comprehensive overview of the feasibility of using natural textiles for strengthening existing structures.

Keywords

Textile reinforced mortars, Plant-fibers, Crack formation, Crack pattern.

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Sisal fiber reinforced mortar for 3D printing applications in construction

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Abstract

The use short fibers in mortars can address some issues for 3D printing technology, providing reinforcing and improving material sustainability. Among fibers, Sisal fiber (SF) is a good option for mortar reinforcement due to its natural origin, irregular cross-section and high flexibility. The aim of this study was to assess fresh and hardened properties modified by sisal fibers on 3D printable bio-based mortars for architectural applications. A 3D printable reference mortar with a 0-0.7 sand and a water to cement ratio of 0.45 was designed. The reference mortar was reinforced with 0.5, 1 and 1.5% volumetric fraction (VF) of 13 mm length SF and with 1% VF of a shorter SF of 6.5 mm length. Different rheological experimental tests were used to calculate initial yield stress and structural build-up of fresh mortars. Besides, several physical and mechanical properties were evaluated, comparing cast-in-mold and manually extruded samples. Finally, a printability study was carried out comparing a manual extruder and a 3D automatic printer robot. It was found that SF reduced initial consistency and slightly increased effective thixotropy over time. On the other hand, the length and amount of SF and the casting procedure showed differences in the physico-mechanical properties. Mortars with small SF amounts showed good printability while higher amounts were prone to clog the 3D printing pump system.

Keywords

Bio-based components, Sisal fiber, 3D printing, mortar, rheology

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Bio-based self-modulating thermal and moisture buffer mortars for Architectural applications

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Abstract

New construction materials for architectural applications need to face environmental and energy efficiency. Self-modulating materials are promising solutions to optimize the energy performance of buildings, by compensating hygrothermal changes of the climate. Among bio-based components for self-modulating mortars, Phase-change materials (PCM) and Superabsorbent polymers (SAP) highlight. PCM can storage and release thermal energy, modulating heat flow and reducing heating and cooling energy demand. SAP can help to achieve suitable indoor conditions as they level air humidity and contribute to an evaporative cooling effect. In addition, these polymers can be made from renewable bio-resources.

This paper presents a study reporting materials selection, mortar composition design and experimental tests and procedures used to assess thermal and moisture self-modulating properties of PCM and SAP modified mortars for architectural applications as buffer layers. A pervious cement-lime mixture was designed and different amounts and combinations of two types of SAP and a microencapsulated PCM were evaluated. Mortars' fresh Workability and setting and hardened physical and mechanical properties, microstructure, thermal (heat conductivity and storage properties) and hygric parameters (water and vapor transport and storage) and carbonation process were studied.

The preliminary results of self-modulating mortars showed that SAP and PCM can increase moisture and thermal properties, enhancing buffer capacities of architectural mortars.

Keywords

Bio-based, self-modulating, moisture buffer, thermal buffer, architecture

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Jute Fiber Composite Mortars: Sustainable Solutions for Thermo-Mechanical Retrofitting in Construction

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Abstract

Notably Man-made fibers are predominantly utilized in the construction and building sector for retrofitting or reinforcing purposes. However, these fibers are costly, non-biodegradable, non-recyclable, and contribute significantly to a higher carbon footprint, unlike natural fibers. Jute fiber, being a bio-based natural alternative, ranks as the second most produced natural fiber and is recognized for its commendable thermal and mechanical properties. This paper explores the dual applicability of jute fiber composite mortar for thermo-mechanical upgrading and retrofitting. The research commenced at the fiber and thread level, involving the assessment of the physical characteristics and mechanical behaviors of raw jute fibers. Subsequently, this data was utilized to create jute fiber composite mortars, incorporating two distinct types. These composite mortars were formulated using three different jute fiber lengths (30 mm, 10 mm, and 5 mm) and four varying fiber percentages (2.0%, 1.5%, 1.0%, and 0.5%) in relation to the dry mortar masses. In total, 24 combinations of composite mortar samples were prepared. These samples underwent flexural and compression tests, as well as thermal conductivity assessments, enabling the evaluation of their mechanical properties and thermal behaviors.

Keywords

Jute fiber composite mortar, Natural fiber composite mortar, Thermo-mechanical retrofitting, Integrated retrofitting.

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ID:142

Shear strengthening of existing concrete beams using Fiber Reinforced Concrete

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Abstract

The improvement of repairing and/or strengthening techniques of existing reinforced concrete structures is a subject of interest in the field of Civil Engineering regarding that a great percentage of civil works involves interventions on existing structures. This research is in the frame of an experimental ongoing program aimed at studying strengthening techniques of concrete structural elements both at ambient temperature and after the exposure to high temperatures. This paper is particularly focused on the shear strengthening of existing reinforced concrete beams using a well-known technique as concrete jacketing but employing a high-performance concrete type. The results of an experimental campaign related with reinforced concrete beams strengthening with jackets elaborated with Self-Compacting Fiber Reinforced High Strength Concrete (SCFRHSC) are addressed. Different jacket widths, concrete jacket types and surface preparations are considered. The experimental program includes Three-Point Bending (TPB) tests on jacketed Reinforced Concrete beams and also other mechanical tests on laboratory scale samples: uniaxial compression and splitting tensile tests on cylindrical samples and TPB on notched prismatic specimens. A comparison between traditional jacketing with reinforced concrete and jacketing using SCFRHSC without steel reinforcing bars is presented. The results show that the considered high-performance concrete is a suitable material for strengthening existing beams with thinner concrete jackets than those necessary using standard concrete and therefore, resulting in a composite element with better sustainability properties.

Keywords

Interventions on existing concrete structures, Structural strengthening, Concrete jacketing, Fiber Reinforced Concrete, TPB tests on jacketed Reinforced Concrete beams.

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Bamboo bio-concretes: a literature review of 8 years of laboratory researches at NUMATS/UFRJ

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Abstract

During the last ten years, the Teaching and Research Center for Low Environmental Impact Materials and Technologies in Sustainable Construction (NUMATS) of the Federal University of Rio de Janeiro (Brazil) has been working on developing several solutions for green construction. The different research groups promoted solutions such as, the use of vegetable fibers/textiles as reinforcement of cementitious composites, the production of bio-based ashes for partial cement replacement, the use of recycling aggregates from construction and demolition, the development of earth-based mortar and the development of vegetable plant based concrete. More specifically, the research group bio-based concretes produced low carbon bio-concretes using plant based aggregates such as wood shavings, rice husk and bamboo particles. This paper aims at presenting the main experimental results of the bamboo bio-concretes development and characterization from 2016 to 2024. In addition to that, the life cycle assessment conducted on some bamboo bio-concretes was also presented. From the different topics studied in this review, the use of bamboo bio-concretes is an interesting solution for carbon sequestration and eco-friendly building construction.

Keywords

Bamboo, bio-based building materials, bio-concrete, sustainable construction

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Experiments on concrete test beams with recycled aggregates and natural

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Abstract

To develop more sustainable concrete mixes, circular and bio-based constituents for the concrete mix are sought. As traditional concrete contains 70% aggregate by volume, using recycled aggregates is an attractive solution within the circular economy. To address concrete brittles, bio-based renewable fibers, such as abaca and coconut, can replace the traditional steel or polypropylene fibers. This study evaluates recycled aggregate concrete with natural fibers, comparing it to traditional polypropylene fibers in terms of mechanical properties. Concrete compressive strength, flexural strength, and dynamic modulus of reference and novel mixes were determined. The results of these experiments show that the compressive strength of the mixes with recycled aggregates is 65% of the control, and that the toughness of the beams with abaca is 48% of those with polypropylene fibers, and of the beams with coconut fiber are 29% of those with polypropylene fibers. The dynamic modulus of the discs with recycled aggregates is 30% of the control, whereas the modulus of the discs with abaca is 15% and those with coconut is 20% of the control. These first results show that concrete mixes using recycled aggregates and abaca fibers are a promising solution. These preliminary results will be used for further research geared towards the development of bio-based materials for tomorrow.

Keywords

Aggregate characterization; bio-based materials, compressive strength, dynamic modulus, flexural performance, post-peak performance, toughness.

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Mini Symposium 8: Advances in the investigation of the bond mechanism of externally bonded composites and FRP bars

Organizers:

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ID:109

Bond behaviour of FRCM-masonry joints after high temperature exposure

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Abstract

This paper presents experimental and analytical investigations about the bond behaviour between different types of FRCM systems (basalt, steel and Polypara-phenylene-benzo-bisthiazole (PBO) FRCM) and masonry substrates. Single lap direct shear tests (DS) were performed on single layer FRCM-clay brick masonry joints after a preheating process at temperatures ranging from 100 ºC to 500 ºC (measured at the interface FRCM/substrate). As expected, the variation with temperature of the bond properties (strength, stiffness and slip at the peak stress) is strongly dependent on the type of strengthening system considered. The results obtained showed that the FRCM systems comprising basalt and PBO fibres presented a greater sensitivity to temperature than those reinforced with steel. For instance, after being exposed to 500 ºC, the specimens strengthened with PBO and Basalt-FRCM presented significant bond strength reductions (more than 50% of ambient temperature values), whereas those reinforced with steel-FRCM exhibited bond strength retentions of ~ 70%. Finally, the suitability of empirical models to predict the variation with temperature of the FRCM bond properties was assessed. The results obtained, evidenced that the predictions of the empirical models are relatively in good agreement with the test results, proving their suitability for design purposes.

Keywords

FRCM composites, Bond properties, PBO, Carbon, Steel, Elevated temperature, Direct shear tests.

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Bond and tensile behavior of Textile Reinforced Mortars with traditional and alternative matrices

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Abstract

Reinforced and prestressed concrete structures frequently need to be repaired and strengthened during their service life due to corrosion deterioration and other pathologies. Composite materials, such as textile reinforced mortar (TRM), have emerged as a promising solution for restoring or improving the load bearing capacity of structural concrete. Previous studies have demonstrated that the effectiveness of this strengthening techniques relies to a large extent on the bond between the textile and the matrix as well as on the bonded length to the substrate. The research presented in this paper aims to evaluate the efficiency of bond characteristics as well as the mechanical properties of various TRM systems. Carbon and basalt fibers were investigated along with conventional cement mortar and an alternative eco-friendly mortar. To examine the bonding behavior of each system, a single lap shear configuration aided with digital image correlation measurement was used. Tensile testing was carried out using a clevis grip configuration. To reduce the impact of the tabs length and prevent slippage between the textile and matrix, some modifications to the test set-up were made. The tension and bond properties obtained from the tests are analyzed and compared, and recommendations are presented regarding the bond and tensile test setups.

Keywords

Textile reinforced mortar, bond behavior, single lap test, mechanical properties

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ID:133

Experimental slip determination of upper GFRP-reinforcement in double span beam tests

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Abstract

The ductility and rotation capacity of steel rebar-reinforced concrete structures is one of the main advantages of this material combination. However new material combinations are arriving due to environmental issues. This can be caused by aggressive environmental conditions with an impact on the durability but on the other hand also by the demand for a reduction of greenhouse gasses. By simply replacing the steel with GFRP (Glass Fibre Reinforced Polymers) rebars a number of problems can be tackled, due to its high corrosion resistance and more environmentally friendly production techniques. However, a number of challenges should be answered in a scientifically sound way, and the redistribution capacity is one of the most important ones. Indeed, in a number of design rules of the actual codes, there is an implicit (to neglect thermal, settlements, shrink and creep effects) and explicit (for redistribution purposes) consideration of ductility, which is in general, delivered by the elastoplastic behaviour of the steel reinforcement. Facing the stress-strain relation of GFRP-rebars this desired behaviour is unfortunately lacking as the material react purely linear elastic until failure. Nevertheless, the system behaviour is not only expressed by the behaviour of concrete and the GFRP-rebar but also by the bound between the GFRP-rebar and the concrete matrix. It is already proven that here some slip can appear and this can facilitate a more ductile behaviour providing the desired ductility and rotation capacity. An experimental test set-up was built at KU Leuven Campus De Nayer consisting of two identical double span (2×1.3 m) beams (0.24×0.30 m²) and with two different configurations of upper reinforcement (so 4 beams in total). The slip of the upper and bottom reinforcement was measured together with the applied loads and observed deformations. In that way the redistribution capacity could be determined, showing the system's ductility despite the two main brittle components. Results will be used in the framework of the revision activities of the new upcoming fib40 publication handling FRP-reinforced concrete structures.

Keywords

Redistribution, GFRP-reinforcement, Ductility, Rotation capacity, Experimental tests

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Investigations on the ageing of GFRP rebar-concrete bond under sustained load

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Abstract

FRP rebars present interesting advantages over steel rebars for internal concrete reinforcement. Yet, as the technique is rather recent, durability investigations are still needed to better understand degradation mechanisms and to provide designers with *optimised* safety coefficients. Although several authors have been interested in the evolution of FRP rebars during ageing, few authors have so far investigated the evolution of FRP-concrete interfacial bond.

This study aims to present some investigations carried out on GFRP to concrete interface ageing. The bond behaviour between GFRP rebar and concrete was experimentally studied focusing on the combined action of thermally accelerated ageing in alkaline environment and sustained loading.

First, the samples geometry and the initial FRP to concrete interface characterizations will be introduced. Then, the ageing protocol will be presented. During this protocol, some of the samples have been submitted to constant load during ageing. To do so, specific experimental devices were developed and will therefore be precisely described. The obtained results will then be pointed out and discussed.

Keywords

FRP to concrete interface, Ageing, Constant load, Test protocol

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Numerical modeling of the bond behaviour of PBO FRCM-concrete joints at elevated temperature

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Abstract

Fabric reinforced cementitious matrix (FRCM) composite systems are being increasingly used to strengthen degraded reinforced concrete (RC) structures because of their high strength-to-weight ratio, ease of handling, reduced costs, and non-combustibility properties. Although these advantageous characteristics, the information available about their mechanical response when subjected to elevated temperatures is still very limited. This paper presents a numerical study that aimed at providing a better understanding about the bond behaviour between a polypara-phenylene-benzo-bisthiazole (PBO) FRCM system and concrete at elevated temperatures. To this end, three-dimensional finite-element (FE) models were developed to simulate experimental steady-state single lap direct shear (DS) tests previously performed by the authors on PBO FRCM-to-concrete joints tested at the following temperature: 20, 85, 150 and 230 ºC. The main objectives were two-fold: (i) to evaluate the influence of the temperature on the bond response between the PBO-FRCM and the concrete substrate; and to (ii) provide a better understanding about the evolution of the stress fields in the composite and at the interface with concrete. The results obtained showed that the FE models were able to reproduce with relatively good accuracy the experimental data, specifically regarding the bond stress vs. slip curves, and the reduction in bond stress and bond stiffness with temperature. The numerical models developed in this work can be used as supporting tools to the fire design of FRCM strengthened RC structures, allowing the optimisation of the strengthening system geometry.

Keywords

FRCM composites, Bond properties, Numerical modeling, Elevated temperature, Direct shear tests; PBO

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Experimental and theoretical study on flexural behaviour of hybrid bonded CFRP RC beams

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Abstract

Fibre Reinforced Polymer (FRP) materials are widely used to strengthen Reinforced Concrete (RC) structures due to their high mechanical and durability properties with respect to traditional techniques. However, intermediate crack debonding (ICD) failure limits the effectiveness of strengthening RC beams in flexure with externally bonded (EB) FRP laminates. Anchorage of the FRP can mitigate this premature debonding and enhance the efficiency of FRP strengthening.
Hybrid Bonding (HB) FRP emerged as a viable method for delaying/preventing debonding of EB FRP RC beams. HB combines adhesive bonding from EB with mechanical fastening through metallic plates, increasing resistance to debonding. Previous research explored the bonding capacity of the HB connection using FRP sheets in single-shear tests, but only a few simplified approaches for predicting the bending capacity of strengthened beams have been developed.
In this paper, the feasibility of HB systems to delay ICD debonding of RC flexural elements strengthened with CFRP pre-cured laminates is assessed through experimental and theoretical studies. For this purpose, three RC beams strengthened with CFRP are tested, one using EB technique and two using HB, with different anchor spacings. Results include load-deflection response, flexural capacity and failure mode, compared to literature provisions. Results show that the HB technique consistently improves the flexural performance of the beam in all considered cases.

Keywords

Reinforced concrete, externally bonded reinforcement, hybrid bonded reinforcement, anchors, debonding

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Shear stress transfer at the SRG-concrete interface: influence of the number of layers

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Abstract

Externally bonded Steel Reinforced Grout (SRG) is a promising technique for strengthening existing reinforced concrete (RC) and masonry structures. SRG is a composite material made of high-strength steel fibers embedded in a geopolymeric (inorganic) matrix. The failure of structural members strengthened with SRG composites typically occurs due to debonding when an interfacial crack develops at the fiber-matrix interface. This paper presents the results of single-lap shear tests performed to study the debonding phenomenon of SRG composites bonded to a concrete substrate. Specimens with one or two textile layers were tested to assess the dependency of the debonding mechanism and bond capacity on this parameter. The results of the single-lap-shear tests are used to derive a local cohesive material law (CML) which describes the interaction between the concrete substrate and SRG strips. Finally, the CML obtained is compared with CMLs proposed in the technical literature and introduced in a FE model to simulate the experimental load vs. global slip responses.

Keywords

SRG-Concrete joint, Debonding, Cohesive Materials Law, Numerical model

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Interfacial behaviour of CFRP-to-concrete joints with mechanical fastening

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Abstract

Mechanical fasteners are employed to anchor externally bonded reinforcement (EBR) carbon fibre reinforced polymer (CFRP) laminates to concrete structures by generating compressive stresses on the joint. However, the optimum parameters for the anchoring system that minimize the potential for premature debonding failure while maximize the ultimate load still need to be investigated.

In this work, single shear tests are performed to an EBR strengthening system under externally induced normal stresses using a large metal plate affixed with bolts. A numerical procedure based on the finite difference method and a metaheuristic optimization algorithm has been utilized to obtain the bond-slip law that describes the constitutive behaviour of the anchoring system. Moreover, the separated contributions of the cohesion of the adhesive joint and the friction induced by the external normal stresses are analysed separately. Decohesion and friction behaviours are experimentally characterized and the separated cohesive and friction stress-slip laws are obtained. The experimental behaviour of the full anchoring system is compared against that obtained by combination of the separated cohesive and friction contributions. The method represents progress in examining how different anchoring parameters, including the size (width and thickness) of the anchor plate and the torque applied to the bolts, influence the performance of the anchoring system in an efficient and systematic manner.

Keywords

Reinforced concrete, externally bonded reinforcement, mechanical fastening, bond behavior, CFRP strengthening.

