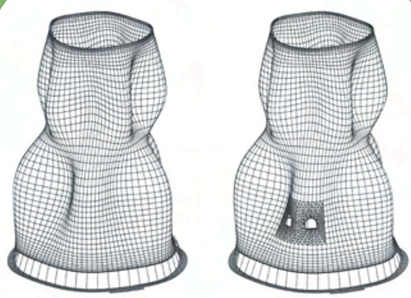
PROGRESS IN STRUCTURAL ENGINEERING, MECHANICS AND COMPUTATION

edited by Alphose Zingoni



PROGRESS IN STRUCTURAL ENGINEERING, MECHANICS AND COMPUTATION

PROCEEDINGS OF THE SECOND INTERNATIONAL CONFERENCE ON STRUCTURAL ENGINEERING, MECHANICS AND COMPUTATION, 5–7 JULY 2004, CAPE TOWN, SOUTH AFRICA

Progress in Structural Engineering, Mechanics and Computation

Edited by

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Preface

The Second International Conference on Structural Engineering, Mechanics and Computation (SEMC 2004) was held in Cape Town, South Africa, from 5 to 7 July 2004. Like its predecessor SEMC 2001 held 3 years earlier, SEMC 2004 aimed at “bringing together from around the world academics, researchers and practitioners in the broad fields of structural mechanics, associated computation and structural engineering, to review recent achievements in the advancement of knowledge and understanding in these areas, share the latest developments, and address the challenges that the present and the future pose”. The large number of high-quality papers presented and the wide spectrum of relevant topics covered, as well as the great diversity of nationalities represented by the participants, confirms that this aim was indeed fulfilled.

These Proceedings contain the 290 papers that were presented at the Conference. These have been classified into a total of 36 categories. The first two categories contain the keynote and invited papers; these deal with a variety of important issues cutting across theory and practice. The 34 categories that follow contain the contributed papers under specific topics, which cover (i) all aspects of structural mechanics such as vibration, dynamics, impact response, buckling, seismic response, soil-structure interaction and damage mechanics; (ii) numerical modelling and computational methods; (iii) practical aspects of the analysis, design and construction of structures; (iv) specific classes of structures such as shells, plates, frames, bridges, buildings, lightweight structures, space structures and foundation structures; (v) a variety of construction materials ranging from the traditional timber, masonry, concrete, steel and glass, to recent innovations encompassing high-performance composites, ceramics, high-strength concrete, fibre-reinforced concrete, stainless steel and smart alloys.

The last 10 to 20 years have seen an upsurge in research on the long-term performance of structures, including condition monitoring, damage detection, and the development of more effective repair and rehabilitation strategies. This is hardly surprising, given the need to prolong the life of existing infrastructure for as long as possible (in view of the often prohibitive costs of new infrastructure), and where new structures have to be constructed, the need to ensure that these will last for many years. This trend in research activity is reflected in the 35 or so papers that deal with various aspects of long-term structural performance. In mechanics, the study of vibration in particular (and dynamics in general) continues to enjoy considerable attention, not only as a means for better understanding the response of structures to earthquake, wind, blast and live-load excitations, but also as a tool for assessing structural damage or deterioration. The need to protect life and property against extreme and sudden events must, of course, remain of paramount importance, and in this regard, a greater number of contributions on *designing* structures for blast, storm and fire resistance would have been desirable, especially given recent world events.

All papers that were submitted for the SEMC 2004 International Conference were subjected to the full process of peer review, and the Proceedings contain only those papers that were accepted following this process. The review of manuscripts was undertaken by members of the International Scientific/Technical Advisory Board, and other identified leading experts, each acting independently on one or more assigned manuscripts. This invaluable assistance, which has greatly enhanced the quality of the Proceedings, is gratefully acknowledged.

Special acknowledgements are due to the following organizations, who were the principal sponsors of the SEMC 2004 International Conference:

- The Joint Structural Division of the South African Institution of Civil Engineering (SAICE) and the UK Institution of Structural Engineers (IStructE)
- The Southern African Institute of Steel Construction (SAISC)
- The Cement and Concrete Institute (CCI) of South Africa
- The National Research Foundation (NRF) of South Africa

The final thanks must go the Authors themselves, who worked hard to deliver papers of high standard. I trust readers will find this wealth of information useful.

A.Zingoni
Editor

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1.
Keynote papers

Structural damage and lifetime estimates by nonlinear FE simulation

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Y.S.Petryna

Institute for Reinforced and Prestressed Concrete, Ruhr-University Bochum, Bochum, Germany

ABSTRACT: In order to connect structural damage with life-time estimates, a new paradigm will be introduced in this paper, requiring, that structural failure is a consequence of damage evolution passing over an ultimate damage bound.

Starting from standard definitions of structural safety and reliability in combination with damage-caused evolutions of the safety margins, the tangential stiffness matrix $\mathbf{K}_T$ is recognized as the most suitable assemblage of structural damage information in a FE damage analysis. The most condensed form of this damage information is the main-diagonal transformation of K_T. Thus from the set of eigenvalues λ_i of $\mathbf{K}_\mathbf{T}$ (its mapping on a unit matrix) or from its frequency spectrum ω_i (the diagonalized mapping of $\mathbf{K}_\mathbf{T}$ on the mass matrix) follows the definition of modern damage indicators. Such damage indicators D_i are—because of the definition det $\mathbf{K}_\mathbf{T}=0$ of structural failure—able to completely accompany a structure's life, from virgin state D=0 to its termination by failure D=1.

These damage indices are proofed to be related to internal energies of deformed/damaged structural states. Then in the paper, the FE solution process for computer simulations is described, which corresponds to the homogenization of the damage description in the constitutive relations up to structural level, applying a multilevel-simulation concept. Necessary degradation properties in the constitutive laws are discussed for reinforced concrete materials. Further, the developed concept is explained by hand of two examples: a RC test frame, and a RC urban plate bridge. Finally, the extension to problems of structural life-duration and residual life-time is commented, always based on the derived intrinsic damage indicators.