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Machine learning for analyzing concrete cover separation in externally bonded FRP RC beams

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Abstract

Strengthening of concrete structures with Fibre Reinforced Polymer (FRP) is one the most cost effective, efficient, and sustainable rehabilitation techniques. Externally bonded FRP can enhance the load carrying capacity of the existing structures. However, the ultimate tensile strength of the FRP cannot commonly be achieved due to the premature debonding of the FRP or delamination of the concrete cover. In this last case, high stress concentration at the free end of FRP laminate, in combination with the shear stresses at that section, cause the initiation of shear crack that, if not controlled by the shear reinforcement, propagates in concrete just below internal reinforcement. Various analytical and empirical models have been developed to predict this phenomenon but none of them could give a failure load with reasonable accuracy. One of the reasons for the poor accuracy of these models is the crack spacing involved in the phenomenon, which is difficult to quantify with accuracy. Machine Learning (ML) has been proved very effective in predicting behaviors that cannot be quantified using mechanics. This paper explores different feature selection methods to rank the dependent variables based on their importance on the prediction. The best set of variables is then used to predict the failure load using various ML algorithms. The algorithms are then ranked best on their R-squared score. Recursive Feature Elimination (RFE) is chosen as the best feature selection method and K-Nearest Neighbors (KNN) is chosen as the best ML algorithm for the prediction of failure load with an R-squared score of 0.97.

Keywords

Fibre Reinforced Polymer, Failure Mode, Concrete cover separation, Parametric analysis, Machine Learning

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Influence of glass-fiber epoxy coating on bond and tensile behavior of FRCM systems

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Abstract

Fibre Reinforced Cementitious Matrix composite systems display outstanding capabilities for the reinforcement of existing structures. Their modeling is challenging for the numerous damage scenarios, and test methods for mechanical characterization are still debated. An open issue concerns the improvement of textile-matrix bonding due to the low capacity of matrix particles to imbue all textile filaments. In this study, the influence of epoxy coating of glass-fiber textile on bond and tensile behavior of FRCM system are addressed through an experimental and an analytical investigation. Six different FRCM systems were considered by combining the same glass-fiber textile, dry or epoxy-coated, and three different matrices based on cement, lime, and gypsum binders. The experimental campaign comprises Direct Tensile Tests (DTT) textile pull-out (TPT), and Direct Shear Tests (DST). The results highlighted the beneficial effect of the epoxy resin coating that modifies the fiber-matrix adhesion mechanism. An analytical investigation was then conducted to verify the results obtained experimentally. In particular, the analysis concerned the analytical modeling of tensile behavior of FRCM systems through integration of the nonlinear differential problem and assuming an exponential Cohesive Material Law (CML). Assumptions also include linear elastic behavior of the textile with limited tensile strength, elastic-brittle matrix, and random distribution of mortar strength. Cracks can open in any position free from the grips, and the global load-slip diagram is built as a composition of partial global-load slip diagrams of the crack-separated sub-portions. For the calibration of the CLMs of the six FRCM systems, the experimental results of TPT and DST were used.

Keywords

FRCM, TRM, glass-fiber textile, epoxy coating, exponential CML, elastic-brittle mortar

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ID:340

Complementary Use of CFRP U-Wraps as Supplemental Shear Reinforcement and Anchorage in Reinforced Concrete Beams Strengthened with Flexural Externally Bonded CFRP Sheets

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Abstract

This research explores complementary shear strengthening and anchorage effects of CFRP U-wraps on reinforced concrete beams strengthened in flexure using externally bonded CFRP sheets. Through experimental testing of large-scale beams, the research aims to enhance the understanding of how the dual strengthening and anchorage functions of U-wraps interact and contribute to the overall structural performance of flexurally-strengthened beams. The specimens were divided into three groups based on existing steel shear reinforcement ratio; each was strengthened with different configurations of U-wraps and fiber anchors. This paper reports the results of twelve beams tested to date. The test matrix is designed in a way that evaluates the conditions under which shear-controlled beams transition to flexure-controlled failure modes, allowing for the evaluation of the dual contribution (i.e., shear strengthening and anchorage) of U-wraps. Based on the initial results, U-wraps increased shear strength by 76% in shear-deficient beams while, at the same time, increasing the strain utilization of flexural CFRP sheets in flexure-controlled specimens by up to 118% over the ACI 440.2-prescribed debonding strain. The addition of U-wraps also shifted the failure mode of flexural CFRP sheet from intermediate crack (IC) debonding to U-wrap rupture or U-wrap debonding.

Keywords

Shear failure; anchorage; experimental study; external CFRP reinforcement.

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Bond behavior between metallic and non-metallic bars and sustainable concrete: preliminary study

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Abstract

The study presented in the paper deals with the development and the characterization of an innovative shrinkage-compensating high-workability alkali activated slag-based eco-concrete for the repair and strengthening of reinforced concrete (RC) members. For instance, reference to the section enlargement of beams and columns (concrete jacketing) can be made.
Furthermore, after the characterization of developed mixture at both fresh and hardened state, the paper focuses on the bond behaviour between the new concrete and metallic and non-metallic (fiber reinforced polymer – FRP) rebars with the aim to: *a)* identify the main parameters influencing the stress transfer mechanisms at the interface and, *b)* to evaluate the bond-slip constitutive relationship by varying the steel bar diameter, the bonded length and, in the case of FRP bars, the surface treatment. To this purpose, a wide experimental program was organized which includes more than 100 pull-out tests performed on several types of rebars bonded to the new concrete and the preliminary results are presented here. The bond performance is also examined through a comparison with the results from similar tests performed by employing ordinary Portland cement concrete blocks characterized by equivalent compressive strength and workability class of the innovative green concrete.

Keywords

Bond, Cement-free concrete, FRP bars, Pull-out tests, Sustainability

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Analytical study of FRP debonding in a real-scale concrete strengthened beam

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Abstract

The exploitation of the mechanical properties of fiber-reinforced polymers (FRP) externally bonded to concrete members is limited by the occurrence of debonding. Single- and double-lap shear tests were performed to study the debonding process. However, the results of these tests fail to describe the debonding process when multiple substrate cracks occur, as in the case of reinforced concrete beams strengthened in flexure. In this paper, an analytical model is proposed to describe the load response of a concrete beam strengthened in flexure with an externally bonded FRP composite. The profiles of the FRP-concrete slip, FRP axial force, and cross-section rotation, the evolution of the cracking process, and the failure mode may be obtained by this model. The results of the model shed light on the debonding process in FRP-strengthened beams and may be used to investigate the relationship between the bond capacity of FRP-concrete interfaces with a single crack and that observed in real-scale strengthened beams.

Keywords

FRP, debonding, analytical model, concrete beam

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ID:478

An investigation on the bond behavior of basalt fiber reinforced polymer (BFRP) rebars embedded in conventional concrete

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Abstract

This research investigates the bond behavior of basalt fiber-reinforced polymer (BFRP) bars in conventional concrete, focusing on its relation to mild steel bar bond behavior and the magnitude of variation. Using BFRP as a replacement for traditional mild steel reinforcement has gained attention due to its inherent corrosion resistance and high tensile strength properties. In environments where steel corrosion poses a significant threat to structural integrity, BFRP offers a promising alternative for improving the long-term durability and longevity of reinforced concrete members and structures. The study aims to evaluate the bond strength between BFRP rebars embedded in conventional concrete through experimental testing and analysis. Various factors affecting bond performance, including surface preparation, embedment length, and concrete mix design, are considered. The findings of this research contribute to a better understanding of the feasibility and effectiveness of utilizing BFRP reinforcement in concrete structures, particularly in mitigating the challenges associated with steel corrosion. Ultimately, the results aim to inform engineering practices and promote the adoption of sustainable and corrosion-resistant materials for infrastructure development, thereby addressing a critical need in the field. The results are also compared to the current ACI 440 bond equation and database of other BFRP data collected by the authors.

Keywords

Basalt fiber-reinforced polymer (BFRP), Bond testing, Rebar pull-out capacity, ACI 440 code comparison.

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Bond behavior of magnesium potassium phosphate cement (MKPC) coating for steel reinforcement in conventional concrete and related repair materials

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Abstract

This research investigates the bond behavior of magnesium potassium phosphate cement (MKPC) coated mild steel bars in conventional concrete, focusing on its relation to both epoxy coated and mild steel bar bond behavior related to the magnitude of variation. In traditional concrete a passive layer protects the mild reinforcing steel from corrosion until the concrete becomes carbonated and then mild steel will start to corrode with access to moisture and oxygen. To combat this, it is common to incorporate an additional layer of protection to the reinforcing steel, such as an epoxy coating or galvanizing the steel with zinc. A novel coating that has been developed to resist corrosion is magnesium potassium phosphate cement (MKPC). MKPC demonstrates potential as an anti-corrosion coating for new construction and repair due to its rapid hardening, early strength, and good bond qualities based upon prior work conducted at Missouri S&T [Zhang et al. (2023)] The aim of this paper is to investigate those bond qualities. Ultimately, the results aim to inform engineering practices and improve the understanding on the bond behavior of MKPC anti-corrosion coated mild steel bars, how it compares to mild steel and epoxy coated steel in conventional concrete for infrastructure development, thereby addressing a critical need in the field.

Keywords

Anti-corrosion steel coating materials, magnesium potassium phosphate cement (MKPC), epoxy coated steel, bond behavior of mild steel, rebar pull-out capacity.

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Mini Symposium 9:
Advances in Fiber Optical Sensing Solutions for Infrastructure, Geotechnics and Earth Sciences

Organizers:

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ID:015

Diagnostics of post-tensioned bridge girders using distributed fiber optic sensors

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Abstract

In contemporary bridge construction, post-tensioned concrete technology stands as one of the prevailing methods. Over the past several decades, it has been extensively employed in the construction of medium-span bridges worldwide. As time has elapsed, many of these structures now demand diagnostic assessments due to their deteriorating technical conditions. A promising approach for diagnosing such bridges involves the utilization of distributed fiber optic sensing (DFOS) technology. DFOS enables continuous measurements to be acquired along the entire length of the structure, which is particularly crucial for these types of bridges. Its advantages have already been demonstrated in civil engineering applications, notably in contexts related to concrete structures. Furthermore, thanks to their construction distributed fibre optic sensors can be used for both new and existing structures. The paper presents research conducted on post-tensioned beams with curvilinear multiwire strands. Optical sensors were installed before and after concreting. The main aims were to measure strains, stresses, cracks, and displacements. It also compared results from monolithic sensors embedded in concrete (for new structures) to sensors in pre-made near-surface grooves (for existing structures) and to detect defects within one beam using sensors inside the cable duct, analysing strain data. DFOS measurements were compared with conventional spot techniques, aachieving very good compliance. This investigation establishes that a well-structured DFOS-based system, encompassing suitable measurement methodologies, optical sensor configurations, installation techniques, and post-processing algorithms, emerges as a relevant tool for the comprehensive diagnostics of post-tensioned concrete bridges.

Keywords

Distributed fiber optic sensing, post-tensioned bridge, structural health monitoring

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ID:100

Distributed Optical Fiber-Based Monitoring of Passive Anchors for Soil Stabilization

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Abstract

Geotechnical structures, such as piles and anchors, play a critical role in providing stability and support in a wide range of civil engineering applications. Ensuring the integrity and safety of these structures and reliably understanding their structural behavior are of paramount importance. This paper explores the application of distributed fiber optic sensors (DFOS) as a cutting-edge technology for monitoring the performance and health of passive composite anchors for soil stabilization. These anchors comprise a conventional carbon steel self-drilling bar with one or more embedded harmonic steel tendons, cemented within the central cavity of the bar. The system is finalized by an external plate for securing the bar and a protective cover for safeguarding the tendon head. Within this context, DFOS technology offers a non-invasive and cost-effective solution for real-time monitoring of various parameters, such as strain and temperature, along the entire length of the fiber optic cable. By integrating fiber optic cables with anchors, continuous, high-resolution monitoring data can be collected, enabling a more comprehensive understanding of the long-term behavior of this specific geotechnical structure. Among the noteworthy advantages of DFOS technology is its capacity to furnish spatially distributed information, facilitating the detection of localized stress concentrations and deformation patterns. The paper will cover some practical considerations, such as installation techniques, sensor calibration, data analysis, and integration with existing monitoring systems. The limitations and challenges associated with DFOS technology in geotechnical applications will be also discussed, including the need for specialized expertise in interpreting the data, the potential for signal attenuation in long cables and the particular care that these sensors require during cable installation and management.

Keywords

Distributed Fiber Optic (DFOS), Passive Anchor, Smart monitoring, Soil stabilization, Spatially distributed information

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ID:104

Distributed Fiber Optic Smart Geosynthetics for Geotechnical Applications in Transportation

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Abstract

We present the latest works in the design, development, validation and industrial application of geosynthetic materials equipped with integrated fiber-optic sensing cables for distributed strain and temperature measurements. The integration of fiber-optic sensors into geotextiles and geogrids – as they are commonly used in geotechnical construction for soil stability improvement, erosion protection, draining, filtering and other tasks – provides a feasible integration method for the sensors into the structure under monitoring. The one-dimensional characteristic of a longitudinal fiber-optic strain sensor is thereby transformed into a two-dimensional shape sensing plane, providing distributed, uninterrupted information on deformation, sinkholes, slope movements, settlements and many more geotechnical indications on structural failure.

Keywords

Distributed fiber-optic sensing, smart geosynthetics, geotechnical monitoring, fiber-optic strain measurement

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ID:122

Optical fiber sensing for monitoring chloride ion concentration and pH in concrete structures

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Abstract

This paper presents the development and assessment of an optical fiber sensing platform for monitoring chloride concentration and pH range in structural health monitoring of concrete structures. Excessive chloride ions possess the ability to corrode the steels of reinforced concrete structures that affect the safety and health of concrete structures. In addition, the pH of concrete structures decreases to a value close to 9.5 that externally exhibits carbonation and durability problems. Thus, we have constructed an optical fiber sensing platform for monitoring chloride ion concentrations and pH range in concrete structures. The schematic of sensing platform setup for chloride ion concentrations and pH measurement which is composed of a fiber optical sensor with CUV-UV cuvette holder, a broadband light source (200-1100 nm), an UV-NIR spectrometer, and a personal computer for data acquisition. We conducted the sensing platform for monitoring the chloride ion concentrations and pH range of two types of water cement ratios for both fresh concrete and harden concrete materials (w/c = 0.35 and 0.65). We have demonstrated the feasibility of the optical fiber sensing platform for monitoring chloride ion concentrations and pH range in structural health monitoring of concrete structures without modifying optical fiber sensors or coating chemical compounds. The optical fiber sensing platform has shown the capacity for monitoring of chloride ion concentrations in the range from 150 ppm to 12500 ppm as well as pH range from 9 to 13.

Keywords

Optical fiber sensor, Concrete, Chloride ion concentrations, pH range, Structural health monitoring

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A ground-breaking distributed fiber-optic pressure sensor for geohydraulic applications

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Abstract

Distributed fiber optic (DFO) technology has provided significant insight into various engineering problems by enabling high spatial resolution and accurate temperature and strain measurements. Recently, a novel distributed fiber-optic pressure sensor (DPS) has been developed at the University of Applied Sciences of Eastern Switzerland (OST), which may change the paradigm of monitoring geohydraulic structure monitoring. The key innovation of the sensor is its ability to measure hydrostatic pressure with high spatial resolution and over long distances.
This study provides a comprehensive characterization of this novel sensor for two different applications. In the first application the DPS was tested in a water column to measure the vertical hydraulic pressure. In the second application the sensor is tested in a laboratory-scale dike (1:4). The DPS was embedded directly into the earth structures, providing real-time monitoring of pore pressure variations during saturation. For both applications, the DPS measurements were compared with conventional pressure and piezometer sensors, demonstrating good agreement.
The results of these two applications illustrate the potential of the DPS to revolutionize geohydraulic monitoring and improve our understanding of dynamic processes in water-related structures. The implementation of this technology promises to improve the safety, predictability, and performance of critical infrastructure.

Keywords

DFO sensor, distributed measurements, distributed pressure sensor, monitoring system

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ID:144

Dynamic strain monitoring of a steel tower in shaking tests by distributed fiber optic sensing

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Abstract

For smart structural health monitoring in civil engineering, distributed fiber optic sensing has attracted attention as a powerful tool. In recent years, dynamic sensing technologies such as distributed vibration sensing DAS and OFDR, which can realize real-time monitoring, have made remarkable progress. In particular, OFDR, which performs strain sensing with high spatial resolution, can quantitatively visualize the strain distribution of civil engineering structures with an accuracy comparable to that of conventional strain gauges. This method has been limited in its application to SHM due to its short measurement range, but with the development of long-distance measurement technology, it is becoming a practical sensing technology in civil engineering. In this paper, we propose a new high-resolution dynamic monitoring based on PNC-OFDR that evaluates the dynamic strain distribution of a steel tower in shaking tests. It was confirmed that the strain distribution evaluated together with the strain gauge is a highly reliable result that indicates the strain behavior of the entire structure.

Keywords

Steel tower structures, Dynamic strain, Distributed fiber sensing, PNC-OFDR

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Monitoring of fracture processes in reinforced concrete beams with DFOS: feasibility study

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Abstract

In this paper, we present the application of distributed fibre optic sensors (DFOS) for the detection of bending and shear cracks in reinforced concrete beam specimens loaded in three- and four-point bending in lab conditions. The main goal of this study is to prove the feasibility for future application of DFOS for monitoring of existing concrete structures such as bridges or tunnels. Each specimen was equipped with more optical fibres: most of them were attached in the channels at the outer surface of the specimens and some of them were fixed to the reinforcement inside the specimens. Specimen geometries, arrangement of reinforcement bars and loading schemes of the specimens were determined by nonlinear FEM before the tests, so that either dominant bending or dominant shear cracks appear during the loading. Some specimens were loaded step-by-step and some of them by continuous loading and the results were compared afterwards. The results showed, that DFOS can ensure exact crack monitoring in all loading stages of the reinforced concrete specimens, which is a good basis for future applications for monitoring of structures in the engineering practice.

Keywords

DFOS, reinforced concrete structures, monitoring, bending, shear

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DFOS-based inclinometers: challenges and potentialities in monitoring slow landslides

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Abstract

In recent decades slope engineering greatly benefited from the use of optical fiber sensing In recent decades slope engineering greatly benefited from the use of optical fiber sensing technology which offers a few advantages over conventional landslide monitoring approaches, including distributed measurements over long distances, and remote, real-time monitoring. Among various uses of Distributed Fiber Optical Sensors (DFOS) in the geotechnical field, the one related to the setting up of a smart inclinometer for monitoring slow landslides interacting with structures and infrastructures seems to be the most interesting and advanced for its usefulness in the detection of soil deformation and, in perspective, for implementation in Landslides Early Warning Systems. However, there is still the need to face technical and interpretation issues. In this regard, starting from the data collected for two years in a complex gravitative landslide, where both conventional and DFOS-based inclinometers were installed, the constraints and potentiality of the new inclinometer are highlighted. The tested Smart Inclinometer, adopting a sensing technique based on the Brillouin scattering phenomena, revealed its capability to capture the main features of the landslide phenomena while revealing that, when the entity of both vertical and horizontal strain components is comparable, an accurate analysis is required to compensate for the thermal effect and the vertical soil deformation along the depth. After compensation, the data monitored with the new DFOS-Inclinometer is consistent with the results of the traditional inclinometer, demonstrating its reliability and feasibility. Moreover, the novel device, returning both the strain components, can serve also as a series of multi-extensometers of very high spatial resolution in turn demonstrating the advantage of DFOS-based inclinometers over conventional displacement measuring techniques.

Keywords

Smart Inclinometer, DFOS, Complex landslides, Innovative geotechnical monitoring

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Unveiling the persistence of Rayleigh signature in Challenging Distributed Measurements

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Abstract

Among the different fiber optic techniques, Rayleigh-based distributed fiber optic sensing offers unmatched spatial resolution and accuracy. With its sub-centimeter spatial resolution and microstrain accuracy over tens of meters, this technology is ideal for precise monitoring in geotechnical and civil engineering applications.
This technique utilizes Rayleigh scattering to track environmental effects on light propagation, and the measurement is done through the spectral correlation analysis of the so-called Rayleigh signature, which is specific to each fiber and can be accounted for to track variation in the light propagation due to the environment. A first measurement of the Rayleigh signature is kept at the beginning of the monitoring campaign, and it is then used as a reference to determine the change in the strain or temperature field affecting the fiber. Still, so far, for installation where fibers were employed in harsh conditions, it has been shown only in quite favorable conditions, i.e., by using the same specific device and setup and over a short time
In this work, we investigate the enduring presence of Rayleigh's signature in optical sensing fibers installed in challenging environments. Our study demonstrates that measurements obtained from optical fibers used in adverse conditions, such as within a foundation pile and soil anchors in an unstable slope, continue to exhibit a Rayleigh signature correlating to the reference one, even after a period exceeding five years since the initial measurements were taken, and using different interrogators and setups.

Keywords

Harsh environments, Long-term measurements, DFOS, Rayleigh

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ID:213

Distributed fiber-optic temperature monitoring in boreholes of a seasonal geothermal energy storage

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Abstract

Monitoring the in-situ temperature is key for the characterization of a seasonal geothermal energy storage. Distributed fiber-optic temperature sensing (DTS) systems provide temporally and spatially continuous measurement data in near real-time that captures borehole temperature dynamics.

In the presented project, three boreholes of a seasonal geothermal energy storage with a vertical depth of down to 500 meters were instrumented with distributed fiber-optic sensors. For this purpose, a standard armored sensor cable was modified to allow for combined DTS, distributed acoustic sensing (DAS) and distributed strain sensing (DSS) at temperatures up to 120 °C. The cable was installed in a loop configuration to allow for temperature calibration using a temperature matching approach. A “Mini-Bend” solution was selected to cope with the limited space and the single valve available for the cable feedthrough at the wellhead of the pressurized system. Using specially designed spacers, the sensor was installed and hold in place successfully in the 2” annulus of the 16” and 10¾” casings.

Within the planned paper, the focus shall lie on the DSS system and the data acquired during cementation. This continuous temperature data showcases the ability of DTS systems to detect small temperature changes in high detail. During the whole backfill process, the current level of the grout was captured by rising temperature values in the range of a few degrees Celsius.

As next steps of this project, spatiotemporally temperature data will be recorded during stimulation treatments of the seasonal geothermal energy storage. The authors believe that the experience made with this fiber-optic monitoring system can be a good demonstration of the capabilities of fiber-optic sensing in deep borehole environments.

Keywords

Distributed Fiber-Optic Monitoring, Deep Boreholes, Renewable Energy Infrastructure, Practical Example

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ID:253

Levee monitoring: DFOS Applications for understanding Levee Seepage

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Abstract

Enhancing the understanding of the geotechnical features of existing levees through on-site examination and monitoring is essential to estimate their security and that of the adjacent environment. However, these tasks are intricate given the extensive length of the levees and the significant variability of soil texture within the structure and base of the levee, particularly in mountainous areas and locations where ancient channels exist in the underlying soil. Traditional methods for levee monitoring involve visual inspections, borehole drilling, in-situ tests, and the deployment of devices like piezometers and tensiometers. Regrettably, these methods often grapple with limitations imposed by their constrained spatial resolution. However, these methods are often constrained by their limited spatial resolution. This investigation ventures into the frontier of embankment monitoring, specifically probing the utilization of distributed fiber optical sensors (DFOS) for gauging temperature variations. The case study here presented elucidates the monitoring of an embankment along the Adige River in province of Bolzano (Italy). Notably, this embankment encountered a significant flood event in Autumn 2023. The gathered data serves a dual purpose: advancing our comprehension of the hydraulic dynamics and safety parameters governing this segment of levees, while also appraising the reliability and potential of these cutting-edge monitoring methodologies.

Keywords

Geotechnical Investigation; Levee Monitoring; DFOS Applications; Seepage; Real scale test.

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ID:325

Performance of low-cost fibre optic cables as leak detection sensors for water pipelines in unsaturated soil

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Abstract

Around a world a large volume of potable water is lost every year from leaks in water distributions networks. Such leaks may go undetected for a long time. When water leaks are suspected to occur from a distribution network, it is usually necessary to appoint a specialist contractor to locate the leak(s), who may use a range of technologies for this purpose. However, all these technologies require the contractor to search for the leak.

A passive means of leak detection can be achieved by burying a suitable fibre optic cable with a new water pipe upon installation. A water leak can affect the optical fibre in three ways. Firstly, the leaking of usually colder water into the ground results in a temperature change around the leak location. Secondly, water leaks affect the pore pressure in the ground, changing the effective stress, causing a degree of ground deformation which, in turn, deforms a fibre optic cable passing through the ground. A third effect may occur when the leak causes soil erosion, resulting in significant straining of the cable. Fibre optic leak detection on pipelines is especially effective in unsaturated soils, which typically experience significant pore water suctions in its in situ state. Changing these suctions due to a leak, results in significant deformation.

Brillouin frequency shift in optical fibres is sensitive to changes in both temperature and mechanical strain, allowing fibres to act as efficient leak detection sensors. Purpose-made fibre optical cable may be expensive, but telecommunication grade cables generally have a low cost and area readily available around the world. This paper will demonstrate the performance of a range of fibre optic cables, including communication grade fibre optic cables, to act as leak detection sensors in the ground.

Keywords

Leak detection, Fibre optic cable, Brillouin frequency shift

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Implementation of an enhanced fiber optic sensing network for structural integrity monitoring at the Brenner Base Tunnel

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Abstract

The reliable assessment of structural characteristics along tunnel linings is essential to understand ongoing deformation processes during construction and operation. Conventional monitoring techniques may involve limitations, either in the spatial or the temporal resolution and do not deliver the overall deformation behavior along the entire lining. Distributed fiber optic sensing (DFOS) has significantly evolved in recent years to monitor large-scale civil infrastructure, with scientific sensing designs being realized within various research projects. The technology can be advantageous for in-situ tunnel monitoring since the distributed strain and temperature sensing feature delivers a complete picture of the linings' structural deformation behavior without blind spots.
This paper introduces the design and realization of an enhanced distributed fiber optic sensing network inside concrete tunnel lining segments, currently being implemented at the Brenner Base Tunnel. The construction is one of the largest civil infrastructure projects world-wide and will be the longest underground railway connection globally with a total length of about 64 km once completed. The designed DFOS system, consisting of more than 35 km sensing cable overall, provides distributed strain and temperature information along numerous tunnel cross-sections, spread over more than 30 km tunnel drive and two different construction lots. After installation, measurements are being continuously performed, autonomously evaluated, and transferred to the ACI online visualization dashboard in real time. The monitoring data is further analyzed by geotechnical engineers on-site to decide whether the actual excavation and supporting method meets the requirements or modifications are needed. The paper outcomes demonstrate that fiber optic sensors have considerably developed from research into innovative practice and are capable to extend or even to replace conventional, geotechnical sensors.

Keywords

Distributed fiber optic sensing, tunnel lining segments, structural integrity monitoring, deformation behavior

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DFOS monitoring system of the longest Polish footbridge made of FRP composites

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Abstract

The high durability, low weight and excellent mechanical properties of fiber reinforced polymers are the main reasons for the increasing popularity of composites as a material for pedestrian and bicycle bridges. This was also the case with the widening of an existing Carpathian Bridge in the center of Rzeszów (Poland). This footbridge consists of five single-supported spans of 4.17 + 23.55 + 23.67 + 23.67 + 23.47 m, with the total length of the superstructure 104.95 m, and it is believed to be the longest Polish footbridge made of FRP composites. The spans of the footbridge were created in the form of sandwich panels and each was manufactured in a single infusion process by the VARTM (vacuum-assisted resin transfer molding) method.

Since the footbridge spans are placed on existing pillars and in the immediate vicinity of the city stadium, a decision was made to equip the structure with a durable and reliable SHM monitoring system. The system based on distributed fibre optic sensors (DFOS) was selected and implemented for monitoring. One of the spans was equipped with sensors in the form of SM9 / 125 single-mode fibres in an acrylic coating. The optical fibres of the DFOS system were placed inside the composite structure between the fabrics of the selected laminates, before the infusion process. Thanks to that, the sensors are completely integrated into the material and not exposed to damage or the influence of the environment.

The paper presents the initial system assumptions, the location of the sensors, and the results obtained during the proof load tests performed on the structure before it was open to the public.

Keywords

Optical sensors, DFOS, footbridge, monitoring, glass fibers

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ID:421

Distributed Fibre Optic Sensors (DFOS) in Measurements of Rail Strain and Displacements

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Abstract

Distributed fibre optic sensing (DFOS) is increasingly being used in civil engineering and geotechnical applications. The key feature, and advantage over conventional point-based measurement methods, is the ability to measure the selected physical quantities continuously over the length of the structure, from a few centimetres to several hundred kilometres. The benefits of this technique are therefore particularly evident when monitoring linear structures such as roads, embankments, bridges, tunnels, pipelines or railway lines. The result of the measurement is not a single value at a selected point on the structure at a given time, but a profile of strains, temperatures, displacements or vibrations, both as a function of time and as a function of length. This allows direct detection of local events such as cracks, stress concentrations, buckling, sinkholes, leaks and others.

The article describes the pioneering application of the DFOS system using composite and monolithic sensors bonded directly to the rail. The monitoring system was launched in early 2023 in central Poland. In total, more than 2,000 metres of sensors have been installed on selected sections, making it the largest system of its kind in the world. Measurements are made on a long-term basis as part of cyclical sessions (with changing external conditions), as well as on a short-term basis (dynamic) during train passes. As the same DFOS sensors can be connected to different optical interrogators (using Rayleigh, Brillouin or Raman scattering), different system outputs can be generated (e.g. strains, displacements or vibrations). The paper summarises the lessons learned during the design, installation, measurements and data post-processing within this system.

Keywords

Distributed Fibre Optic Sensing, Rail, Strains, Displacements, Measurements

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Mini Symposium 10:
Economic assessment and Life-Cycle performance in building and civil engineering works

Organizers:

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ID:033

Evaluation of technical, environmental and social performances and impacts of bio-based products for a more sustainable building sector

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Abstract

In Italy, several circular start-ups and university spin-offs active in the green building sector are producing innovative materials and building products (e.g., vegetal materials for insulation, bio-bricks, thermo-acoustic insulating panels, screeds and substrates, non-toxic natural paints) and construction systems by using local agricultural products (e.g., hemp) and by-products (e.g. wheat straw, rice straw, rice husk, food waste) proposing them as alternatives to the conventional building materials, products and systems. These products are in some cases also certified with an Environmental Product Declaration or by the ANAB-ICEA certification specific for green building products and offer many advantages (technological, aesthetics, environmental, social, healthy and comfort living). This study evaluates, by means of qualitative interviews and the life cycle assessment method, the technical, environmental and social performances of green building products and materials produced by a sample of Italian circular start-ups. The performances of these products are compared with those of conventional building products in order to grasp their positive and negative environmental and social impacts.

Keywords

Bio-based products, circular start-ups, green building, life cycle assessment, building products and systems

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ID:056

Cultural heritage and seismic disasters: Assessment methods and damage types

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Abstract

The identification of adequate evaluation methodologies of earthquake damages to Cultural Heritage is a highly topical subject, considering the frequency and intensity of the seismic phenomenon, in recent times, in Italy. The subject is related to the broader theme of the attribution of a "monetized" economic value to the cultural assets, widely investigated in the appraisal and evaluation Italian disciplines. In this perspective, the article aims to verify the principles and evaluation methods for the monetary assessment of the damages caused by earthquake disasters. Starting from the definition of cultural assets as in the Italian legislative system, the article highlights the characteristics and several values of cultural assets; it then defines, in a systematic way, the damage and its differentiation, subsequently discussing the main damage evaluation approaches.

Keywords

Cultural heritage, Seismic disasters, Valuation methods.

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A Cost-Based programming model for reduction of seismic vulnerability in Neapolitan metropolitan area

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Abstract

Vulnerability is a big issue for small inland urban centres, which are exposed to the risk of depopulation, as well as for metropolitan areas particularly exposed to seismic disasters. In the context of recent concentration of a high number of earthquakes in Neapolitan metropolitan area, seismic vulnerability's valuation become a crucial issue. In some Italian regions, municipalities are implementing seismic vulnerability reduction policies based on the Emergency Limit Condition, which has become a basic point of reference for ordinary land planning.
This study proposes an approach to seismic vulnerability reduction consisting of three main stages: 1) knowledge — the typological, constructive, and technological descriptions of the buildings, specifically concerning their degree of vulnerability; 2) interpretation — analysis with the aim of outlining a range of hypotheses with respect to damage in case of a prospective earthquake; 3) planning — the identification of the courses of action intended to meaningfully reduce the vulnerability of buildings. This last stage includes a cost modelling tool aimed at defining the trade-off between the extension and the intensity of the vulnerability reduction works, given the budget.

Keywords

Seismic vulnerability, Neapolitan metropolitan area, Cost-based programming model.

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ID:074

Cost sustainability management through Risk Assessment: an Italian Case Study

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Abstract

Life Cycle Thinking Approaches, which are often used as decision support tools in large-scale projects, allow for the assessment of construction projects throughout all their life stages, from design to decommissioning. This study, by focusing on the design and construction phases of large-scale projects, aims to assess their economic sustainability through a cost management and evaluation tool. The project's construction costs, estimated during the design phase, undergo numerous changes and fluctuations throughout the project development and its inevitable variations. Having early knowledge of future costs with as much precision as possible in the initial decision-making stages significantly determines the success of a project and reduces delays, i.e. time overrun, in subsequent phases. This paper aims to test a cost overrun mitigation tool by estimating the probability of occurrence and the impact of stochastic events associated with various project risks. The proposed cost management tool will be applied to a large-scale Italian project, that was recently completed, to assess the escalation in estimated costs and their potential ex-ante mitigation from the design to the construction phase.

Keywords

Construction Costs, Large-Scale Projects, Risk Assessment, Cost Overrun, Life-Cycle Thinking

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The irreversible depreciation of a building and the threshold for demolition

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Abstract

The Italian territory is characterized by the presence of numerous degraded buildings, which consequently experience significant depreciation due to their age and obsolescence, resulting in a reduction in their attributed value. This phenomenon is observed in various areas of the country, both in large cities and small urban centers. Degraded properties pose a problem from an aesthetic perspective, as they contribute to a negative visual impact on the surrounding environment and can affect the quality of life of local communities. They also present socioeconomic challenges considering the costs required to restore degraded buildings to normal conditions of use. Indeed, there is a clear relationship between depreciation and the cost of intervention or maintenance of building structures. Well-maintained properties naturally experience much lower depreciation rates compared to properties that receive insufficient maintenance. The causes of property degradation can be multiple, with one of the main factors being the lack of maintenance, primarily due to inadequate property management by the owners, as well as the economic unsustainability of necessary redevelopment interventions. Degraded properties also pose an increasingly relevant challenge for local authorities and the entities responsible for land management. Similar to vehicles, aircraft, or ships, where salvage value can be a crucial element in the decision to replace them, it is essential to understand in the case of building structures when depreciation can be considered curable or incurable. The evaluation of whether depreciation is curable or not depends not only on the comparison between the cost of renovation/redevelopment and the cost of demolition and reconstruction but also on the urban rent, which is a determining factor. It is within this perspective that the authors attempt to define a threshold for demolition beyond which depreciation becomes irreversible.

Keywords

Depreciation, Obsolescence, Demolition threshold

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Building upcycling vs. building reconstruction investment decisions: a life cycle methodology simulation

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Abstract

Decision-making processes concerning investments in building upcycling vs. building reconstruction of the existing stock involve environmental aspects besides the economic-financial ones. For example, material and energy preservation, waste management, Embodied Energy (EE), and Embodied Carbon (EC) management in construction processes are crucial aspects that concern different scales: from the material/component/system scale up to the whole building, the urban scale, and civil engineering works and infrastructures. As illustrated in previous work, foreshadowing the perspective of a more restrictive regulatory framework on EE (e.g. prohibiting the displacement of materials with residual energy potential), EE and EC should be considered as hidden components of building real estate market value. Thus, these should be internalized into investment decision-making processes under an economic-environmental and circular perspective. Thus, this contribution aims to present the first simulation of a methodology previously theorized, filling a gap in the scientific literature on the topic. The methodology focuses on a joint economic-environmental valuation of alternative investment projects by internalizing environmental components into the conventional financial cash-flow analysis. Assuming the circular economy principles, Life Cycle Costing (LCC) indicators and Life Cycle Assessment (LCA) indicators are modeled in the Discounted Cash-flow Analysis (DCFA). The simulation is conducted with reference to a case study by implementing a data set based on literature and according to the following workflow: alternative scenarios definition, precisely a retrofit intervention (upcycling), and a demolition and reconstruction one; EE and EC monetization for both scenarios; internalization of the environmental components into the DCFA; implementation of the Global Cost and the new 'Global Benefit' into the Net Present Value (NPV) calculation; and results interpretation focusing on the residual end-of-life value. The results of this simulation are yet to be explored in a concrete application. Still, they represent the first step of an approach potentially capable of including environmental and social externalities even in the private real estate investment decisions, considering the holistic sustainability of the whole project life cycle.