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Structural use of aluminium alloys in civil engineering

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ABSTRACT: *How can aluminium and its alloy satisfy the requirements of civil engineering structures? In which applications can they compete with other structural materials, like steel?* These are the main questions to which the designer want to receive a prompt and convincing answer, since the use of aluminium alloys started to become a new trend in the range of the so-called civil engineering.

This paper tries to give a contribution in this direction, not only to explain the main reasons of the choice of this new material in the existing applications, but also to emphasise the main aspects which can help the future developments of this challenging technology.

The result of the application of proper design criteria is shown by means of many constructions (buildings, bridges, special structures) built around the World in the last decades.

In the 21st Century, the aluminium designers have the possibility to take great advantages from the rational use of the modern codification, like Eurocode 9 “Design of Aluminium Structures”, whose basic principles are also illustrated in this paper.

KEYWORDS: Aluminium alloys, aluminium structures, Eurocode 9.

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Structural health monitoring of large-scale bridges: Research & experience

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ABSTRACT: In Hong Kong, the Wind And Structural Health Monitoring Systems (WASHMS) for the Tsing Ma Bridge (suspension), Kap Shui Mun Bridge (cable-stayed), Ting Kau Bridge (cable-stayed), Hong KongShenzhen Western Corridor (cable-stayed) and Stonecutters Bridge (cable-stayed) have been or are being developed by the HKSAR Government Highways Department. The implementation and operation of each of the systems is an integration of analytical skills, instrumentation and information technologies with the knowledge and experience in bridge design, construction, management and maintenance. For a large-scale cable-supported bridge, developing a long-term monitoring system which is really able to provide information for evaluating structural integrity, durability and reliability and ensuring optimal maintenance planning and safe bridge operation, poses technological challenges at different levels from selection of proper sensors to design of structural health evaluation system. This paper describes the research and practical experience of a team in the Hong Kong Polytechnic University related to the implementation and efficient operation of bridge health monitoring systems in Hong Kong and the Chinese mainland.

KEYWORDS: Structural health monitoring, bridge monitoring, cable-stayed bridge, suspension bridge.

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2.
Invited papers

Analysis of stiffened rectangular plates using the element-free Galerkin method

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ABSTRACT: An element-free Galerkin method for static analysis of concentrically and eccentrically stiffened thin plates will be presented. Imposing displacement compatible between the plate and the stiffener, displacement fields of the stiffener can be expressed in terms of the mid-surface displacement of the plate. The strain energy of plate and stiffener can be superimposed to obtain the stiffness matrix of the stiffed plate. Because there are no elements used in the meshless model of the plate, the stiffeners need not to be placed along the meshes as what they are done in the FEM. The stiffeners can be placed on any locations and will not lead to remeshing of the plate. The validity of the element-free Galerkin method is demonstrated by considering several concentrically and eccentrically stiffened plate problems. The present results show good agreement with the existing analytical and finite element solutions.

KEYWORDS: Element-free Galerkin method, meshless, stiffened plate, static analysis.

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Railway bridges: Some historical failures and current problems

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ABSTRACT: Bridges form essential links of the permanent way of our railways. Their development encompasses the various building materials of the ages: wood, stone, brick, cast iron, wrought iron and steel. Their occasional failures have often been the stimulus to research into the proper use of materials, design and maintenance methods.

This paper, which draws largely on the experience of the UK, will begin with a short review of some historical failures: some well known like the Tay Bridge disaster, others not so well known, but important in the development of good practice, such as the failure at Chester of a bridge designed by Robert Stephenson. Preliminary investigations prior to construction, such as the investigations carried out on the tubular sections of the Britannia Bridge in North Wales, have proved to be landmarks in design methods. A similar claim can be made for the extensive work carried out to elucidate the dynamic loadings on bridges caused by the "hammer-blow" of steam engines.

The maintenance of bridges, some well over 120 years old, is a major concern and cost for railway administrations. Corrosion is ever present on metal bridges, even if painting is continuous, as exemplified by the Forth Bridge in Scotland. Fatigue acts in an insidious manner, often conjointly with corrosion, sometimes separately. Masonry and brick-work are attacked by water and by colonising plants.

Foundations are weakened by the scouring action of water flow of rivers or tidal action of estuaries and failure due to this cause are well documented. Road vehicles frequently collide with the abutments of bridges or become wedged under restricted clearances. This problem is so common that many administrations have put in place elaborate systems to combat what, at first sight, seems to be an easily avoided problem.

The paper will conclude with a discussion of some techniques of condition monitoring of bridges that are designed to permit maintenance to be performed on a planned basis rather than in reaction to crisis.

KEYWORDS: Railways, bridges, failure, collapse, accident, materials, scour, corrosion, inspection, maintenance.

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Near fault earthquake effects on the response of concrete structures

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ABSTRACT: Near-fault ground motions have special characteristics that affect the response of structures. In the near field in the forward directivity zone, the velocity records are characterized by pulse type motion of long duration. In addition, the short travel distance of the seismic waves does not allow enough time for the high frequency content to be damped out of the record. The objective of this study is to evaluate the effect of near fault earthquakes on the response of various reinforced concrete structures. Four moment resisting frame buildings of three, six, twelve and twenty storeys were designed according to current codes. The nonlinear response of the structures when subjected to a set of near fault ground motion was analyzed. Results were obtained in the form of maximum inter-storey drift, storey shear demand, static nonlinear pushover and dynamic capacity curves. It was found that structures designed to meet the minimum code requirements may suffer severe damage when subjected to near-fault records.

KEYWORDS: Near fault, earthquake, response, reinforced concrete, moment resisting frame, base shear, drift, dynamic capacity curves.