Keywords

Discounted Cash-flow Analysis, Embodied Energy, Embodied Carbon, Global Cost, Global Benefit

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Sustainable structural retrofitting for historic buildings: a long term decision analysis approach

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Abstract

The structural design of retrofitting solutions for historic buildings, as known, is a complex decision-making process and can be effectively integrated by various approaches able to take into consideration the entire life cycle of the project. In this context, the present contribution intends to develop and assess a decision tool for the design of refurbishment interventions for historic buildings, adopting a Life Cycle Thinking approach and integrating the long-term multi-attribute decision analysis. Starting from the multi-parameter analysis of a case study building, two timber- and one concrete-based structural interventions of floors strengthening are analyzed using an ELECTRE-based method, and considering a combination of economic, architectural, environmental, and structural effects related to present, medium, and long-term performance aspects. The proposed study, as shown, demonstrates that the rehabilitation of existing buildings, and particularly the structural design requirements for retrofit, can be effectively supported and optimized to integrate technological performances with economic, architectural and environmental considerations by taking into account the long-term effects of different solutions.

Keywords

Intertemporal Multi-Criteria Decision Analysis (MCDA); life cycle thinking; historic buliding; structural retrofit; cross-laminated timber; concrete

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Life Cycle Costing for Structural Analysis and Design

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Abstract

Life cycle engineering has emerged as an effective approach to improve the design of products and materials, to reduce maintenance, and to contain costs from the construction phase to the end of life. In other terms, construction decision-makers need to consider the sustainability of a material or building element at any stage of its life cycle, discussing the resulting economic and environmental repercussions right from the design phase. Therefore, it is increasingly necessary to use both technical and economic evaluation approaches that can select investment initiatives in order to contain the overall costs that the investor has to bear until the decommissioning of the works.
This paper will first provide an overview of existing research on the Life Cycle-based approach for the economic evaluation of structural materials and civil infrastructure systems. Then, a Life Cycle Cost (LCC)-based model is defined to evaluate and compare the structural and economic performance of civil engineering constructions. The logical-operational steps on which the model is based concern: structural analysis of buildings; estimation of life-cycle costs; assessment of Global Cost; comparison of the performance of design alternatives.
Applications to case studies allow the model to be validated.

Keywords

Structural Analysis and Design, Sustainability, Economic model, Life Cycle Costing.

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Life Cycle Sustainability Assessment of Industrial Flooring

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Abstract

The use of fibre-reinforced concrete for industrial floors makes it possible to significantly contain the phenomenon of crack formation and propagation, which is the cause of degradation in traditional concrete floors. In fact, the structural fibres in place of the welded mesh form a homogeneous and omnidirectional reinforcement throughout the screed layer and, as a result, increase the load-bearing capacity of the structure due to a high residual tensile strength after cracking.

This study intends to compare the environmental and economic performance of two alternative technological solutions for large span industrial floors: on the one hand, the traditional concrete solution; on the other hand, the innovative one made of fibre-reinforced concrete, specifically, the tensofloor with post-tensioned reinforcement. To this end, an assessment approach based on the integrated use of Life Cycle Costing (LCC) and Life Cycle Assessment (LCA) is defined. This approach makes it possible to assess: (i) the financial sustainability of technological solutions considering the costs related to the entire life cycle, from implementation to disposal; (ii) the environmental impacts generated by project alternatives in a cradle-to-grave perspective.

The application of the model to case studies demonstrates that the higher durability of the innovative post-tensioned system compared to the traditional one makes it possible to: reduce maintenance costs, global costs and interruption of production activities; increase functional performance; ensure lower environmental impacts, as the use of smaller quantities of rehabilitation materials results in a significant reduction of CO_2 emissions.

Keywords

Industrial flooring, Technological solutions, Evaluation model, Life Cycle Costing, Life Cycle Assessment.

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Recovery of historic real estate: Life Cycle Costing and economic feasibility

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Abstract

The tools currently available for the parametric estimate of the costs for the recovery of properties, in the phase of verifying the economic feasibility of the interventions, do not present satisfactory levels of accuracy.

In addition to the intrinsic forecasting difficulties at a planning level characterized by a limited level of knowledge of the artefact to be recovered, and a certain terminological confusion especially in professional contexts, there is also limited attention to this issue in the scientific field, which is further reduced since the dynamism of the construction sector and its weight within the Italian economic system decreased.

With rare exceptions, estimating studies have often looked more deeply into the topic of cost estimation in the executive project phase, in which the level of information is objectively much more detailed.

These conditions are even more accentuated in the case of historic building heritage, due to the well-known difficulties in generalizing situations.

A further, significant limitation of the parametric tools currently available is the absence of connections with the Life Cycle Cost.

This contribution constitutes the start of a research path which, starting from the recognition of existing literature, aims to develop a tool for rapidly estimating costs in the feasibility project phase of restoration interventions on historic real estate.

Keywords

Parametric estimation, Life Cycle Cost, Economic feasibility, Historic real estate

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Building upcycling vs. building reconstruction investment decisions: a focus on the discount rate

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Abstract

The necessity to internalize environmental components in the investment decision processes concerning building up cycling vs. building reconstruction of the existing heritage has been explored in a correlated contribution to this Symposium. In that work, a methodological proposal is presented to support the environmental-economic valuation of project options using the discounted cash flow analysis (DCFA). A DCFA simulation shows Embodied Energy (EE) and Embodied Carbon (EC) as hidden cost components influencing the NPVs calculation. According to a life cycle perspective, global cost and global benefit were assumed to formalize the NPV indicator. To complete the reasoning in this contribution, the IRR calculation is simulated through the same operative modality, focusing on the issue of selecting an appropriate discount rate. Assuming the presence of environmental and financial input variables in the DCF model, a “time preference” discount rate seems inappropriate. Thus, centrality is posed on the Environmental Hurdle Rate technique, based on the use of different rates - “green,” “yellow,” and “red” -given the degree of the negative contribution to the environment produced by an input variable and related cost. This is explored as an alternative to the financial (or market) discount rate when in the presence of environmental components. The results are obtained by simulations on two alternative scenarios: the retrofit of an existing residential building and the demolition and reconstruction. These confirm the importance of the discount rate capability to influence the DCF model output by modeling environmental cost components and their expectations given the potential technological development over time. The results can even change the final preferability ranking by the environmental hurdle rate instead of financial rates. With this second part, the methodology can support environmentally responsible investment decisions in the construction sector at different scales.

Keywords

Discounted Cash-flow Analysis, Environmental Costs, Discounting, Environmental Hurdle Rate.

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Mini Symposium 11:
Seismic-Fire combined assessment and optimization of interventions for buildings and infrastructures

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ID:127

Post-earthquake fire performance of a steel frame

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Abstract

The effects of earthquakes and fires are typically analyzed separately in engineering design. However, historical events highlight that fires following earthquake (FFE) can cause significantly more damage than an earthquake alone. The 1906 San Francisco earthquake exemplifies this, with fires destroying 80% of the city. Other major FFE events include Tokyo (1923), Kobe (1995), and Tohoku (2011) earthquakes. Earthquakes can damage infrastructure, leading to potential ignitions and structural fire performance deterioration.

This paper focuses on the post-earthquake fire performance of an eight-story five-bay steel frame using a probabilistic FFE framework aimed at developing FFE fragility functions and considering uncertainties in the ground motions, fire behaviour, and material properties. Damage to structural and non-structural components is considered. In this respect, the probabilistic FFE framework generates the fire scenarios based on seismic response. The seismic response is assessed through nonlinear time-history analyses. Then, post-earthquake fire ignitions in specific compartments are assessed based on the structural damage, determined by inter-storey drift ratio (IDR) and peak floor acceleration (PFA). Compartmentation and opening characteristics as well as the potential for fire spread are considered based on seismic damage in windows, doors, and partition walls following seismic fragility functions found in the literature. Finally, thermomechanical analyses are performed, and failure criteria based on displacement and displacement rate are applied to the beams and columns.

The results of the probabilistic analyses were used to produce fragility functions to evaluate the probability of exceeding a limit state conditioned on an intensity measure in the context of FFE.

Keywords

Steel frames, Fire following earthquake, fragility functions, probabilistic framework.

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Fire-induced Structural Failure Analysis of an Industrial Warehouse Roof Truss System

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Abstract

Fires are complex and hazardous phenomena governed by the laws of thermodynamics and fluid dynamics. Contrary to common belief, they are not rare occurrences, with approximately 130 buildings in Italy alone experiencing fires daily. The structural behavior under such extreme conditions is difficult to model as material mechanical properties are significantly influenced by temperatures, and thermal deformations alter structural responses.
This paper focuses on investigating the fire scenario and the failure of a reinforced concrete industrial warehouse through dynamic fire simulations and nonlinear thermo-mechanical analyses. The warehouse roof is constructed with truss arches featuring three-hinged joints with a steel chain. The arches are regularly spaced at 5.0 m intervals, with a clear span of 19.40 m and a measured height of 8.40 m at the peak and 5.0 m at the supports. The study is composed of two fundamental phases: simulation of fire conditions using Fire Dynamics Simulator (FDS) and investigation of the structural elements collapse through finite element structural analysis.
This analysis reveals that, due to thermal stresses, the chain in the roof truss can no longer perform its intended role within the arch, resulting in displacement at the ends and subsequent column collapse. Being a structure designed over 50 years ago, it lacks structural redundancy or robustness.

Keywords

Fire, CFD, Structural Failure, Finite Elements, Warehouse

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Acoustic Emission monitoring of OPC mortars at elevated temperatures in fracture tests

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Abstract

The action of moderate and high temperatures produces the degradation of main physical and mechanical properties of Ordinary Portland Cement (OPC) composites. As an example, from an application point of view and at a structural level, the case of concrete radiation shielding containers in nuclear facilities can be mentioned, which can be severely affected by thermal cracking. In this work, the results of Acoustic Emission (AE) monitoring of mortar prismatic specimens under three-point bending tests are analyzed. Samples are firstly submitted to a heating treatment in an electrical furnace, with maximum target temperatures ranging between 100 to 600 ºC. After the heating process, the prisms were cooled down and finally, mechanically tested, i.e. under residual conditions. The AE signals were continuously recorded during each bending test and its characteristics at different loading stages were explored, scrutinizing variations in AE parameters, such as event rise time, amplitude and energy. Additionally, average frequency (AF) and RA value parameters were employed to assess fracture modes aiming to highlight situations where tension or shear/mixed modes predominate through the test. A comparative analysis of the AE characteristics during loading path and progressive damage is presented.

Keywords

OPC mortar, Acoustic Emission, Temperature, three-point bending tests

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Fire behavior of Automated Rack Supported Warehouses

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Abstract

The fire behavior of the automated rack-supported warehouse (ARSW) is a topic of great interest both for the scientific community and for the manufacturers of industrial racks, however, their behavior in case of fire of is still poorly known. ARSWs are a particular type of steel racks that combine the structural efficiency of steel construction with automated machines for handling stored products. The paper focuses on investigating the fire scenario and the collapse mechanism of a typical ARSW by considering a fire model that allows vertical and horizontal propagation, starting from a localized fire, evaluated, and validated against experimental results. The study is composed of two fundamental phases: fire simulation by using both the Computational Fluid Dynamics model and zone model and investigation of the structural elements collapse through finite element structural analysis. These analyses were performed with two different software SAFIR and ABAQUS, to compare their capability to obtain the collapse mechanism of these structures.

Keywords

Automated rack-supported wherehouses (ARSW); cold-formed steel members (CFS); fire resistance.

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Fragility curves derivation under fire actions for different types of bridges

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Abstract

The Italian infrastructure network of bridges is complex, due to the orography of the territory and the presence of different hazard sources. Furthermore, during their service life these infrastructures can be subjected also to extreme actions such as the fire. This paper presents a procedure for the fragility curves derivation under fire actions for different types of bridges. The novelty the work is to apply the fragility assessment also to the fire resistance aspects, especially related to the infrastructures. Two case study pilot R.C. and composite steel-R.C. bridges are modelled by implementing different fire scenarios. By using the linear regression, the structural response parameters of the bridges are correlated to the intensity of the fire. Finally, lognormal fragility curves are obtained, measuring the capacity of the case study bridges. The study also shows which of the fire scenario parameters can be better correlated to the structural response of the bridges.

Keywords

Fire safety, structural fire resistance, infrastructures, fragility curves

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FEM modelling of fire behaviour of RC beam strengthened by externally prestressing

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Abstract

Since the 1950s, external posttensioning or unbonded prestressing was found to be a powerful tool for retrofitting existing bridges. Unbonded prestressing is a system in which the post-tensioning tendons are located outside the concrete cross section and the prestressing forces are transmitted to the girder through the end anchorages, deviators, or saddles. At the same time, statistical studies showed that the number of bridges damaged due to fire is significantly more than the number of bridges damaged due to earthquakes. This paper focuses on the fire performance of a reinforced concrete bridge beam that is strengthened by external prestressing. The investigation is performed by a mixed experimental and FEM modelling approach. Initially, test is performed on a model of a bridge beam. In order to induce cracking and damage, the beam is subjected to two symmetrically placed concentrated loads until the reinforcement undergoes large plastic deformation. Then a strengthening intervention by external prestressing is performed, and the effectiveness of the strengthening interventions is checked by a new experimental test. Both the initial test inducing cracking of the beam and yield of the reinforcement, the strengthening intervention by external prestressing, and the new loading on the strengthened beam are modelled by FEM. Once the FEM model is validated, a first evaluation of ULS capacity of the beam is performed. Then, fire performance is investigated by different fire scenarios defined by the geometric characteristics (dimensions, burning rate), the emissive power (thermal radiation, fuel type), and radiation transfer. Then the cross sectional temperatures resulting from fire, the loss of external prestressing efficiency, and the global fire resistance were studied by the FEM.

Keywords

External prestressing, fire performance, FEM, experimental test, bridge beam

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Mini Symposium 12:
Innovative solutions for fatigue strengthening of existing structures

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Stress recovery behavior of a promising NiTiNb-SMA plate for bonded prestressed strengthening

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Abstract

Shape memory alloys (SMAs) are functional metallic materials, possessing a remarkable characteristic known as the shape memory effect (SME), by which a considerable recovery stress can be generated through a simple thermal activation. A NiTiNb-SMA plate is employed in this study, aimed at prestressed strengthening of steel members. To better understand the mechanism of the generation of recovery stress, tests were conducted on the NiTiNb-SMA plates (thickness 1.5 mm) to characterize the basic mechanical properties and stress recovery behavior. Tests include: tensile failure test, prestraining, activation, and re-activation. The influence of key parameters such as prestrain level and activation temperature on the stress recovery behavior of this NiTiNb-SMA plate was evaluated. Re-activation was discussed. Test results revealed that the largest recovery stress reached 448.6 MPa when the material was prestrained by 8% and activated at 180℃. This suggests that the activation temperature of 180℃ could be optimal for this material to generate sufficient recovery stress. Such a strategy should be promising for bonded prestressed strengthening, as this activation temperature would have limited influence on the adhesive bond of the bonded prestressed strengthening system.

Keywords

Shape memory alloy (SMA), Nickel-Titanium-Niobium (NiTiNb), stress recovery behavior, prestressed bonded strengthening stystem, fatigue strengthening.

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Application of toughened epoxy adhesives in CFRP-repair of fatigue damaged steel elements

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Abstract

Repair of fatigue damaged steel elements by using carbon fiber reinforced polymer (CFRP) represents a valid alternative to standard methods. CFRP materials have a sufficiently high Young's modulus to bridges the local stresses across the crack lips, to reduce the crack opening displacement and to promote then crack closure. CFRP strips can be also pre-stressed to achieve and additional reduction of the fatigue crack propagation rate, leading eventually to crack arrest.
The main issue related to the use of externally bonded (EB) CFRP strips for the repair of cracked steel elements is the debonding of the reinforcement from the substrate. This usually occurs in the adhesive layer (cohesive debonding) since a correct preparation of the steel substrate and a proper selection of the composite in combination with the adhesive type avoid interface debonding. Besides, the high stress concentration at the crack tip results in CFRP debonding which has a detrimental effect on the effectiveness of the repair. When standard epoxy adhesives are used, the experimental evidence has shown that a semi-elliptical shape with an aspect ratio equal to 1/5 can be assumed for the debonded area.
In this paper, toughened epoxy adhesives are used to bond CFRP lamina in the cracked area of fatigue damaged steel elements. These are then subjected to fatigue loading to investigate both the fatigue crack propagation in the steel substrate and the shape of the debonding area by using digital image correlation (DIC) techniques. Results are compared to previous experimental results with standard epoxy resins to study the effectiveness of toughened adhesives.

Keywords

CFRP, fatigue damaged steel elements, toughened epoxy adhesive, debonding, fatigue crack propagation

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Reinforcement method for fatigue-damaged steel structures using toughened epoxy resin adhesives

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Abstract

The average condition of railway and road bridges has significantly deteriorated in the recent decades due to an unexpectedly strong increase in heavy traffic. This has led to an increased fatigue loading causing fatigue cracks which consequently decrease the service lives of bridges. An innovative reinforcement method has been developed comprising a carbon fibre-reinforced polymer (CFRP) patch being attached to the fatigue-damaged steel structure by means of toughened epoxy resin adhesives to bridge the fatigue cracks. The use of adhesives facilitates the creation of impermeable joints and enable efficient dissimilar materials bonding, providing a high capacity for energy and vibration absorption. Adhesive bonding enables a more uniform and continuous distribution of the stresses through the joined area. The primary goal of this reinforcement method is to increase the remaining service life of fatigue-damaged steel structures.

The fatigue life of pre-damaged steel specimens, that are reinforced by the adhesively bonded CFRP patches, is examined in fatigue tests. Three different variants of CFRP patches are tested to examine a broader spectrum of reinforcement materials. To assess the influence of the reinforcement, the crack propagation in reinforced and untreated steel specimens is compared. Furthermore, special attention is given to the characterization of the adhesives used and the assessment of their corrosion resistance. The experimental investigations on pre-damaged steel specimens and the adhesives demonstrate the significant potential of the novel reinforcement method.

Keywords

Structural adhesive, Epoxy, Toughness, Fatigue, CFRP

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ID:177

Identifiability of the parameters contained in cyclic cohesive zone model for CFRP-to-steel bonded joints

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Abstract

The application of externally bonded CFRP-to-steel reinforcements has shown its effectiveness in reducing crack growth and extending fatigue life when subjected to repeated cyclic loadings. Failure usually occurs due to cohesive debonding within the adhesive interface and therefore the interfacial behavior is crucial in guaranteeing the effectiveness of the bonded system. The adoption of cyclic cohesive zone models represents a valid solution for the description of interfaces between two materials, providing a useful tool for the numerical characterization of such bonded applications. An important issue generally associated to the use of a cohesive model refers to the correct calibration of its parameters, necessary to guarantee a reliable use of the model. Therefore, this work proposes a robust inverse analysis procedure for the identifiability of the model parameters governing the fatigue induced behavior in an exponential cyclic cohesive zone model. Single-lap direct shear tests are considered for the numerical investigation of the interfacial bond behavior. Maximum and minimum displacements at the loaded end of the specimen and axial strain measurements in a discrete number of points of the specimen surface are considered as input data of the inverse algorithm. Virtual data perturbed by different levels of noise are used and a meta-model reduction technique is properly calibrated in order to reduce the computational cost of the forward operator and to solve the inverse problem in a stochastic context through a Monte Carlo like procedure.

Keywords

Inverse analysis, CFRP-to-steel bonded joints, Fatigue, Cohesive zone model

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The influence of CFRP fatigue behavior on CFRP-to-steel bonded joint systems

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Abstract

Externally bonded CFRP-to-steel systems exhibit fatigue degradation when subjected to repeated cyclic loadings, consequently leading to cohesive debonding failure at the interface. Therefore, the cyclic degradation of the composite patch needs to be properly investigated.
This work presents the preliminary results of an experimental and numerical investigation on the composite fatigue damage behavior and its possible influence on a CFRP-to-steel bonded joint system response. The fatigue degradation of single-lap direct shear tests is numerically modelled considering separately the damage occurring at the bonded interface and in the composite. The interfacial behavior of the adhesively bonded joint is described by adopting a cohesive zone model approach, while the composite damage behavior is described by adopting a fatigue residual stiffness model based on macroscopic stiffness degradation. Experimental results of tensile fatigue tests on rectangular CFRP laminate coupons and of single-lap direct shear tests are presented and used for the model parameters calibration. Then, the numerical response obtained considering the composite material either elastic or accounting for the fatigue damage is compared. The interfacial behavior maintains its role as leading failure phenomena of the bonded system. The introduction of the composite damage behavior shows up in a reduction of the number of cycles at failure rather than on the global slip at failure of the joint, being not or slightly affected, and this influence results to be larger with many loading cycles at failure.

Keywords

Fatigue, CFRP-to-steel bonded joints, Finite element model, Direct shear test

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ID:387

Failure damage analysis of UHWMPE/PET foam sandwich structures under high-velocity impact

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Abstract

The present work deals with the high-velocity impact (HVI) behaviour of composite sandwich structures based on experimental and numerical method. The composite sandwich structure consists of two ultra-high molecular weight polyethylene (UHWMPE) laminates and a PET (polyethylene terephthalate) foam core. A series of HVI tests were conducted on the UHWMPE/PET foam sandwich structures to investigate the HVI performance and damage mechanisms. Micro-computerized tomography (µCT) characterization method was used to detect the internal damage patterns in the sandwich structures. A finite element model (FEM) was developed which Puck's failure criteria simulates intra-layer failure, cohesive law simulates inter-layer failure and the crushable foam plasticity model combined with ductile damage criterion simulates the foam failure. After validation of the proposed model by experimental results, the damage mechanism of the sandwich structures under HVI loading was examined, and the effects of impact velocity on the failure patterns and residual velocity were discussed. Several key conclusions from this study are summarised as follows: 1. Circular hole-type damages were only observed on the upper panel, even though the impactor penetrated the composite sandwich structure. On the lower panel, only linear crack-type damage along the fibre direction were generated due to the rebound of the stretched fibres after the impactor penetrated. 2. Generally, the peak impact force and energy absorption values increase with higher impact velocity. However, when the impact velocity is less than the critical value (Critical velocity =200 m/s for the composite sandwich structure in the study), both the impact force load and energy absorption values remain relatively stable and are not significantly influenced by variations in impact velocity. 3.Foam cores in composite sandwich structures generate an upward rebound force during HVI when they are compressed to a certain extent, resulting in the appearance of a third peak in the impact load curve and absorbing more energy. 4.The presence of UHMWPE fibre interspersed in the panel tended to inhibit the spread of damage in the impacted region. Only matrix tension damage showed noticeable propagation during HVI, and matrix tension damage increased with the impact velocity, reaching a plateau when the velocity exceeded 250 m/s.

Keywords

High velocity impact (HVI), Damage mechanism, Composite sandwich structure, Micro-computed tomography (µCT), Ultra-high molecular weight polyethylene (UHMWPE).

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Numerical analysis of SCF of CHS T-joints strengthened with prestressed CFRP

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Abstract

Fatigue failure is one of the main concerns of welded tubular joints owing to inevitable welding defects and severe stress concentration along the intersection. In addition, the complex geometry of the joint makes it inconvenient to reinforce by traditional repair methods. Carbon fiber-reinforced polymer (CFRP) composite has been widely used for structural strengthening due to superior strength-to-weight ratio, good fatigue and corrosion resistance, as well as ease of installation. Although tubular joints strengthened by using non-prestressed CFRP sheets have been investigated in references, application of prestressed CFRP has not been reported. This study proposed a form of prestressed CFRP sheets for the fatigue strengthening of circular hollow section (CHS) T-joints. Three-dimensional finite element models were developed for both CFRP-strengthened and unstrengthened CHS T-joints to calculate the hot spot stress distribution, which was verified using experimental test data and Lloyd's Register (LR) equations. A parametric study was then carried out to explore effects of CFRP strengthening parameters on the SCF reduction coefficient ψ, including the prestressing level (p), CFRP width (w), and CFRP layers (n). It was found that prestressing CFRP changed the stress distribution and values along the weld toe. With the increase of prestress, the position of the maximum stress gradually moved from the saddle point to the crown point. Besides, the strengthening parameters had significant effects on reduction of the hot spot stress along the weld toe.

Keywords

Prestressed CFRP, CFRP strengthening, Circular hollow section T-joints, Finite element analysis, SCF reduction coefficient

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Mini Symposium 13: Natural fibres for eco-compatible solutions in seismic and energy upgrading of masonry structures

Organizers:

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ID:029

Performance of Flax Textile-Reinforced Mortar Systems Subjected to Accelerated Ageing

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Abstract

Natural fibre textiles have recently attracted the interest of both academia and industry as an alternative structural reinforcement in Textile-Reinforced Mortars (TRM), as they can offer the required mechanical performance while minimizing their environmental impact. Although the short-term performance of these novel bio-composites has been documented, their durability, which is fundamental to guarantee their long-term effectiveness, is yet to be investigated.

This paper presents the preliminary results of an experimental programme on the tensile performance of flax-TRM systems subjected to accelerated ageing. Composites consisting of two and three layers of flax textiles embedded in a lime-based mortar were conditioned in water for 2000h (~83 days), at controlled temperatures of 23°C and 40°C. Bare textiles were also conditioned in a lime solution for the same duration and temperature conditions to assess and decouple the deterioration mechanisms at the textile and composite scale. The mechanical behaviour of both unconditioned and aged textiles and composites was characterised through uniaxial tensile tests and their response was monitored using a combination of contact and non-contact methods (2D-DIC). The results are assessed in terms of residual mechanical characteristics of constituents and composites, and the critical deterioration mechanisms are identified and commented upon.

Keywords

Natural fibres, flax, TRM, durability, mechanical characterization

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Innovative Retrofitting Solutions: Integrating Jute Fiber Textile Reinforced Mortar to Enhance Masonry Performance

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Abstract

The construction and building sector consumes a significant amount of energy in its complete lifecycle, therefore it also has a higher carbon footprint. Whereas the majority of the existing masonry buildings are vulnerable to natural or man-made disasters, as these were constructed without following any seismic standard. This paper highlights integrated upgrading or retrofitting of masonry walls with a Natural Fiber (NF) Textile Reinforced Mortar (TRM) system to mitigate both structural and thermal issues. Here for the NFTRM system, various jute fiber products have been used for upgrading or retrofitting purposes. A balanced structural and thermal properties of the masonry have been proposed here. Notably, jute fiber nets (with mesh type “2.5 cm x 2.5 cm”) and diatons have been used for enhancing the masonry wall’s strength, while for the composite mortar preparation, a combination of 30 mm jute fiber length and 1% fiber of jute fiber with respect to the dry mortar mass has been chosen for masonry wall’s thermal upgrading. It has been observed that due to the application of the jute NFTRM system, the load-bearing capacity (+ 198.51 kN) increased and the insulation capacity improved, i.e, thermal transmittance reduced (- 0.64 W/m^{2}K) for the upgraded masonry wall, with respect to the un-strengthened masonry wall.

Keywords

Integrate upgrading, integrated retrofitting, Natural fiber TRM, Jute fiber TRM, Structural and Thermal upgrading/retrofitting.

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A new biocomposite material mixing past and present to look toward the future

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Abstract

In the last decades interest of researchers in the field of vegetal fiber-based biocomposite materials to be used for structural strengthening has grown significantly. This interest is primarily driven by the plant fiber abundance, renewability, cost-effectiveness, historical-compatibility, and eco-friendly features. This work investigates a novel biocomposite material for structural strengthening of masonry structures made of hydraulic lime mortar, enhanced with different kind of additives, and mixed with Spanish broom and hemp fibers coated with graphene. Mechanical properties of these biocomposite materials are addressed experimentally by three-point bending tests and uniaxial compression tests. The results are compared to a reference material, made of classical lime mortar, to investigate the best performances in the fiber-matrix bond. In particular, stress-strain curves are recorded to estimate maximum strength and strain together with a measure of fracture energy.

Keywords

Biocomposite material, mechanical characterization, vegetal fibers, lime mortar, graphene.

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Use of nanocomposite coatings and chemical treatments to improve mechanical performance of bio-composite materials

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Abstract

The building industry demonstrated a growing interest in recently developed biocomposite materials for structural strengthening based on natural fibers as an alternative to synthetic fibers. In the last years, research activities are focused on investigating the mechanical properties of different types of natural fibers, e.g. hemp, sisal, kenaf, Spanish Broom fibers. Despite the numerous advantages associated with the use of these natural resources, their performance is affected by shortcomings in morphology, mechanical behavior, and durability. These factors can compromise the interaction between matrix and fibers, resulting in poor structural performance. Indeed, when natural fibers are embedded in mortar-based matrices, cracks of the mortar can occur at early load stage before the natural fibers begin to fulfill their reinforcing role. This work investigates the use of bio-based coatings and treatments for natural fibers to address these issues, e.g. treatments based on sodium hydroxide and graphene-based coatings.

Keywords

Biocomposite material, coating, vegetal fibers, durability, graphene.

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ID:268

Experimental investigations on lime mortars reinforced with hemp braids

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Abstract

The need of experimenting sustainable components for building products is underlined by the prominent energy and raw material consumptions and carbon dioxide emissions, which see the construction industry as main responsible. Natural fibers, in particular hemp ones, are very worthwhile thanks to their adequate mechanical properties and environmental advantages. The research aims to experiment two types of lime-based plasters reinforced with hemp braids with different diameters, added in the mixture in different percentages, as seismic retrofit systems of existing buildings. In particular, two premixed NHL mortars, namely M5 and M15, and three diameters of hemp braids (0.4 mm, 1 mm and 2.2 mm) in percentages by weight of lime from 0.25% to 3%, are examined. The amount of water absorbed by hemp braids is assessed by performing imbibition test and allows to define the quantity of water to add in the mixture. All the mix designs are tested on a shaking table to evaluate the effect of hemp braids on the workability of the mortar and, finally, compressive and bending tests are performed on the mixtures considered as acceptable doughs after the preliminary test phase. The results of the laboratory tests show that hemp braids produce a decrease in the workability of the plasters that remains acceptable for low percentages of fibers. The braids also allow an increase in the flexural strength and a decrease in compressive strength, which is however not detrimental for application in seismic zones. In both mechanical tests it is evident the sewing and confinement effect of the fibers, that allow a more ductile behavior of the inspected mortar.

Keywords

Sustainable materials, Natural fibers, Hemp braids, Experimental analysis, Physical tests, Mechanical tests.

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Hemp-FRCM for seismic retrofitting of masonry structures

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Abstract

The recent earthquakes in the Mediterranean area provoked serious damages and collapses to the existing buildings, including masonry ones, that represent the highest percentage of current structures. The need of preserving the existing structures to prevent economic and human losses is always accompanied by the compelling necessity of also conserving the environment due to the increasing attention to the sustainability issues. In this framework, retrofit solutions, that are already widespread and considered effective in the construction sector, can be improved from an environmental point of view. One of the most applied techniques in the past years for masonry structures is the Fiber Reinforced Cementitious Matrix (FRCM), that is usually made of artificial fibers such as steel, carbon, and glass. The sustainability of this kind or reinforcement can be improved by replacing artificial fibers with natural ones, such as hemp, that claims good mechanical properties and is carbon negative. The research means to experiment a retrofitting system, called Hemp-FRCM, that is made of a hemp mesh drowned in a lime matrix. In a first phase, the system is investigated by applying the reinforcement on masonry samples made of solid bricks and carrying out compressive tests. In a second phase, the adhesion capacity to the substrate, by performing delamination tests on two different supports, namely solid bricks and yellow Neapolitan tuff blocks, is performed. The test results show premising results on the possibility of using hemp meshes, instead of artificial ones, for the structural retrofit of existing masonry buildings.

Keywords

Hemp mesh, FRCM, Masonry buildings, Sustainable materials, Compression tests, Delamination tests.

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Influence of PLA impregnation on the performances of vegetable fibers for lime-based composites

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Abstract

In the recent years the application of inorganic lime-based Textile Reinforced Mortar (TRM) for repairing existing masonry structures has gained a relevant interest due to the strong compatibility between masonry elements and the strengthening composite. In addition, several research groups worldwide have recently focused on the possible use of natural fibers for replacing the traditional reinforcement (e.g., steel, fiberglass, basalt, PBO, aramid, carbon, etc.) generally employed for TRM composites. As a matter of the fact, the natural fabrics (easily available and biodegradable) present comparable resistance to conventional fabrics, good compatibility with the lime-based mortars and elastic modules compatible with masonry elements. On the other hand, it has been also demonstrated that one of the most relevant aspects on their possible application is related their long-term and durability performances which can be mitigated with coating and impregnation treatments.
In this context, the present paper presents the preliminary result of an experimental campaign aimed at investigating the influence of a biodegradable coating system (PLA - polylactic acid) applied to different types of natural fibers (made of flax and jute) on the resulting performances either from the physical and mechanical standpoint. The results demonstrated a significant improvement on the resulting performance of the natural fibers which can be employed for the production of natural TRM composites.

Keywords

Textile reinforced mortars, Plant-fibers, Impregnation, Mechanical performances.

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Investigating volume stability Performance of paste with Phragmites Australis (PA) Fibers

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Abstract

Environmental sustainability is a critical concern in the construction industry due to its substantial energy consumption and carbon dioxide emissions. This study addresses the sustainability of building materials by exploring the volume stability of cementitious system by adding natural fibers, specifically those derived from the Phragmites Australis (PA) plant. Natural fibers exhibit high strength and stiffness, making them suitable for structural applications. In this experimental study, four paste mixes were prepared, incorporating varying percentages (0%, 0.5%, 1%, and 2%) of PA fibers. Testing included drying shrinkage, autogenous shrinkage, and expansion. Results showed a notable reduction in paste shrinkage, with percentages of 12.7%, 19%, and 29% observed at 7 days with the addition of 0.5%, 1%, and 2% PA fibers, respectively, at an elevated temperature of 45°C. These findings suggest the potential for PA fibers to mitigate shrinkage in building materials, thus contributing to the overall environmental sustainability of construction practices.

Keywords

Sustainability, PA fiber, Volume stability, Paste, Elevated temperature

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Masonry structures retrofitting by geopolymer plaster reinforced with natural fibers

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Abstract

Geopolymers describe a class of aluminosilicate materials obtained by alkaline activation of an aluminosilicate precursor at low temperatures and nowadays represents a very strong competitor to Portland cement-based materials in the field of constructions. To improve the mechanical characteristics of geopolymers the adoption of fibers (natural or not) has been proposed and this is the topic of a very large literature. From the other hand. nowadays the problem of environmental sustainability is very important and the geopolymers possess many features making them as the cutting-edge material of the future. Further, the adoption of natural fibers makes geopolymers even more interesting from the environmental sustainability point of view. From the other hand strengthening of existing masonry structures is a very important topic in the field of structural engineering as well as in that of restoration. In both fields it is important to adopt sustainable materials showing the requested mechanical characteristics. Aim of the paper is to verify the use of geopolymer plaster reinforced by natural fibers as strengthening tool for masonry structures. The aim will be firstly reached by suitably modelling the mechanical behaviour of samples of geopolymer plaster realized in laboratory starting from experimental results and secondly modelling the behavior of a masonry panel reinforced with such plaster by means of a suitable FEM model in Abaqus.

Keywords

Reinforced plaster, Geopolymers, Masonry structures, Retrofitting, Natural fibers

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FRCM System with natural fibers mesh

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Abstract

In the context of wall consolidation of historic or monumental buildings, there is an increasing demand to use strengthening techniques that involve eco-friendly materials. FRCM (Fibre Reinforced Cementitious Matrix) systems are widely used in the static and seismic rehabilitation of existing Italian buildings, in particular for the reinforcement of masonry structures. They consist in the creation of reinforced plasters (inorganic matrix mortar) with thicknesses between 5 and 15 mm through the interposition of structural mesh made up by different materials such as high resistance steel, aramid, basalt, carbon, AR glass. The qualification of the systems in Italy can take place according to the Guideline of the Ministry of Infrastructure and Transport which defines the characteristics of the components, the requirements and the test methods to follow to establish the performance of the FRCM systems. The present work has placed in this context, illustrating the results achieved by an experimentation with new reinforcement mesh, made up of interwoven natural fibers that come from pure plant origin, combined with lime-based structural mortars typically used in historical field. The system and the mesh have been characterized by some mechanical properties according to the Italian Guideline for the technical qualification of FRCM.