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Finite element and experimental studies of tension field action in composite plate girders

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ABSTRACT: The paper presents the details of the studies undertaken to investigate tension field action in the case of steel-concrete plate girders. The studies include a series of tests to failure on medium-scale composite plate girders and the corresponding inelastic finite element analysis of the test girders. A three dimensional finite element model, using a general purpose finite element software, has been used to carry out the nonlinear analysis on composite plate girders under negative bending and shear loading. Details of the finite element modeling and the experimental program are presented in the paper. In the experiments, extensive instrumentation to measure strains and deflections in the girders were provided so that complete behaviour of the girders could be traced and the growth in the tension monitored. Results obtained from the finite element analysis are compared with the corresponding experimental results. It is observed from the comparison that the proposed nonlinear finite element model is capable of predicting the ultimate load behavior of steel-concrete composite plate girders to an acceptable accuracy. Results are also presented to explain the development of the tension field in the webs and, to illustrate a measure of the contribution by the concrete slab acting compositely with the girder to the changes in tension field compared to a plain steel girder.

KEYWORDS: Finite element, nonlinear analysis, plated structure, tension field action, plate girder, composite girder, steel-concrete composite, shear buckling, web buckling.

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Elastic out-of-plane buckling of laterally-fixed arches subjected to uniform bending

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ABSTRACT: This paper presents a closed form solution for the elastic flexural-torsional buckling of a laterallyfixed circular arch that is subjected to uniform bending. The formulation makes recourse to an orthogonal rotations matrix to derive the finite strains and the energy equation for buckling. Whilst the lateral buckling of pinned arches has received some research treatment, it appears that the flexural-torsional buckling of fixed arches has not been reported in the open literature. The buckling solutions are quite different from those of pinned arches, and furthermore they illustrate that the concept of an 'effective length' approach, that is often useful for determining the buckling response of straight beams or columns, is not applicable for the flexural-torsional buckling of arches.

KEYWORDS: Arches, buckling, elastic, fixed, flexural-torsional buckling.

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Some trends and advantages of wood application in contemporary civil engineering

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ABSTRACT: The wood is one of the oldest materials used by peoples to build of homes and bridges. Now such activity is extended on wider application. So, contemporary we say about very wide domain of man activity called as civil engineering. During centuries, the wood application has different trends. It follows each time of actual possible technology to be applied by erection of particular objects. Specially, in middle of XX century, for the reason of mass production of steel, aluminium, concrete, reinforced concrete and composites, the wood was almost eliminated from civil engineering applications for carrying systems. But even in this domain technology was slowly going ahead and simultaneously designers were starting yet once more carefully consider to come back to this material. There can be used natural round-poles, planks, play-wood, glued elements, bamboo, etc. The wood has many advantages: it is lightweight and ecological materials, natural, self-renovate, easy in production, for connecting and in montage, it belongs to elegant materials and it is cheap, too. Applying modern technologies, it is resistant for: corrosion, insects, time, and relatively on fire, too… Specially, glued wood can be formed in any forms and shapes. Its architectural possibilities are infinite.

Now, wood is quickly coming back to many objects for:

– single girders,
– space bar structures, single-, double- and more layered for roofing systems—plane, vaults and domes, for structures of large span,
– elements of composite girders, plates and shells, are combined often with other materials.

In paper, are mentioned some examples of structures designed by: S.Du Chateau, P.Huybers, K.Linkwitz, J.K.Natterer, J.Chilton, Z.Mielczarek, K.Kawaguchi and the other printed in some books and presented during some world conferences, specially during LSCE 1995, 1998 and 2002 in Warsaw.

KEYWORDS: Wood, timber, structures, connections, materials, technology.

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Strain hardening, local buckling and lateral torsional buckling in plastic hinges

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ABSTRACT: Modern design codes for steel structures, and Eurocode 3 is the most significant example, require that second-order effects are taken much more seriously in design based on plastic theory. In the UK in particular, plastic design has become the norm for a large class of low-rise framed structures and this situation has potentially serious implications for both the economy of the resulting designs and the complexity of the design procedure. It has been well-known since the outset of plastic design that the deleterious influence of second-order effects is at least partially offset by strain hardening in the plastic hinges and that, in many practical cases, these two effects may be approximately in balance.

This paper first reviews the early research into the influence of strain hardening and shows that this offers a suitable approach for inclusion in second-order plane frame analysis software but that more information is required regarding the characteristics of modern steels and modern UB/IPE sections. This information is provided by a recent numerical study based on the results of a large number of mill tests. Complimentary numerical research reveals that strain hardening has to be used with caution because the possibility exists that a stable strain hardening moment-rotation relationship may not be obtained because of local buckling, lateral torsional buckling and their interaction. At the time of writing, it is not clear whether current guidelines are sufficient to ensure that this does not happen.

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Debonding in FRP-strengthened RC beams due to intermediate flexural cracks

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ABSTRACT: An important failure mode for an RC beam strengthened with an externally bonded FRP plate is debonding of the FRP plate from the soffit of the beam due to major flexural cracks. In this failure mode which is commonly referred to as intermediate crack (IC) debonding, debonding initiates at a critical section in the high moment region and then propagates to one of the plate ends. Despite many experimental and theoretical studies of this debonding failure mode, accurate predictive models for IC debonding failures have not been developed. This paper presents a new smeared crack approach for the finite element simulation of the IC debonding process, in which a new model for the FRP-to-concrete interface capable of capturing the effect of local slip concentrations near a flexural crack is proposed. The finite element model is shown to be accurate through comparisons with the results of 45 beam tests. The paper also presents an accurate and simple design model based on interfacial shear stress distributions from finite element analysis. The new design model is shown to be accurate through comparisons with the test results of the same 45 beams.

KEYWORDS: FRP, concrete, bond-slip model, design model, debonding, finite element analysis.

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First hinge design of thin-walled steel members

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ABSTRACT: The study consists of three parts summarizing recent research and presenting a new approach to first hinge design of thin-walled steel members. First analytical and numerical methods for the evaluation of plastic cross section resistance depending on the internal forces and section shape are reviewed and compared. The second part discusses and summarizes problems resulting from application of first hinge design to 3D beamcolumns and compares results with consistent materially nonlinear structural analyses. Part three is concerned with a new generally applicable approach for evaluation of plastic resistance of open thin-walled steel cross section with arbitrary shape and subjected to simultaneous bending, uniform and nonuniform torsion.

KEYWORDS: First hinge design, thin-walled members, cross section resistance, linear/nonlinear optimization, plastic torsion, nonuniform torsion.

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Forces in bridging and bracing systems for roof purlins with concealed fixed sheeting

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ABSTRACT: Roof systems with concealed fastened sheeting attached to purlins and subject to wind uplift and gravity loads are studied using 3D frame models that account for thin-walled torsion of the purlins and the diaphragm shear stiffness of the sheeting. Axial forces and bending moments in the bridging system supporting the purlins are computed and compared with the laboratory test results of full scale roof systems. Parametric studies of roof systems investigating the effects of the number of rows of bridging and the sheeting diaphragm stiffness are presented.

KEYWORDS: Roof systems, purlins, bridging, sheeting, computer models, testing.

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Thermal buckling of laminated composite and sandwich plates

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ABSTRACT: A single-layer (global) higher-order theory is presented for analyzing thermal buckling problems of laminated composite and sandwich plates. The complete effects of both shear and normal stresses can be taken into account within the approximate two-dimensional theory. Based on the power series expansions of C^{∞} continuous displacement components, a fundamental set of equations of a two-dimensional higher-order theory of laminated plates is derived through the principle of virtual work. Several sets of the governing equations of truncated approximate theories are applied to the analysis of thermal buckling problems of a simply supported laminated composite and sandwich plates. Critical temperatures of a simply supported laminated composite and sandwich plates are obtained by eigen-value problems. The two-dimensional global higher-order theory can predict the critical temperatures and modal displacement distributions of simply supported laminated composite and sandwich plates subjected to thermal loadings accurately.

KEYWORDS: Laminated composite plates, sandwich plates, higher-order plate theory, thermal buckling, critical temperature, modal displacement.

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Structural aspects of wind energy turbines

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ABSTRACT: The fast increase of the wind power market in Europe, especially in Germany and Spain, promoted a dynamic development of wind turbine technology in the last decade. New concepts in the field of construction, control and generation resulted in improved quality and efficiency of the wind turbines. With the growing rotor size an increasing energy capture could be reached, thus contributing to reach the overall aim of any recreational energy production—the reduction of CO_2 emissions.

The paper will present some overall aspects concerning the actual and future development of wind energy capacities world-wide. Especially addressed are experiences and challenges in proof and construction of wind energy turbines in Germany, considering

- different foundation concepts,
- alternative tower constructions: steel or concrete,
- high-cycle dynamic loading and response,
- fatigue behaviour.

The assessment of dynamic response and fatigue behaviour is of essential importance for design and life-cycle prediction. Both are characterized by the eigenfrequencies considering the realistic stiffness of the structure, i.e. flexible soil properties and non-elastic tower stiffness depending on non-linear material properties of the tower's structure. This especially holds true for concrete towers with highly non-linear material laws, different for concrete under compression and under tension.

The paper will focus on some actual research results in this issue.

KEYWORDS: Wind energy, concrete, high-cycle fatigue, damage behaviour, resonant response.

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Root hair tip growth

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ABSTRACT: Tip growth of plant root hairs is basic and deceptively simple. A single cell has a wall that is cylindrical with a prolate spheroid as an end cap. The growth takes place in the end cap. The mechanical loading which drives the growth consists of turgor pressure of magnitude 5–10 atmospheres. A Lagrangian formulation provides the kinematics of the growth process, and indicates that for steady state, axisymmetric growth, the current velocity depends on only the geometry and the stretch ratio. The ratio of current mean strain rate to mean stress provides a coefficient of growth rate. This depends on position, which can be interpreted as a dependence on the stretch ratio, i.e., the past history of the wall element. Thus a simple mechanical description appears to be appropriate.

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Numerical analyses of fracture in structural materials

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ABSTRACT: Crack growth analyses are often based on using critical values of crack-tip parameters, such as the stress intensity factor, the J-integral or the COD. The prediction of crack growth may also be based on the fracture mechanism operating on the microscale, by using constitutive relations that account for the mechanism of damage evolution. This has been done in various studies of crack extension by ductile void growth to coalescence. Also for creep failure in metals at high temperatures the mechanisms of diffusive cavity growth in grain boundaries and grain boundary sliding have been used in studies of creep crack growth, and low cycle fatigue has been studied in terms of continuum damage mechanics. In the lecture examples of these analyses will be presented. Also the representation of the fracture process in terms of a traction separation law for the crack surface, with standard plasticity theory accounting for the inelastic deformations around the crack, can lead to very useful understanding of crack growth behaviour. The discussion will include such applications of cohesive zone models.

KEYWORDS: Fracture mechanics, crack growth, damage mechanics.

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3.
Industrial shell structures and buckling of shells

New developments in hyperbolic cooling tower design

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ABSTRACT: Due to the rising demand for cheap and economical electric energy, balanced by requests for its resource-saving production, natural draft cooling towers have grown to enormous heights. Simultaneously, their shells developed to the largest existing reinforced concrete shell structures. Compared to shell roofs or shell tanks, cooling tower shells are exposed on both faces to the plant environment, generally aggressive media due to fossil fuel. Additionally in German power stations, aggressiveness in the cooling towers' interiors is slightly increased by release of cleaned flue gases therein, saving a smoke stack as gas dissipation device.

So in addition to classical design conditions for deadweight G, wind W, temperature ΔT and hygro-thermal attack, often probably seismic actions, durability is the key issue in the design of these structures. Possible structural shell repairs are limited to rather short shut-downs of the plant, but with inner and outer surfaces of more than 60.000 m^2 each for the Niederaussem tower, sufficiently long shut-downs for surface repairs are illusionary.