Keywords

Geosynthetic materials, Geogrid, Concrete pavements, Cyclic loads, Fatigue behavior

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Strengthening Existing Structures with Post-tensioned Natural Fibre Ropes

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Abstract

Natural fibre products have recently been introduced to the construction industry owing to their advantages, such as cost-effectiveness, lightweight, corrosion resistance, and low carbon footprint. Such products have been utilized for flooring, roofing, insulation systems, and more limitedly, as a replacement for steel reinforcements in reinforced concrete (RC) members. This study investigates the effectiveness of strengthening existing structures by post-tensioning them using unbonded ropes made from natural jute fibre (NJF). Analytical investigation, finite element (FE) analysis, and experimental campaign have been carried out to evaluate the effect of post-tensioning with unbonded NJF ropes on the flexural behaviour of RC beams. The proposed post-tensioning technique has improved the load-carrying capacity by 18.6% and reduced the deflection of the beam at the service load by 45%. The investigation disclosed that the post-tensioning ratio had dominated the behaviour proportionally, i.e., the more post-tensioning applied, the better capacity and serviceability performance achieved. Further, such a technique is found to possess the potential to overcome the serious issue associated with post-tensioning, represented by corrosion of steel cables, offering more flexibility by enabling the replacement of the unbonded ropes when needed. The outcome represented by enhancing the flexural performance of structural elements and controlling the serviceability by post-tensioning using natural jute fibre (NJF) ropes is deemed promising, especially when considering the advantages from an environmental perspective. This innovative technique may set the base for further employment of natural fibres in the construction industry to mitigate the increasing impact of construction which is continuously degrading our mother earth, and to save its resources for future generations.

Keywords

Natural fibre, post-tensioning, sustainability, flexural performance, serviceability.

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Experimental study on thermal matrix composite for seismic-energy upgrade of masonry buildings

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Abstract

The existing building stock is mainly constituted of masonry constructions built long before the modern seismic regulations and the issue of energy saving in energy-intensive buildings as well. Following the well-known problems referred to climate change and the need to reduce energy consumption, the issues of sustainability and reducing the environmental impact of the construction sector have become increasingly relevant. In this context, the present research addresses an integrated way for both structural and energy upgrade of masonry buildings. Specifically, innovative fibre-reinforced composite materials assembled by using lime-based thermal matrices combined with a balanced high-strength basalt fibre were experimentally investigated at the Laboratory of the University of Florence. These composite materials are identified by the acronym FRLM (Fiber Reinforced Lime Matrix). An initial work concerned the selection of thermally efficient and compatible matrices and, then, the composite materials were investigated through tensile tests and single shear tests in order to evaluate their bond performance. Different bond lengths were evaluated with the aim of identifying the effective one.

Keywords

Masonry, FRLM, Composite Materials, Mechanical Behaviour, Thermal matrix.

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Mini Symposium 14: Advancements in Risk and Reliability Assessment of Existing Structures

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ID:048

Safety Concepts for Building Materials with Time Dependent Properties

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Abstract

For all buildings and structures a sufficient safety standard is essential. In building codes like the EN 1990 failure probabilities are defined for different buildings members and applications. Materials as well as actions are characterized by safety factors to fulfil the failure probability requirements and to enable in this way a safe design. But materials with time dependent properties can complicate this process.

In this paper different ways to determine the resistance of these materials based on long term tests are presented. For this reason it is important to define characteristic values also for the long term resistance, if the code is based on a semi-probabilistic safety concept.

In addition different safety concepts for these materials are discussed regarding technical, economical and practical aspects. As examples the approaches from the EN 1992-1 Annex R, the approach from ACI 440 and CSA and the German approval abZ 1.6-238 are evaluated. A combined performance based approach for a higher economical efficiency with the same proven level of safety is presented at last. This is all shown with practical values and examples.

Keywords

GFRP rebar, safety concept, design, long term testing, time dependent property

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NLFEA damage assessment of RC framed buildings subjected to column settlements

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Abstract

The prevention of progressive collapse of buildings due to abnormal actions has gained interest in recent years. In Reinforced Concrete (RC) frames, strong settlements of one or more columns, caused e.g., by design or construction errors, underground works or foundation failure, can be considered as an example of such abnormal actions. Downward displacement of a limited number of structural elements should not result in disproportionate collapse of the whole structural system or a major portion of it, especially in case of public buildings. Therefore, it is important to establish damage limit states for such indirect actions, which can be used to assess the reliability level of existing structures, as well as to proper design Structural Health Monitoring (SHM) systems. Recent research shows that the behaviour of RC buildings during accidental events can be predicted by means of Non-Linear Finite Element Analysis (NLFEA), which considers material and geometrical nonlinearity.

In the present study, NLFEA is used to examine the behaviour of an existing building with RC framed structural system subjected to column strong settlements. Firstly, the modelling methodology is validated against the outcomes of experimental tests from the literature concerning the progressive collapse of a planar RC frame with and without infill walls. Then, the behaviour of an existing Italian school building subjected to an evolutive movement triggered by column strong settlements or column removal is simulated by both considering and neglecting the presence of infill walls. Damage evolution in the structural elements is assessed with respect to performance limit state thresholds available in the literature. The proposed methodology can represent a useful tool for the assessment of building vulnerability against soil failures and can be extended in the future to different settlement scenarios.

Keywords

NLFEA, progressive collapse, damage limit states, RC frames, uneven settlement

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Robustness versus redundancy of existing structures: critical review and application

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Abstract

Progressive collapse is defined as the propagation of failure from a local damage that results in structural collapse. Throughout history there have been many tragic building and bridge collapses that have increased the amount of interest and research in the field of progressive collapse within the structural engineering community. Notable cases include the collapse of the two World Trade Center towers in New York City in 2001, and the collapse of the I-35W truss bridge in Minneapolis in 2007. Even though there is no universally accepted definition, structural robustness can be described as the ability of a system to absorb an initial damage and not collapse. Although often used interchangeably with robustness, redundancy is defined as the ability of a system to carry additional load after the first member has failed, an attribute that has been advocated as beneficial for robustness.

A critical review of the definitions of robustness versus redundancy from a structural engineering perspective will be presented, accompanied by a review of the existing robustness and redundancy measures published in peer-reviewed journals and technical documents. Furthermore, this paper will showcase a new structural robustness and structural redundancy index that were formulated to account for all relevant aspects of each characteristic identified in literature. Following the critical review, the new indices will be utilized to assess an existing truss bridge subjected to various damages as a real-life case study. Nonlinear static finite element analyses of the truss bridge in intact and damaged states will be performed to obtain the necessary index parameters. Lastly, a retrofit will be proposed for the bridge to increase its robustness and redundancy and illustrate the application of the structural robustness and structural redundancy indices when improving the safety of existing structures.

Keywords

Robustness, Redundancy, Structure, Nonlinear, Truss

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Random finite element reliability assessment of existing concrete structures – case studies and research direction

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Abstract

The material properties of concrete and reinforcing steel in reinforced concrete structures vary spatially across the structural dimensions due to the inherent heterogeneous nature of concrete. The spatial variation is further affected by active deterioration mechanisms such as freeze thaw damage, alkali silica reactivity, and corrosion of the reinforcing steel as all of these mechanisms are random. The spatial variation of concrete mechanical properties (compressive strength, tensile strength, modulus of elasticity) and corrosion effect of reduced section loss influence the structural reliability, and hence, the structural risk. Random nonlinear finite element (RNFE) simulation has been recently employed to assess structures with spatially varying properties using reliability analysis.

The objective of this paper is to present a systematic framework for structural risk-based condition assessment of existing steel reinforced concrete structures by employing a new class of probabilistic structural analysis using RNFE simulation. The methodology of performing the analysis will be detailed followed by presenting lessons learned from its application in real-life condition assessment projects in Canada. The paper will provide readers with insight into the application of advanced methods of analysis in consulting work for risk-based condition assessment of critical infrastructure. Recommendations for future research and analysis refinements will be discussed.

Keywords

Condition Assessment, Existing Structures, Random Nonlinear Finite Element, Reliability, Risk

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Novel reliability evaluation of existing structures using digital image processing and random finite element simulation

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Abstract

The growth in the number of structural assessment and evaluation projects worldwide is attributed to the gradual aging of existing structures and the necessity to prolong the lifespan of deteriorating structures. Reinforced concrete (RC) structures are susceptible to deterioration as a result of concrete cracking and steel corrosion. Evaluations of current RC structures are undertaken to ascertain adherence to building codes, the necessity for enhancements, or to rectify structural inadequacies. Reliability techniques are utilized to quantitatively assess the structural integrity of existing RC structures, taking into account the inherent uncertainties related to the applied loads and the resistance of the structure. The main difficulty in evaluating the safety of current RC structures, namely in determining the reliability index, is to formulate accurate resistance models. This problem is particularly pronounced when observable indications of structural deterioration, such as cracking and steel corrosion, are evident.
The primary aim of this research is to develop, validate, and implement a new computational framework for evaluating the structural integrity of RC elements. This framework utilizes digital image processing (DIP) techniques in conjunction with random finite element (RFE) simulation. In this approach, actual images of the structure under investigation are employed to construct finite element (FE) models, while random fields are utilized to represent the spatial variability in material properties. The recommended framework is anticipated to enhance the accuracy of the reliability estimate by mitigating the uncertainty associated with the concrete crack pattern and minimizing the uncertainty related to the corrosion process in steel, if applicable.

Keywords

Reliability analysis; Random finite element method; Reinforced concrete; Digital image processing; Structural degradation

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ID:244

Application of 3D laser scanning technique in precise identification of falling-off hazards of external walls

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Abstract

Falling-off of the external walls on high-rise building had occurred frequently in recently years, which caused the property damage or personal casualties and endanger urban public safety. A method using 3D laser scanning technique was studied for the detection of potential safety hazards such as hollowing and falling-off of building external walls. Based on the point cloud data, especially the z-coordinate values of the point cloud data, the identification criteria for the safety hazards such as hollowing and falling-off was established, and a precise hazard identification algorithm was developed and applied to quantitative detection of building external walls. The detection results were compared with that of the infrared thermal imaging to verify the identification ability for hazards with different positions or sizes. Fixed targets were arranged near the external wall to collect the point cloud data regularly, and the flatness model of the entire external wall was established. Then, the variation characteristics of the hollow area and height with time were analyzed based on contour lines generated from the flatness model, which would provide technical basis for the assessment and monitoring of falling-off hazard of external wall. The research results show that the proposed 3D laser scanning technique can precisely identify the falling-off hazards of the external wall.

Keywords

Falling-off hazard of external wall; 3D laser scanning technique; point cloud data; quantitative identification; periodic monitoring.

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Multi-scale and multi-refinement framework for seismic risk assessment of urban areas

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Abstract

In the last decade, significant advancements have been carried out towards a national seismic risk assessment in terms of expected damage and related impact measures. These studies typically rely on a statistical census-data-based characterization of the building stock. Nevertheless, the decision-making process for the selection of the most suitable risk mitigation policies would highly benefit from a more specific building-by-building vulnerability evaluation. Moreover, at the urban area scale, it is crucial to properly consider the most critical interconnections between different layers (e.g., building stock, utility networks). In this context, and as a part of a wider research project, this paper aims to develop an innovative framework for seismic risk assessment of urban areas. The investigated procedure employs a multi-scale approach, from individual elements (e.g., single buildings, water pipelines), to various clusters and interconnected layers and, finally, the entire urban area. Moreover, a key feature relies on a multi-refinement level framework, which allows for the evaluation of loss metrics even in the case of limited knowledge. Alternative refinement levels involve: i) typological-based vulnerability assessment; ii) analytical/mechanical procedures, and iii) numerical (software-based) simulations. The uncertainties for each refinement level are assessed and propagated. The proposed procedure is illustrated for different archetypes of urban areas. Implementing such a framework in a City Digital Twin environment can enhance the awareness of stakeholders and the general population towards seismic risk prompting decision-makers in taking action.

Keywords

Seismic risk, Seismic vulnerability, Urban area, Urban networks, Risk management

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Mini Symposium 15: Shape Memory Alloys (SMAs) for Engineering Applications

Organizer:

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Strengthening of bridges with iron-based shape memory alloy bars embedded in UHPFRC

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Abstract

Bridges are designed for a service life of up to 100 years. Hence, and as older design codes are partly obsolete today, a significant number of structures still in use lack the required levels of resistance and exhibit heavy deterioration. With the increasing focus of the construction industry towards sustainability and circularity, there is a trend to develop innovative and efficient strengthening methods that enable the repair of under-designed or damaged structural components rather than rebuilding new structures. To this end, this paper presents a research project aiming at developing a new method for flexural strengthening of bridge decks, which consists in applying a top layer of Ultra-High Performance Fibre Reinforced Concrete (UHPFRC) prestressed with iron-based shape memory alloy (Fe-SMA) bars over the existing Reinforced Concrete (RC) structure.
To analyse this novel technology, a case study is developed. The performance of the new system is compared to the strengthening using B500B steel reinforcing bars embedded in UHPFRC and the main advantages of the new method are highlighted. Furthermore, a detailed characterisation of the bond behaviour of Fe-SMA bars embedded in UHPFRC is carried out through component-level bond tests. Design parameters such as the temperature of activation of Fe-SMA, the concrete cover and the bar material are studied. The bond-slip relationships show very high bond strengths, even after a slight deterioration of the bond properties resulting from the heating.

Keywords

RC bridges, Flexural strengthening, UHPFRC, Fe-SMA, Bond-slip behaviour

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Ni-Ti SMA bars in bridge engineering - research and new development

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Abstract

The superelastic characteristic of shape memory alloys (SMAs) is the primary feature of this metallic material in controlling permanent lateral drift in bridges subjected to strong earthquakes. Among various SMA types that have emerged into development of large diameter bars suitable for application in bridge structures is the Nickel Titanium alloy because of its "yield" strength being relatively close to that of mild steel normally used in bridges. By eliminating or minimizing permanent lateral drift, a bridge that would otherwise be rendered unserviceable can continue to function and keep the traffic flow especially for emergency response vehicles after strong earthquakes. This feature has been recognized and has translated into design guidelines development and a showcase bridge demonstration project in the State of Washington. Despite this major advantage, many bridge owners are reluctant to use NiTi due to its high cost. A new generation of NiTi incorporating Cobalt has emerged with an apparent "yield" strength that is approximately 50% higher than that of NiTi while its cost being only moderately more expensive. A study to determine the basic material characteristics of NiTiCo is in progress to determine its viability for bridge engineering application. The presentation will summarize research, development, and application of NiTi in the past decade with insight about potential use of NiTiCo bars.

Keywords

Shape memory 1, Nickel-Titanium 2, Cobalt 3, Bridges 4, Earthquakes 5

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Self-centering capacity of RC columns reinforced by martensitic NiTi SMA bars in plastic hinge region

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Abstract

This study aimed to assess self-centering in reinforced concrete (RC) columns incorporating martensitic shape memory alloy (SMA) bars within the plastic hinge region. Three RC columns were prepared: one conventional, the others with SMA bars in the hinge zone. Columns, 400 mm in diameter and 1400 mm in height, with an aspect ratio of 3.5, were used. SMA bars, 400 mm long, were connected to steel rebars with specialized couplers. Through cyclic lateral loading, lateral displacements and corresponding forces were measured. Strain in the SMA bars was also recorded. The RC column with SMA bars displayed a plastic hinge near the couplers, concentrating concrete damage at this location, a departure from the conventional column failure mode. SMA bars remained elastic, while steel rebars yielded within the couplers. The RC column with SMA bars demonstrated exceptional self-centering, recovering about 95% at a 5% drift. However, its energy dissipation capacity was lower than the conventional RC column. The equivalent damping ratio for the RC column with SMA bars stabilized at approximately 3% after a 1.75% drift. This suggests that the remarkable self-centering capacity in the RC column with SMA bars was primarily due to the elastic behavior of the martensitic SMA bars.

Keywords

Self-centering capacity, plastic hinge, RC column, martensitic SMA bars, pushover behavior

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Strengthening of an Existing RC Building with Superelastic SMAs

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Abstract

Retrofit of deteriorated Reinforced Concrete (RC) structures has been widely investigated to enhance their performance and avoid the environmental impact due to demolishing and reconstruction. As conventional design concept is oriented to a predictable, ductile behavior allowing for significant inelastic deformation, implying extensive damage of structural members and leading to costly repairs after serious earthquake incidents, smart materials occupied with an inherent re-centering ability have been investigated for retrofit applications to reduce structural damage, constituting potential candidates for innovative interventions that can improve the structural resilience under seismic actions. In this work, a RC building situated in Athens, Greece is used as a case study to evaluate the potential of Shape Memory Alloys (SMAs) in structural retrofit, exploiting their property to reset inelastic deformations by unloading exhibiting the superelastic effect. Different types of SMAs are investigated to assess the effectiveness of the proposed retrofit scheme as an alternative solution to conventional steel performing pushover and non-linear dynamic time history analysis with SeismoStruct software. Results provide useful information on the application of SMAs as a damage-control and cost-efficient scheme in structural retrofit with the view to deal with the issue of significant residual deformation after earthquake action.

Keywords

RC buildings, Seismic Retrofit, Smart Materials, Shape Memory Alloys, Superelasticity

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Study of activation parameters in Fe-SMA reinforced concrete structures using multiphysics modelling

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Abstract

In recent years, shape memory alloys (SMAs) have been widely employed for a variety of structural purposes. Among different types of SMAs, iron-based SMAs (Fe-SMAs) have been recently used as reinforcement for concrete structures because of their distinct mechanical properties and lower production costs. In such applications, the pre-strained Fe-SMAs must first be activated in order to apply the necessary pre-stress to the structure. The process of activating Fe-SMAs in concrete involves three main physical steps, including the generation of heat in the SMA through the passage of an electric current, the transfer of heat from the SMA to the concrete, and the creation of pre-stress in the specimen. In the present study, the activation process of a Fe-SMA-reinforced concrete beam is simulated through multiphysics modelling with Comsol software. For Fe-SMA reinforcements, two different geometries—bar and strip—are taken into consideration. For these two kinds of specimens, comparisons are made on the temperature and stress distribution results. Initially, the model is verified with the available experimental data. Afterwards, using a parametric study, the results are examined for the impact of geometrical parameters and activation parameters, such as applied voltage and activation time. The presented modelling technique can enhance the use of Fe-SMAs in a variety of engineering domains, particularly civil engineering fore reinforcement of concrete specimens.

Keywords

Fe- SMA, Multiphysics simulation, Activation, Pre-strain

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Practical Applications of Fe-SMA for Punching Shear Strengthening of RC Slabs

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Abstract

Punching shear failure causes a sudden and brittle collapse in column-supported reinforced concrete slabs, which can occur due to increased loading, design and construction deficiencies, or long-term degradation of the structural system. Recently introduced innovative materials aim to improve strengthening methods, minimizing disruptions for building owners. Among these materials, iron-based shape memory alloys (Fe-SMA) show promise for effectively reinforcing and prestressing existing concrete structures.
Based on the authors' experience in structural assessment and strengthening of existing buildings and parking garages, two specific applications are presented: strengthening with Fe-SMA bars in the hogging moment region to enhance the slab's bending resistance above the column, and in the sagging bending region to transfer moments while preventing plastic moment redistribution. Both case studies include punching shear calculations following Level III/IV approximations according to fib model code.
This paper highlights the practical and effective use of iron-based shape memory alloys in addressing punching shear deficiencies in existing concrete slabs, offering a valuable solution to enhance the safety and performance of RC structures.

Keywords

Iron-based shape memory alloy, punching shear, structural strengthening, practical application, condition assessment

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Contact Pressure Evolution in Heat-Treated Iron-Based Shape Memory Joints

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Abstract

This paper presents an experimental investigation into the behavior of open-ended Fe-based Shape Memory Alloy (Fe-SMA) tubes under biaxial pre-straining conditions, focusing on development of interface contact pressure as a result of the shape memory effect (SME). During the pre-straining process of Fe-SMA tubes, the cross-section undergoes complete inelastic deformation with a non-uniform distribution. Consequently, non-uniform biaxial pre-strain emerges across the cross-section, leading to the formation of stress-induced martensite in both the radial and circumferential directions. This results in the alteration of the SME due to the direction and interaction of biaxial martensite. Consequently, the material experiences a complex pre-strain state, posing challenges in assessing the SME in Fe-SMA tubes. Nevertheless, it is possible to interpret the complex overall SME performance on the basis of measurements of the resultant pressure exerted by the Fe-SMA tube on a substance, thereby limiting its free recovery. This study explores the development of the interface contact pressure highlighting the impact of heat-treatment on the gripping capacity in Fe-SMA tubes. Via coupling of analytical models with results extracted from an experimental campaign, the resultant pressure at the interface throughout the course of activation is quantified aiding to assess the SME performance. The experimental setup involves Fe-SMA and steel tubes enabling the quantification of interface contact pressure through principal strain measurements at the inner diameter of the steel tube, allowing for differentiation of SME performance under as-received and heat-treated conditions.

Keywords

Fe-SMA, multi-axial shape memory, Thick-walled Fe-SMA

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Durability of RC Beams with NSM Fe-SMA after Eight-Year Exposure and Sustained Loading

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Abstract

Low-cost iron-based shape memory alloys (Fe-SMAs) have emerged as a viable alternative to carbon fiber reinforced polymers (CFRP) for near-surface mounted strengthening of reinforced concrete (RC) structures, particularly due to their ease of prestressing and their plastic behavior similar to reinforcing steel. The short-term behavior has already been investigated in detail, yet the durability of such systems still remain a relatively unexplored area, as there is a scarcity of long-term experimental studies available. To address this gap, two RC beams strengthened with NSM Fe-SMA were subjected to natural environmental conditions for an extended period of 8 years, during which they were subjected to sustained loading beyond their cracking load level. Subsequently, the beams were subjected to four-point bending loading until failure. Results were compared with a previous short-term study involving identical specimens that had not been exposed to environmental factors or sustained loading. A comprehensive cross-section analysis (CSA) further complements the experimental results, which effectively captured both the long-term and bending behavior. Influence of concrete creep and shrinkage, as well as Fe-SMA relaxation is discussed by employing the CSA. Lastly, influential parameters and their impact on structural performance were identified via sensitivity analysis.

Keywords

Iron-based shape memory alloy, Near-surface mounted strengthening, Prestressing, Durability, Sustained loading

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Iron-based shape memory alloys for Steel Construction: A Review

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Abstract

This study reviews the recent works on the development and application of iron-based shape memory alloy (Fe-SMA), the so-called memory-steel, for steel structures. First, the studies on the material properties of Fe-SMA in terms of shape memory effect and superelasticity are discussed. Next, the use of Fe-SMA in prestressed strengthening of steel structures is explained, including the applications in strengthening of steel girders, connections, and fatigue crack repairs. Various strengthening solutions such as using mechanically anchored or adhesively-bonded Fe-SMA, as well as the studies on the behavior of the Fe-SMA-to-steel bonded joints, are discussed. The use and application of Fe-SMA for strengthening of a 113-years steel bridge has been explained. In addition, studies on the innovative application of the Fe-SMA as pipe couplers are presented. At the end, innovative ongoing research on the additive manufacturing of architected Fe-SMA (4D-printing) are discussed.

Keywords

Memory-steel, Fe-SMA, pseudoelasticity, shape memory effect, structural strengthening, mechanical anchorage, epoxy adhesive bonding, coupler, additive manufacturing, 4D printing

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Development and Characterization of Thin Iron-Based Shape Memory Alloy Prestressing Wire

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Abstract

Iron-based shape memory alloys (Fe-SMA) have been used successfully in the previous years as prestressing reinforcement in the form of rebars, rods and flat strips, for various types of structural elements and loading scenarios. This paper introduces a new application of this material in the form of thin wire. An experimental characterisation study is presented herein for Fe-SMA wire that was drawn to a diameter of 0.5 mm, regarding its tensile stress-strain response and recovery stress development upon heating, for different activation temperatures and prestraining levels. Furthermore, an investigation is presented regarding the effects of heat treatment conditions on the mechanical response and prestressing performance of the wire, with the aid of crystallographic analyses by means of electron backscatter diffraction and high energy X-ray diffraction. For the optimum heat treatment conditions and activation temperature range considered in this study, the measured tensile strength and recovery stress of the Fe-SMA wire was 1200 MPa and up to 430 MPa, respectively. The results indicate a strong potential of Fe-SMA as a candidate prestressing material where small diameter wire cross-sections are desired instead of solid tendons (for example, multi-strand twisted wire ropes), or as novel short fibre reinforcement for concrete with prestressing capabilities.

Keywords

Iron-based shape memory alloy, Fe-SMA, wire

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Computational Modeling of Concrete Composites with Short Shape Memory Alloys Fibers

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Abstract

The application of fiber-reinforced concrete (FRC) in the construction sector is a developing area of study and application. Shape memory alloy (SMA) is one promising material for use as fibers in FRC due to its ability to revert to its original shape after deformation, a phenomenon known as the shape memory effect (SME). FRC may be pre-stressed and self-repaired by combining SMA with the SME characteristic. Nevertheless, modeling SMA-FRC using conventional finite element methods (FEM) is demanding. This paper presents an innovative technique for modeling SMA-FRC utilizing multiscale modeling. The article describes the methods for generating micromechanics, homogenization, boundary conditions, and coupling micro- and macro-models. The results demonstrate that employing multiscale modeling may significantly lower computing costs while presenting extra insights about the SMA-behavior FRCs on the microscale. The results also suggest that employing SMA fibers can generate sufficient pre-stressing forces in the concrete, improving the stiffness and durability of the concrete. Nevertheless, several parameters like fiber geometry, pull-out strength, SMA phase transformations, and crack progression are simplified in the article. The authors intend to resolve these limitations in further research and compare the findings to experimental data. The usage of SMA-FRC has significant potential for enhancing the durability and strength of concrete buildings, and the unique multiscale modeling technique given in this study can assist in the advancement of research in this sector.

Keywords

Multiscale modelling, shape memory alloy (SMA), fiber-reinforced concrete (FRC), pre-stressing

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ID:343

Design Criteria for Self-Centering and Energy Dissipation of Fe-SMA Prestressed Segmental Columns

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Abstract

Severe seismic events often lead to detrimental residual displacements in traditional monolithic bridge columns, resulting in serviceability issues and substantial repair costs. Conversely, post-tensioned segmental columns display beneficial self-centering behavior and minimal residual drifts. Despite these advantages, such structures exhibit limited energy dissipation capacities and require heavy mechanical equipment for prestressing through conventional tendons. This study introduces an innovative self-centering segmental column system utilizing the unique shape memory effect (SME) of iron-based shape memory alloy (Fe-SMA) bars for prestressing. A 3D finite element (FE) model, developed in ABAQUS, was validated against experimental results to evaluate the seismic performance of the proposed column system. The validated model was then utilized for a focused investigation into the influence of the ratio of energy dissipating (ED) bars to Fe-SMA bars on the self-centering and energy dissipation behavior of prestressed segmental columns. The results highlight the capability of Fe-SMA bars to provide effective self-centering and energy dissipation due to their self-prestressing and high ductility.

Keywords

Fe-SMA, Prestressing, Segmental columns, Self-centering; Energy dissipation

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Mini Symposium 16: Systems and methods for transport infrastructure surveillance and monitoring

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Real-Time evaluation of bridge girder deflection under heavy vehicles

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Abstract

Bridges are crucial components of infrastructure and facilitate the movement of goods and people. Ensuring the preservation of the structural integrity is critical to the safety of users.
Modern Anomaly Detection techniques enable the detection of structure damage from data recorded by structural monitoring systems. One of the most significant quantities is beam deflection, which, however, is difficult to measure directly. Therefore, this research focuses specifically on the assessment of bridge girder deflection, a critical aspect of structural health monitoring, using a variety of sensors and techniques. For different sensors, the measurements obtained and possible correlations with beam deflection were analyzed.
The study involves a comparative analysis of different methods for estimating the deflection of bridge girders under different loading conditions. The techniques are compared by simulating isolated girders, and complete bridge decks under different traffic conditions.
The overall objective is to identify the most suitable sensors and methods for accurately estimating the deflection of bridge girders.

Keywords

Structural Health Monitoring, Bridge Engineering, beam deflection.

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Structural health monitoring design for the A3 bridges in Naples

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Abstract

The paper shows the design approach of structural health monitoring (SHM) systems for a group of viaducts realized in ’70 that connect in the port of Naples with the A3 Italian highway. Given the frequent traffic of heavy vehicles, due to the commercial activities of the port, and deterioration phenomena of the existing structures, a reliable monitoring system can be an important support to enhance their safety and structural integrity over time allowing timely maintenance intervention. The bridges constituting the infrastructure are mostly simply supported structural systems with several half joint (Gerber) bearings. However, the structural schemes are characterized by different geometrical layouts, especially for main beams and piers. Superstructure decks are made of post-tensioned PC beams or composite steel-concrete beams/caissons. An integrated monitoring system was designed considering dynamic and static measures. Multiaxial accelerometers were located to measure acceleration during the transit vehicle and to identify main dynamic properties of the superstructures, as well as interactions with the substructures. Furthermore clinometers, displacement transducers, humidity and temperature sensors were added to collect deformability parameters under the traffic loads. Accelerations recorded at different times of the day on one viaduct are briefly shown, pending the collection of more data that will allow a check on the consistency of the measurements recorded by the various instruments. The finite element model of the structure that will be used as support in interpreting the measurements is briefly introduced.

Keywords

SHM, Bridges, Prestressing, Reliability, Gerber,

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Vibration-based Bayesian FE-model updating of a curved approaching span of the Indiano Bridge

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Abstract

The development of accurate finite element (FE) models of existing bridges represents a challenging issue due to the uncertainties on boundary conditions (e.g., friction of the supports and their behavior with the traffic loads, out of plumb of pylons, soil-structure interaction, etc.), material properties and damping estimations. Full-scale measurements are usually employed for updating a preliminary FE model through deterministic methods, although probabilistic approaches should be preferable due to the non-negligible uncertainties present in both modeling and measurements. This work deals with the Bayesian FE-model updating of a curved approaching span of the Indiano Bridge (Florence, Italy) through full-scale vibration tests. The case study is represented by a steel/concrete composite deck slab bridge with a span of about 25 m. The deck has been equipped with both a wireless accelerometer network and wired sensors, to increase the number of measuring points and to compare the results of the two sensor typologies. A procedure based on the Bayes theorem has been developed and tested on the considered case study incorporating both model uncertainties and measurement errors. The work also includes strain measurements on the anti-lift devices, consisting of steel bars, employed to avoid the overturning of the curved deck. The bars have been equipped with strain gauges and their deformation has been recorded along with the vibrations detected by the accelerometers installed.

Keywords

Bayesian FE-model updating, Ambient vibration tests, Curved beam bridge.

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Experimental correlations between crack opening and corrosion measurements in PC beams

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Abstract

The assessment of concrete structures suffering corrosion deterioration represents nowadays one of the most crucial topics for the engineering community, in order to avoid sudden failures result-ing in human losses and high financial damages. Within this framework, monitoring through in-situ inspections the conditions of existing reinforced concrete (RC) and prestressed concrete (PC) structures can represent a key tool for planning repairing and strengthening interventions. In this work, 10-year-old prestressed concrete beams subjected to natural chloride attack due to wet and dry cycles of seawater, have been experimentally investigated to estimate corrosion. Along their length, different measurements, such as potential and resistivity have been performed to highlight the longitudinal corrosion pattern. Then, also concrete cover losses and crack openings were detected, in order to try to find a correspondence between surface defects and corrosion measures, so as to improve the knowledge of corrosion phenomenon in PC beams, considering the spatial variability.

Keywords

Corrosion, prestressed concrete beams, inspections

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Safety assessment of a CFRP retrofitted bridge

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Abstract

The maintenance of existing bridges sometimes requires an intervention to increase their residual bearing capacity during their service life. The bridge strengthening can modify significantly the original structural behaviour, but in many cases the lack of a specialized standard for existing structures in the past prevented the designer to operate a suitable check of the updated performance. In the paper, an example of a three-span overpass, built in the sixties, located on the east shore of Maggiore Lake is investigated. The main aim is to check the serviceability and the ultimate limit states of the bridge when variable loads are applied. The bridge is a second category bridge, that means that no trucks with a total load exceeding 44t can freely cross the bridge. The bridge is a girder bridge 21.1 m long: the central span is 0.92 deep and 10 m long, while the external spans are 0.32 m deep and 5.4 m long. In 2013 a significant restoration was carried out due to the bad condition of the infrastructure. The eleven P/C beams, 0.8 m deep, were retrofitted by means of CFRP strips and the top slabs over the two internal piers were also strengthened by additional reinforcement. After a basic diagnostic aimed at verifying the mechanical characteristics declared in the documentation attached to the drawings and the pictures of the retrofitting intervention, a load test driven by a preventive structural analysis carried out by means of a linear elastic approach allowed to fix a control procedure aimed at guaranteeing the safety conditions in the future time.

Keywords

Existing bridge, CFRP retrofitting, safety assessment, loading test, monitoring

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ID:365

Assessment of Environmental-induced Degradation on Reinforced Concrete Tie Rods in a 70-Year-Old Arch Bridge

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Abstract

Given the present landscape of existing bridges in Italy, a significant portion of which date back to the mid-20th century, the need to conduct detailed investigations on the current deterioration state and on the safety of these infrastructures becomes evident.
This work, focusing on a case study involving reinforced concrete tie rods removed from a 70-year-old arch bridge and preserved for mini-invasive diagnostics, addresses the critical need of understanding the current condition of such elements and to assess whether the common non-destructive techniques can be used to monitor the progress of deterioration. Both electrochemical measurements (e.g. corrosion mapping potential) and mini-invasive diagnostics were conducted to assume the current corrosion state of steel bars, and mechanical tests were performed to assess member capacity. In addition, this study allowed to investigate the effectiveness of the past restoration interventions, determining whether they achieved the designed outcomes.
The research demonstrates the effectiveness of these diagnostic measures, proposing their repetition in situ for a non-continuous reliable structural health monitoring of those elements over time.

Keywords

Reinforced Concrete tie rods, mini-invasive diagnostic, corrosion state, structural health monitoring, restoration interventions.

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ID:404

Integrating Structural Health Monitoring for Safety Assessment and Restoration Planning

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Abstract

The aging of structures and infrastructures in Italy highlights the necessity of procedures to assess their safety conditions and life-cycle performance. Very often, the costs associated with the repair and maintenance operations needed for all infrastructures overcome the available budget of managing bodies. It is thus necessary to set up and use prioritization methodologies. Within this framework, Structural Health Monitoring (SHM) is increasingly recognized as a crucial tool to deepen our understanding of the structural behavior of existing bridges. This paper deals with the activities carried out on the "Ponte Nuovo del Popolo" bridge, situated in the city center of Verona, Italy. The bridge exhibited an extensive damage pattern, primarily affecting the main reinforced concrete beams, posing some very important questions about its structural safety. Following the structural verifications, SHM was employed as a tool to keep the structure in service and assess the operational conditions while planning and designing the necessary repair work. The SHM system was installed in 2012, immediately after the structural verification, and remained operational until 2022. Concurrently, restoration works started in 2021. This study presents a comprehensive overview of the bridge deterioration, the structural verification process, and the use of SHM to guide the restoration interventions, emphasizing the integral role played by SHM in enhancing the overall understanding and management of aging infrastructure.

Keywords

Reinforced concrete bridges, structural health monitoring, operational condition, structural safety, life-cycle performance

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ID:418

Large scale implementation of SHM and control rooms for the remote control of bridges

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Abstract

Planning, maintaining and optimizing the resources in the field of infrastructural networks management entails complex decision management to be effective. The involved activities generally include compiling an inventory, carrying out monitoring and maintenance activities, and executing interventions to upgrade the safety levels to the increasing demands. From a structural and financial point of view, preventive monitoring help optimizing the asset maintenance. However, a major concern in this field is that the structural performance is usually described by visual inspection-based structure condition states only.
To adequately consider the actual structure safety level and the eventual progressive deterioration of the bridge or viaduct performance, the use of structural health monitoring systems is of paramount importance. In this framework, the Italian Ministry of Infrastructures has launched a large-scale plan, funded by the National Recovery and Resilience Plan, for implementing a dynamic monitoring system for the remote control of bridges, viaducts and tunnels of the main road system in Italy. This plan foresees the creation of an integrated inventory and risk management platform for 12.000 bridges/viaducts, the SHM equipment of 6.500 structures, and the information modelling of some of them. This paper, after introducing the main features of the national plan, reports and discusses some activities related to SHM of bridges and creation of a dedicated control room that Autostrada Brescia-Verona-Vicenza-Padova S.p.A., one of the leading motorway concessionaries in Italy and part of the Abertis Group, is carrying out.

Keywords

Motorway infrastructural system, structural health monitoring, control room.

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Mini Symposium 17: Advancements in Object Digitization and Analysis: A Mini-Symposium on Innovative Tools and Methods

Organizer:

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ID:115

Enhancing Heritage Building Preservation with MCDM and HBIM: A Research Proposal

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Abstract

Heritage Building Information Modelling (HBIM) has emerged as a response to the global focus on sustainability and architectural heritage preservation. This specialized subset of Building Information Modelling (BIM) caters to the challenges posed by historical structures, facilitating their conservation and safeguarding. HBIM integrates semantic and geometric data to comprehensively represent historical buildings. Its seamless integration with Multi-Criteria Decision-Making (MCDM) techniques can empower informed decisions that balance historical significance and sustainability. The synergy between HBIM and MCDM streamlines heritage documentation, restoration planning, risk assessment, and regulatory compliance. Challenges in this integration, including data accuracy, uncertainty management, and stakeholder engagement, must be addressed through strategies such as semantic models, standardized workflows, and user-oriented tools. This fusion enhances visual assessment, allowing stakeholders to evaluate impacts on aesthetics, structure, and history before acting. It fosters transparency and consensus, and balances technicality with cultural sensitivity. This research proposal outlines a comprehensive framework to integrate MCDM techniques and HBIM to improve decision-making in heritage building preservation and management. The proposal presents a four-step framework, focusing on stakeholder feedback, workflow improvement, methodology, and practical implementation. It aims to improve these processes' effectiveness, sustainability, and cultural sensitivity, although challenges like interdisciplinary collaboration and resource constraints must be navigated. Despite limitations, the proposed framework has the potential to represent a significant advancement in heritage preservation decision-making.