The paper will report first generally on the new cooling tower, then on typical structural design efforts for cooling tower shells of extreme largeness, namely the shape optimization of the tower, the construction of the flue gas inlet, the application of special acid-resistant high-performance concrete, and on design concepts within the durability design of the shell.

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Nonlinear analysis of a collapsed heater stack during the Ismit (Kocaeli) Turkey earthquake of August 17, 1999

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ABSTRACT: During the Ismit (Kocaeli) Earthquake of August 17, 1999, a 115 m high reinforced concrete chimney or heater stack, located at the Tüpras Refinery, collapsed. The falling debris cut 63 pipes, which contributed to interrupted production for 13 months. This stack was designed and constructed according to international standards and is representative of similar structures at refineries throughout the world, including those in earthquake-prone regions. It was distinguished from similar stacks at the site by a much larger rectangular opening for the flue duct, circumscribing a horizontal arc of about 50°. The opening was located about 1/3 of the height above the base and appeared to be the region of initiation of the collapse.

The investigation is focused on the dynamic response of the stack due to an earthquake motion recorded at a nearby site. In this paper, the results of a response spectrum analysis of the Tüpras stack and a generic U.S. stack are described. Then, a nonlinear static analysis of the collapsed stack using a demand-collapse comparison is summarized. The demand is represented by an acceleration-displacement response spectrum based on the recorded motion as well as some smoothed adaptations typical of design spectra, while the capacities are calculated from pushover curves using a nonlinear reinforced concrete finite element analysis.

Results are described that show the effects of the hole and the orientation of the motion with respect to the hole. The results confirm that the stack could readily fail under the considered earthquake and are also consistent with the debris pattern.

KEYWORDS: Stack, chimney, stress concentration, response spectrum, earthquake analysis.

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Stability of spherical shells under external pressure

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ABSTRACT: Most of the present design rules and recommendations for spherical shells are based on experimental tests in the laboratory. With the progress of the computer based methods systematic numerical simulations are now possible taking into account all relevant details. On this basis a draft for design rules for fully spherical shells as well as for spherical caps is presented and discussed in the paper. This proposal is also employed for the improvement of European recommendations and shall supplement the Eurocode 3 ENV 1993, 1999 which does not include the chapter on the buckling design of spherical shells. The results are obtained by solving the fully nonlinear equations for imperfect spherical shells using a semi-discrete finite element method. This approach described elsewhere in the literature—was especially developed for shells of revolution and has been applied to various problems.

KEYWORDS: Spherical shells, buckling behavior, recommendations, imperfection sensitivity, shells of revolution, semi-discrete method, parametric numerical simulations.

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FEM study of steel liquid storage tanks

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ABSTRACT: A study is conducted of two sets of above-ground steel liquid storage tanks. The first set comprises often broad tanks with height-to-radius ratio generally less than 1.0. These tanks are representatives of a typical oil storage tank farm. The second set of tanks comprises of ten tall tanks, with height-to-radius ratio generally exceeding 2.0. These tanks are representative of tanks which buckled or collapsed during past earthquakes. The finite element method (FEM) is used to carry out collapse and vibration analyses of the tanks. Existing differential quadrature method (DQM) programs are used to confirm some of the FEM results, and further validation is obtained by making comparison with available results in the literature. The factor of safety of the tanks as given by the API 650 code is also calculated. Correlations between the FEM and code data are sought. Finally a preliminary study of the effect of ring stiffeners is made, and conclusions are drawn.

KEYWORDS: Liquid storage tank, stiffeners, finite element method.

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Numerical approach for the identification of critical load factors for high-strength concrete shells

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ABSTRACT: Besides reaching ultimate stresses the loss of stability is the second mechanism to loose loadbearing capacity. This kind of failure is mainly observed at structures with low bending stiffness but high compression stresses. Thus the loss of stability is an important proof for steel constructions cause of their low thickness-height ratio. As well this behavior is well-known from the design of slender steel resp. reinforced concrete columns. Hereby the research in the last decades has reached a high level and has led to various detailed proof concepts in the corresponding codes.

The description of the material nonlinearity seems no longer be a handicap due to the formulations of continuum mechanics and high computing capacity for such an analysis. In addition, the recent improvement of reinforced concrete to a material with higher stiffness and higher compression strength has opened the possibility to minimize wall-thickness at design state, thus enhancing the danger of buckling failure. Finally the fact that the stability failure is not mentioned in the new German code DIN 1045–1 any longer, but only considered by the restriction of steel and concrete deformations have been the motivation to analyze the loss of stability of such structures in a more realistic way with respect to the nonlinearities of the composite material reinforced high-performance concrete.

The paper will present numerical approaches to identify the buckling phenomena of large-scale shell structures made of reinforced concrete. Especially concrete with strength above 50 N/mm^2, so-called high performance resp. high strength concrete, is considered. It is planned to show an alternative way to determine a more realistic critical load factor for future design and proof of thin concrete shells like cooling towers, shell roofs and especially large-sized solar chimneys.

KEYWORDS: FE-analysis, shell, high-strength concrete, material nonlinearity, stability, buckling, bifurcation.

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Long-term structural performance of cooling-tower shells: A review of thirty years of research

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ABSTRACT: This paper comprises a review of research by various investigators since the early 1970s, on the long-term structural performance of concrete cooling towers, and covering case studies of towers that experienced structural damage, as well as theoretical studies of causes of structural deterioration. The paper first looks at the issue of loading on cooling towers, as prescribed by existing codes. Attention is then paid to two major aspects of structural deterioration, namely excessive deformation and cracking of the shell, and known cases of damage and collapse are discussed. Views on the possible causes of cracking in concrete cooling towers, and on the processes of crack initiation and subsequent propagation, are considered. Of particular interest are studies on the influence of surface imperfections on the cracking behaviour and collapse mechanisms of towers. Various findings on the causes of deterioration and collapse of cooling towers are summarized; these include inadequate design, construction imperfections and grouping effects under wind loads.