Keywords

HBIM, MCDM, Decision-Making, Data Management, Stakeholder Engagement

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ID:367

A Deep Active Learning Framework for Crack Detection in Digital Images of Paintings

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Abstract

Over time, all paintings tend to deteriorate because of aging and storage conditions. Cracks formed on the surface of paintings are the most common types of degradation. The automatic detection and mapping of cracks is a key problem for art restoration, conservation treatments, and analyses such as art authentication. However, this task is challenging, and existing methods often require tedious manual effort in feature engineering and parameter tuning.
Methods based on deep learning (DL) can learn features from data and show promising results. However, DL relies on large sets of previously annotated data, which are not easily available in this application. Furthermore, the high variability of the crack detection task, encompassing different types of paintings and a variety of shapes and patterns of cracks, makes these methods hard to apply to previously unseen paintings.
To address these challenges, we developed a deep active learning (DAL) method for crack detection. DAL methods start with a model trained on little annotated data, perform their tasks, and then suggest to the oracle (here, a human annotator) new samples to annotate before retraining the model. By retraining the model iteratively in an efficient way, our method needs much less data than traditional DL, learns continuously from new annotations by a human-in-the-loop, enables learning from partially annotated data, and performs better on previously unseen paintings. It can also leverage several modalities at the same time, namely photographs in the visible and infrared spectral range and X-ray images.
Our method is equipped with a web interface to be used easily by art restorers and non-experts. It is able to improve itself continuously with the input from all users. We demonstrate the application of the proposed crack detection tool in a concrete use case as a means of supporting the restoration of old master paintings.

Keywords

Digital painting analysis, crack detection, deep active learning

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ID:369

IoT and Digital Twin: a new perspective for Cultural Heritage predictive maintenance

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Abstract

The cultural heritage of a nation represents one of its most important assets because of the multiple economic and social implications connected to it. In the case of Italy, it is safe to say that its tangible and intangible cultural heritage represents one of its most important resources both from an economic point of view, due to the induced effects it creates, and for the historical memory it enshrines. The preservation of this heritage must be one of the main objectives that a nation must pursue In this scenario, a significant contribution has been made by the Internet of Things paradigm, which has made it possible to collect real-time data from sensors placed on the structures to be monitored, thus enabling the implementation of methodologies for predictive maintenance. A further contribution to the development of these methodologies came from the emergence of the Digital Twin concept, a digital model of an intended or actual real-world physical product, system, or process (a physical twin) that serves as the effectively indistinguishable digital counterpart of it for practical purposes. To make the Digital Twin even more effective, it is possible to link it to the real structure through the HBIM, that is a process applied to existing buildings or monuments that aims at the creation of so-called 'intelligent models'. The latter is rich in geometric information and inclusive of the state of preservation of materials, in which all components are parametric objects with well-defined semantics and capable of containing all historical information derived from appropriate documentary analysis. This paper aims to present a methodology that can consider HBIM models as Digital Twins enriched with data provided in real-time by IoT-based infrastructures placed on the structures to be monitored. Models are acquired in an increasingly precise and reliable manner thanks to modern surveying methods such as laser scanning and photogrammetry. The proposed methodology, which is articulated in a well-defined workflow, was applied in a real scenario: the Archaeological Park of Velia and, more precisely, Porta Rosa, a 4th-century B.C. construction that constitutes the oldest known example of a round arch in Italy. The first results of the experiment are more than satisfactory.

Keywords

Digital Twin, Predictive Maintenance, IoT

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ID:370

Metaverse and Museum: a Case Study

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Abstract

The Metaverse concept, which has developed very rapidly in recent years, has also reached the cultural sector by defining new ways of visiting museums, archaeological parks, exhibitions, and other events. The aim of this research article is to present the experience conducted with the MAV - Museo dell'Artigianato Valdostano located in Fènis in Valle d'Aosta, which saw the design and realization within the Metaverse of an exhibition space containing digital artistic artifacts obtained by digitizing real ones. The purpose of the virtual museum is to create a complementary environment to the real museum, expanding its access potential and enhancing its contents on a global level. In this article, an attempt was first made to define, through a study of the state of the art, which technologies are at the basis of the Metaverse and which make the visit a realistic and immersive virtual experience. Then, we moved on to identify the methodology to be followed for a complete definition of the exhibition space and its artistic objects. As a first step, the objects to be exhibited in the virtual museum were digitized and modeled, by means of dedicated software, using laser scanner-based scanning methodologies. Once the digital element was obtained, we moved on to the modeling of the virtual museum environment within which the objects were placed. Subsequently, an in-depth study was conducted on the interaction of man, space, and object, which made it possible to study how the avatar, guided by the user, relates within a virtual space and, on the basis of the feedback provided by the users using the space, the final organization of the museum was arrived at. During this phase, the fundamental concept of interaction emerged, which was implemented and highlighted through the application of motion and audio triggers in order to make the environment more immersive. For an optimal view of the space, although it is also accessible through classic devices such as smartphones or PCs, a six-degree-of-freedom visor was used to accentuate the sense of presence within the environment.

Keywords

Metaverse, Digital Museum, Virtual Reality

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ID:373

Optimized Supporting Structures for Small Artefacts: Generative Designed prototypes

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Abstract

Retrievals of small and medium scale are one of the fundamental and most numerous parts of the entire museal heritage set. Their exposition represents an issue, looking for supporting structures that could be non-invasive, aesthetically pleasant, customized, and, last but not least, safe and stiff enough to avoid any damage to the artefacts. Through the usage of several engineering methods, starting from the retrieval and the exhibition requirements, optimized supporting structure can be developed. The procedure here reported and applied starts from the Reverse Engineering acquisition in order to obtain the 3D model of each retrieval, also comprehending color and texture information. After that, exhibition and preservation requirements, given by heritage experts, are translated in engineering requirements, with the usage of an immersive Virtual Reality environment. With these inputs, the developed Generative Design Method (GDM), using CAD, CAE and optimization tools synergically, can optimize the configuration of supporting interfaces with the artefact and then can generate a lightweight conceptual design through a generative design process. In this way we can take into account all the given requirements, obtaining a lightweight support, topologically optimized, highly customized, non-invasive, possibly pleasant, able to resist in safety, and additively manufacturable. In this paper, the procedure is applied on different retrievals from Museo Civico dell'Agrocimino of Soriano nel Cimino, Italy, with different scales and materials, proving the robustness of the method.

Keywords

Reverse Engineering, Cultural Heritage; Generative Design; Virtual Reality; Parametric Optimisation

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ID:374

Manini Connect: IoT for integrated building monitoring

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Abstract

Constructions are conceived today following multi-risk scenarios encompassing natural and anthropic hazards, in the context of a rapid climate change. Nevertheless, currently the monitoring of local demand and/or performance on specific buildings is very poor due to the absence of a praxis towards the installation and the management of sensors, dedicated to the performance of the whole building. This makes the post-event field surveys and damage mapping extremely difficult, and retrofit intervention timespans very long, with negative reflection over the resilience of the whole built heritage. Manini Connect is an innovative patented system providing a response to this issue through integrated monitoring of precast structures. Through a set of interconnected sensors, the system monitors the static and dynamic behavior of the structures during critical events (earthquakes, strong winds, heavy rainfalls, collisions, blasts, etc.) and thermo-hygrometric parameters inside/outside the building. Moreover, it can be coupled with sensors devoted to the monitoring of the air quality inside the building, the local production of energy from renewable sources, and the consumptions in terms of electricity, water, gas, waste, etc. Taking advantage of the production of precast structures in offsite permanent plants, some sensors and utilities are easily inserted in the columns and cast within them during the production phase, whilst other typologies are collected into an external box installed on the roof throughout the building construction process. The data are received in real-time by the dedicated internal control center of Manini Prefabbricati SpA, and, after the occurrence of an exceptional event is revealed by the overcoming of predetermined thresholds of demand parameters, the system sends alerts for check. The user has himself constant access to the data through a dedicated platform accessible from PC and other devices. This allows to set predictive retrofit/maintenance works in response to anomalies or damages detected by the system, as a function of the parameters archived from the structural design of each specific building.

Keywords

Real-time data, Predictive maintenance, Smart building, Connect

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ID:375

The Helmallery multy-storey building: an example of metaverse museum for cultural heritage dissemination

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Abstract

The paper delves into an innovative collaboration between Pini Group and Helm, leveraging their distinct expertise across various engineering domains, encompassing the design of civil and industrial structures, 3D modeling, and software development, among others. The culmination of this partnership is a groundbreaking metaverse museum that is a synergy of technological advancements. This museum, situated in Decentraland, the pioneering fully decentralized virtual world, serves as a bridge between the virtual and physical reality, ensuring the dissemination of cultural heritage while preserving the sanctity of the real world. Drawing from the wealth of experience gained in this venture, there are plans to extend this knowledge across diverse fields. This includes but is not limited to structural and architectural design, data acquisition, processing, and educational initiatives. The result of this endeavor is the "Halmallery," a multi-story building set to showcase not only its architectural prowess but also the promising future prospects. The forthcoming developments encompass the integration of Non-Fungible Tokens (NFTs) to offset the costs associated with implementing intricate 3D models. Additionally, blockchain technology will play a pivotal role, introducing transparency by recording and tracking changes in data. This strategic use of blockchain ensures accountability and traceability, enhancing the overall integrity of the metaverse museum project.

Keywords

Metaverso, museum, dissemination, computer science, construction conceptualizzation.

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ID:376

Digital models for the knowledge, protection and enhancement of historic bridges. Definition of an operational protocol

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Abstract

The tools and methods of investigation for the knowledge of architectural artefacts have received a notable boost in the last decade thanks to the rapid evolution of technologies such as 3D laser scanners, mobile scanners, range-based modeling, image-based Modeling. The coordinated use of these technologies, in an integrated digital methodology, allows us to provide accurate three-dimensional models of the architecture. The application of survey methodologies in a specific field such as bridges, especially if of historical-monumental value, it has highlighted some peculiarities such as, for example, the relationship with the environmental context and the technical-constructive component; the bridge, being in fact also an infrastructural work, must also be investigated from the point of view of its structural behaviour.

Although the survey activity should always be understood as a single scientific process knowledge, from a methodological point of view of evaluating the main peculiarities and critical issues, three phases can be distinguished: acquisition, processing and interpretation, each of which has specific problems. Beyond the consolidated scientific methodology, each significant activity represents a *unicum*, as each object is unique. However, the experiments carried out in carrying out our research on some bridges of particular historical value have made it possible to define a procedural protocol and to codify a methodology that can be used and repeated in similar examples. The setting up of such a protocol is not intended as a simplification and standardization of the detection process, but rather as an aid within a critical path, in order to obtain an optimization of the entire detection and analysis process.

In addition to the application of procedures for the acquisition and processing of three-dimensional models consolidated in recent years, we also wanted to test the potential of HBIM (Heritage Building Information Modeling) processes applied to Cultural Heritage. Although research is evolving very rapidly, the process and the related BIM modeling applied to cultural heritage still requires further investigation since current models do not allow us to effectively and exhaustively relate all the components that characterize the study of an ancient bridge.

Keywords

3D Modeling, Scanner laser, Mobile Laser, Image-based Modeling, Cultural Heritage

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ID:377

Innovative tools and methods for digitizing both visible and non-visible attributes of cultural heritage items. Part I: needed tools and strategies

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Abstract

This work explores the steps that can facilitate the implementation of a collaborative cloud for cultural heritage.

Digitization serves as the initial step toward digitalization, encompassing a range of socio-technical phenomena that may unfold after digitization. Both processes are integral to a broader domain that: 1) involves physical inspection methods, business models aimed at enhancing inspection performance, integrity engineering, and decision-making; 2) provides valuable data to enhance the design, production, and maintenance throughout the useful life of cultural heritage objects. Vrana and Sing (2020) proposed labeling the aforementioned domain as the Non-Destructive Evaluation (NDE) 4.0 domain, emphasizing its nature as "a suite of cyber-physical technologies". These technologies include Digital Twin (DT), Industrial Internet of Things (IIoT), Semantic Interoperability and Ontologies, Industry 4.0 Data Processing (Big Data Analysis), Blockchains, Non-Fungible Tokens (NFTs), and Artificial Intelligence. Particular emphasis is placed on the concept of Digital Twin, initially introduced in 2003 at the University of Michigan during the Executive Course on Product Lifecycle Management (PLM), as outlined by Grieves (2014). Subsequently, Glaessgen and Stargel (2012) proposed Digital Twins for supporting the production of NASA and U.S. Air Force vehicles. They envisioned Digital Twins as facilitating "integrated multiphysics, multiscale, probabilistic simulation of an as-built vehicle or system that uses the best available physical models, sensor updates, fleet history, etc." In this framework, a methodology will be presented to create and implement innovative tools and methods for digitizing and digitalizing attributes of cultural heritage items.

Keywords

Cultural Heritage, Digitization, Digitalization, Digital Twin

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Innovative tools and methods for digitizing both visible and non-visible attributes of cultural heritage items. Part II: a multi scale approach

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Abstract

The process of object digitization and digitalization includes several key steps and considerations: 1) segmentation and classification involves dividing the object into regions with homogeneous properties and assigning labels to each region based on its characteristics. 2) Digitalization refers to the process of discretizing specific geometric entities based on a predefined level of detail. The level of detail chosen depends on the scale of representation, visualization, and thematic content. Strongly related to the digitalization is geometrical model implementation that can serve different objectives such as those concerning the structural analyses of the digitized object. In this framework two methods will be presented concerning microplane (Bazant and Oh, 1985) and lattice based model that data back to the Hrennikoff (1943) model. Those methods will be discussed including applications that concern: concrete element, Fiber Reinforced Polymer (FRP) materials used for the reinforcement of existing concrete elements as well as new FRP element. Depending on the adopted scale the numerical model can be implemented based on Voronoi (1908) Diagrams and Delaunay (1934) triangulations that find applications in various fields, including cluster analysis, record access scheduling, and collision detection.

Keywords

Cultural Heritage, multiscale modeling, lattice models, microplane models

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ID:380

3D vibration measurements with optical systems: selected methods for measurement enhancements

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Abstract

This paper presents selected surface measurement enhancement techniques while using a three-dimensional vibration measurement optical system. In this case, the 3D scanning Laser Doppler Vibrometer (3D LDV) is used to obtain the frequency response function of the investigated objects. The 3D LDV system allows for contactless measurements of complicated objects and is ideal for cultural heritage objects where, in most cases, it is not permitted to mount sophisticated sensors or use contact methods for the excitation of vibrations. This approach can incorporate sound pressure to input the energy into the system and a laser Doppler vibrometer as sensing technology. In this way, the whole measurement procedure is performed in a completely non-contact way. Additionally, a high number of scan points can be obtained in a very short time. In the case of many objects, especially heritage ones, the additional problem is the lack of visibility of some surfaces from the place where the 3D LDV system is mounted or/and the lack of sufficient signal strength for proper signal acquisition. This paper presents some typical problems and solutions to those issues. Some solutions include the advanced use of mirrors, stitching of measurement planes, and the use of enhancement surface techniques to improve signal strength during the measurement of particular surfaces or for particular difficult environmental conditions. This last element is especially worth evaluating in the case of the measurement of cultural objects in dark and dusty locations. The results demonstrate the feasibility of applying selected methods for 3D vibration measurement by the LDV system for specific objects.

Keywords

3D LDV, vibration measurements, mirrors, signal enhancement, doppler effect

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ID:381

Monitoring of the polychrome of the historic vaulting in the main presbytery of St. Mary's Basilica in Krakow using advanced 3D techniques

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Abstract

The paper presents the results of the analysis of the conservation status of the historic polychrome covering the surface of the vault in the main presbytery of St. Mary's Basilica in Krakow. Due to the historical value of the examined construction, the main assumption of the implemented research program was to use non-destructive and non-contact methods. Based on 3D scans, an inventory of the vaulting geometry was conducted. Subsequently, an analysis of thermal maps of the vault surface was performed, leading to a preliminary assessment of detachment areas of the polychrome. The temperature distribution across the surface of the polychrome was analyzed as an indicator determining the extent of potential detachments. A consistent temperature distribution indicated the absence of detachment. The areas where changes in temperature values were recorded were analyzed for potential detachments and discontinuities. The presented research program allowed for a non-contact and non-destructive assessment of the condition of the subject polychrome.

Keywords

Polychrome conservation, NDT, 3D scans, Thermal analysis, Vaulting geometry

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A workflow for rigorous tunnel deformation analysis of MLS data

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Abstract

Inspecting and monitoring the conditions of an infrastructure are two key steps in increasing user safety and properly managing available resources and are preliminary to the later steps of decision-making on the interventions to be put in place. Traditional techniques involve visual and manual inspections, which inevitably involve the closure of the section being investigated with time and resource consumption. The Mobile Laser Scanner (MLS) technique based on LiDAR (Light Detection And Ranging) technology allows modelling via a point cloud of the tunnel intrados quickly and without traffic interruption. To analyze the intrados of the tunnel, we would need to have it in a plane system needing the change from a 3D reference system to a 2D one. This requires a coordinate transformation that is strictly dependent on the development of the tunnel, which rarely results in being part of a perfect cylinder. The proposed methodology focuses on analyzing the intrados of a tunnel by applying an automated point cloud unrolling algorithm based on the RANSAC (RANdom SAmple Consensus) method. Intensity values were then analyzed to assess possible water infiltration, and the roughness values were calculated to assess the integrity of the surface part of the tunnel wall and highlight both degradation such as spalling and swelling and highlight any cracks or expulsion of steel bars. Deformation is evaluated on each individual section at given interaxle spacing by analyzing the differences between the circumference interpolated by the RANSAC method and the point cloud describing the section. The results can be useful in identifying all those sections in tunnels that need emergency interventions and therefore characterized by high priority of intervention or alertness. The test site is San Liberatore tunnel located on the A3 Naples-Salerno freeway section (Campania Region, Italy). The tunnel analyzed is in the southern carriageway near Vietri sul Mare. It extends for a total length of about 100 m within an area at the foot of Mount San Liberatore. The results, although limited to two types of distress, are helpful in identifying all those sections in tunnels that need emergency interventions.

Keywords

LiDAR, MLS, Monitoring, Algorithm, Distress, Infrastructure, Tunnel, Roughness

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