KEYWORDS: Cooling tower, loading, durability, crack propagation, deformations, imperfections, condition survey.

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Post-buckling of cylindrical shells in terms of different shell theories

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ABSTRACT: The sensitivity of the shell theory with regard to the initial post-buckling behavior of cylindrical shells is carried out by comparison of three different shell theories: Donnell in 1933, Sanders in 1963 and Timoshenko in 1961. The procedure involves non-linear partial differential equations which were converted into a sequence of three linear sets. A general code was developed and used in studying the effect of higher exactness of the shell theory on the imperfection sensitivity behavior. It was found that the more accurate the theory used, the lower the sensitivity to imperfection.

Buckling behaviour of model steel base shells of the Comshell roof system

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ABSTRACT: Steel-concrete composite shell roofs (Comshell roofs) are formed by pouring concrete on a thin stiffened steel base shell which serves as both the permanent formwork and the tensile steel reinforcement. The thin steel base shell, constructed by bolting together open-topped modular units consisting of a base plate with surrounding edge plates, is a steel shell with thin stiffeners in both directions. The new system retains all the benefits of thin concrete shells, but eliminates the need for temporary formwork and minimises the required falsework. A key issue in the design of such shell roofs is to ensure that the steel base shell can carry the wet concrete loading safely. This paper presents the results of a series of buckling experiments on model steel base shells under simulated wet concrete loading.

KEYWORDS: Shells, concrete shells, bolted steel shells, composite construction, modular construction, wet concrete loading, buckling.

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Buckling of a stiffened cylindrical shell structure

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ABSTRACT: The linearized buckling problem of a submerged stiffened cylindrical shell structure subjected to a uniform external pressure is considered. The structure consists of a series of four circular cylindrical shells, with axes in the horizontal plane, and with 45° oblique ends. The shells are joined together end-to-end producing a complete 360° turn. The loading is assumed to arise from a deep-water external pressure. For the analysis, a finite element method (FEM) software is used. Results from the analysis are validated through comparisons with related results given in the literature. The effect on the buckling pressure of variations of the problem parameters including shell size, shell thickness, and different reinforcement schemes, is determined. This work represents a preliminary study on this form of shell structure, and provides useful information for engineers interested in its application.

KEYWORDS: Stability, cylindrical shell, stiffeners, finite element method.

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Verification of a new analytical solution for the buckling of long embedded cylindrical shells using finite elements

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ABSTRACT: The analysis of buckling of cylindrical shells embedded in an elastic medium is important in the design and construction of buried tubes. The problem has recently been reanalysed using the energy method together with a Rayleigh-Ritz trial function, and some rather interesting results have been obtained. For simplicity, linear elasticity theory, inextensional buckling and perfect contact between the shell and surrounding medium have been assumed. The analytical solution thus obtained is very similar to that of Forrestal and Herrmann if the surrounding medium is incompressible, i.e. with Poisson's ratio of 0.5. For other values of Poisson's ratio, however, the two solutions diverge. The smaller the value of v, the bigger is the difference, with the solution of Forrestal and Herrmann being relatively insensitive to changes in Poisson's ratio of the surrounding medium. Moreover, the newly derived solution gives lower predictions for the buckling load and hence can provide better agreement with experiments even without considering imperfections.

In this paper, the new buckling solution for an embedded cylindrical shell is verified by comparing its predictions with those using a commercial, finite-element (FE) software for a range of material and geometric parameters. It is shown that there is excellent agreement between the elastic buckling loads given by the new solution and those predicted by FE. Attempts are also made to extend the analytical solution to cover smooth shell-medium interface.

KEYWORDS: Elastic buckling, embedded shells, finite element method.

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Numerical and experimental studies on the role of plastic hinge in the buckling behaviour of spherical shells under axial impact

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ABSTRACT: Thin walled spherical shells have been used for many applications because of its energy absorbing capacity in the plastic deformation. As it is closer to the ideal energy absorber by deformation, the buckling behaviour has been important for the design methodology in crucial applications like aerospace. In this paper, the buckling behaviour of the spherical shells has been considered. Various aluminium geometry spherical shells have been selected and various models are spun. A gravity drop rig is used to carryout dynamic experiments. Numerical simulations are carried out for all the designated samples using LS-DYNA® and the load, acceleration, velocity, deformation histories are obtained. Material, geometric and contact nonlinearities are incorporated during the analysis. The stress-strain curve of standard sample made from the material is used as input. Piecewise linearity is taken in the plastic region of the material curve. Initial velocity is given and suitable friction factor between the plate and specimen is assumed. The obtained values from dynamic experiments are used for validation.

In analytical approach, mathematical models developed for spherical shells using energy method under static load is compared with dynamic conditions. The obtained models compare very well with the experimental results. The rolling plastic hinge that played an important role in the energy absorption has been predicted and numerically simulated. Experiment results also confirm the assumed variation of rolling plastic hinge radii.

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4.
Laminated composite plates and shells

A semi analytic approach for analysis of laminated piezoelectric cylinders

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ABSTRACT: A class of novel analysis methods for determining the structural response of piezoelectric cylinders is presented. The said class of methods is based on the decomposition of the mechanical and electrical fields into cross-sectional and axial parts. These decomposed fields are used to obtain the variational form of the governing equations of electrostatics and elasticity in the cross-sectional plane. The axial problem, that is consistent with the aforementioned decomposition of the fields, admits analytical solutions. In its most general form, such solutions are the superposition of so-called *Saint-Venant* and *Almansi-Michell* solutions. The cross-sectional problem is discretized and solved via finite element methods. The method, obtained thus, is a *semi-analytical method* for prismatic domains. For brevity, an axisymmetric version of the proposed semi-analytic method is presented here, but the method can handle arbitrary cross-sectional geometry and material distribution. An example application is provided, which involves the determination of optimum thickness to inner radius ratio and crystal orientation angles of a homogeneous Lead-Zirconium-Titanate (PZT4) cylinder for various actuation and sensing modes.

KEYWORDS: Piezoelectricity, sensors, actuators, semi analytic, finite elements, PZT.

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Buckling analysis of composite panels

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ABSTRACT: One approach to formulating geometrically nonlinear shell finite elements is to accept the linear formulation as representative of shell behavior and upgrade it to a nonlinear shell element using the perturbation method. Load perturbation of the linear discrete equilibrium equations of an element in its global coordinate system leads to the well established definition of the geometric stiffness matrix as the gradient of the nodal force vector when the stresses are held fixed. This approach has been successfully applied to trusses, space frames, membranes and thin isotropic shells.

Here the CST (constant strain triangle) membrane finite element and the DKT (discrete Kirchhoff theory) plate finite element comprise the linear shell element. The geometric stiffness matrix is then derived by first performing a load perturbation on the linear equilibrium shell equations with respect to the local coordinates system to yield the in-plane geometric stiffness matrix. Then out-of-plane considerations that involve the effect of rigid body rotations on member forces complete the local geometric stiffness matrix formulation. The local coordinates' route is taken in order to circumvent the taking of impossible derivatives of the 3-D rotation matrix.

In addition, described herein is an experiment of epoxy-graphite curved composite panels under uniform axial compression. The tests were performed at the Aircraft Structures Laboratory of the Technion. Results of one panel are used to validate the effectiveness of the presented shell element.

KEYWORDS: Geometrically nonlinear analysis, buckling of shell structures, composite material, finite element formulation.

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Numerical analysis of strength of a composite structure on an example of chosen construction with damage caused by external conditions

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ABSTRACT: The composite blade of the polish made helicopter “Sokół” (“Falcon”) was taken into considerations. The FEM model enables analysis of failure of particular plies in laminates that build the structure of the blade. The model has been verified on the base of experimental tests performed by the manufacturer. The maximum loading force of the spar was determined in the numerical test of stretching until the first damages to the plies occurred in the sections close to the axis of rotation. The case of load by centrifugal force was taken into consideration with the use of the model of the whole blade. The analysis of composites of the blade was conducted with the use of Hill’s criterion of failure. In case of getting a hit various forms of damage to a blade are possible and they can be simulated numerically with the use of the elaborated FEM model. The FEM model of helicopter main rotor composite blade takes into account arrangement of laminates and characteristic details of construction, among others step decrease of thickness of roving strips.

The model was verified in comparison to experimental measurements of deformations made on the set of real blades undergoing the load of their dead weight and additional known test weight. The error did not exceed 5%. Behaviour of the model under the nominal centrifugal load complies with the real observations. Especially, the natural deflection tends to disappear under centrifugal load. Such behaviour of the model complies with the behaviour of the real construction.

It may be used for simulations of the process of fracture of construction.

KEYWORDS: Finite element method, composite structure, helicopter main rotor blade.

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Performance characteristics of compound curved sandwich shell structures

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ABSTRACT: Sandwich shells have recently emerged as aesthetically pleasing, efficient and economical structural systems, with a number of applications. They combine the advantages of sandwich layer technology together with those of shell action. With different materials and thicknesses used in the sandwich layers, their performance characteristics largely remain unquantified and there are no guidelines at present for their design. This research has been conducted to provide verification, through finite element modeling and testing, for the application of this technology to domed styled dwellings with research currently being conducted into the further application to roofing structures.

KEYWORDS: Sandwich panel, sandwich shell, shell, dome, FEM, compound curved.

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On the stiffening effect of fibre-reinforced composite panels

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ABSTRACT: An increasing demand has been noticed in the use of fibre-reinforced polymeric materials for large plated structural applications such as in the ship and civil construction sector. Structural plates made out of FRP materials comprise a number of laminae of relatively stiff fibre reinforcements set in mostly low-modulus resin matrices laminated together. The failure mode of fibre reinforced composite materials is rather more complex than that of isotropic material. Most structural plate elements are combined with stiffening elements and are subjected to large transverse loads, such as water pressure on a ship’s hull or air pressure on aircraft.

Experimental investigation has been focused on the failure behaviour of stiffened and unstiffened composite panels under such loading conditions. These experiments will provide evidence to benchmark the theoretical derived equations for laminated orthotropic stiffened and unstiffened panels under transversal loading cases.

To investigate the ultimate ply failure of composite panels it is necessary to observe the strain and stress of each ply in a laminate. For the measurement of the strains on several locations in each ply, strain gages are embedded inside the laminate. In this investigation, six different specimens made of four layers of unidirectional glass fibre and an epoxy resin, differing in shape and number of the stiffeners or in fibre direction pattern. Local strain differences from layer to layer or location to location on the same layer indicates failures and material behaviour. An array of twenty strain values for each load step until the ultimate failure of the plate are noted and finite element analysis is carried out to compare the results.

KEYWORDS: Stiffeners, composite panels, finite element analysis and transverse loading.

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Higher order refined theory for the stress analysis of angle ply composite and sandwich plates

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ABSTRACT: Analytical formulations and solutions to the stress analysis of simply supported anti-symmetric angle ply composite and sandwich plates hitherto not reported in the literature based on a higher order refined theory already reported in the literature are presented. The theoretical model presented herein incorporates laminate deformations which account for the effects of transverse shear deformation, transverse normal strain and stress and a nonlinear variation of in-plane displacements with respect to the thickness coordinate-thus modelling the warping of transverse cross sections more accurately and eliminating the need for shear correction coefficients. A simply supported plate subjected to sinusoidal transverse load is considered throughout as a test problem. The equations of equilibrium are obtained using Principle of Minimum Potential Energy (PMPE). Analytical solutions are obtained using Navier's solution technique. The accuracy of the solutions obtained using the model is first established by comparing the results with the solutions available in the literature. After establishing the accuracy, new results for the multilayer sandwich plates with angle ply face sheets are presented which will serve as a benchmark for future investigations.

KEYWORDS: Analytical solutions, higher-order theory, sandwich plates, navier's solution, antisymmetric, angle ply, stress analysis.

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Thermal residual stress analysis of functionally graded Ni-Al_2O_3 plates

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ABSTRACT: Functionally graded materials (FGMs) have recently attracted much interest as heat-shielding materials since they consist of continuous change of composition of different material components. Functionally graded plates (FGPs) experience thermal residual stresses due to mismatches of thermal and mechanical properties of their constituents. This paper addresses thermal residual stresses in Ni-Al_2O_3 functionally graded materials using the finite element method for uniform, linear and parabolic temperature distributions across the plate thickness. It was found that the thermal residual stresses were strongly dependent on the compositional gradient and temperature distributions. In the case of the linear variation of composition (m=1.0), the parabolic temperature distribution results in minimum residual stresses. The maximum residual compressive stresses on both surfaces of the FG Plate occurred for a parabolic temperature distribution for m<1.0, whereas maximum residual tensile stresses appeared for a uniform temperature distribution and for m≥1.0.

KEYWORDS: Functionally graded materials, thermal residual stress, thermal analysis, finite element method.

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Researches on load-bearing capacity of point-support laminated glasses

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ABSTRACT: In this paper, experiments, including a long-term test, are conducted on laminated glasses in order to study the load bearing capacity. The load-displacement relation, load-stress curves and also curves of displacements and stresses changing with time are obtained and the effect of loading time is analyzed. Comparison between experimental results and the design code (Technical Specification for Point-Supported Glass Curtain, CECS127:2001, CECS is the abbreviation of China Association for Engineering Construction Standardization) indicates that the current design code will lead to conservative results. Based on experiments, a finite element analysis on laminated glass is performed. The computational model is established on the basis of experimental data. Using this proposed model, numerical studies on laminated glasses with different thickness can be conducted. The modification on the equivalent thickness of laminated glasses given in the design code (CECS127:2001) is suggested. The work of this paper will be helpful to further improving the accuracy of the current design code.

KEYWORDS: Laminated glasses, experiment studies, creep characteristics, equivalent thickness.

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Residual stresses in thermoset polymer composites

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ABSTRACT: In this research, the residual stresses in thermoset polymer composites are studied. In general, these stresses are studied in macroscopic and microscopic points of views. Curing process, moisture and temperature are the main reasons for establishment of these stresses in composite materials. The stress free temperature for a laminated composite is measured for various samples. Two analytical and one experimental method are used for determining the macroscopic residual stresses due to curing process of orthotropic thermoset polymer composites. The classical lamination theory is used for calculation of residual stresses in each layer of laminated composites. It is shown that the capability of the classical lamination theory in calculation of the residual stresses without considering the temperature dependent properties is very well. However, the final shape of unsymmetrical laminated specimen at room temperature, calculated by classical lamination theory, is not accurate generally. Energy method is used for modification of classical lamination theory in anticipating the final shape of the unsymmetrical laminated composites. Using hole-drilling method, glass/epoxy and carbon/epoxy laminated composites are studied experimentally. It is shown that the hole-drilling method for accurate measurement of the residual stresses in the first layer of laminated composites is a reliable method.

KEYWORDS: Residual stress, composites, laminate, hole-drilling method, glass/epoxy, carbon/epoxy, experiments.

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Vibration analysis and shape control of laminated composites with piezoelectric elements. Antifouling process

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ABSTRACT: Structures immersed in sea water are rapidly covered by fouling. This problem reduce precision, cause structural instability and affect operational performance. Numerous works have been carried out in order to present an effective protection system using the mechanical propagation waves. Active control of vibration by piezoelectric materials distributed about the structures is the interesting application of piezoelectric materials for antifouling process. This paper develops the theory of piezolaminated plate, followed by vibration analysis. The active vibration and shape control of composite plate is studied using the governing equations of motion. This study evaluates the effectiveness of actively controlled piezopolymers for antifouling process.

KEYWORDS: Vibration, active control, shape control, piezoelectricity, composite, fouling.

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5.
Other plate and shell problems

Analogy model for the axisymmetric elastic edge bending problem in shells of revolution based on Geckelers approximation

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ABSTRACT: In this paper a general approach to the analysis of axisymmetric stress states at arbitrary shell junctions of thin-walled axisymmetric shell structures is presented which is based on a newly developed effectivering analogy model. The axisymmetric elastic stiffness of this analogous effective ring is equivalent to the axisymmetric elastic boundary stiffness of the related shell segment. The effective ring has a two-point crosssection with one point located at the shell boundary and the other one located excentrically above the plane of the circular boundary. The ring is capable of exactly representing the linear-elastic static force-deformation behaviour due to uniform radial boundary forces and meridional boundary moments acting at the edges of long axisymmetric shell segments, i.e. exact in the sense of Geckelers approximation. This ring girder analogy represents a long-searched missing link and the resolution of a paradox, since the Geckeler approximation suggests an analogy between the edge bending effects of (long and steep) general shell of revolution and the cylindrical shell. However, this analogy has only restricted validity, i.e. for the governing differential equation and fundamental solutions, but not for the solutions of the boundary value problem. The well-established effective area model, quite naturally, represents a special case of this more general effective ring model by restraining the meridional rotations. The analysis procedure developed in this paper is general, yet straightforward to apply and simple enough to be used in daily engineering work or to be included in future design codes. The effectiveness of the proposed analogy model is demonstrated by practical examples.

KEYWORDS: Shell of revolution, edge bending, exponential decay, effective length, effective area, effective ring girder, analogy model, Geckeler approximation, Reissner-Meissner equations, axisymmetric loading.

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Effective and efficient analytical study of full circular cylindrical shells

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ABSTRACT: In this paper the homogeneous solution to the Morley-Koiter differential equation, describing the elasto-static behavior of thin full circular cylindrical shells, is analytically solved for boundary conditions at the circular edges. A series development in circumferential direction is employed and an exact solution for the eight roots of the characteristic equation is presented. This solution can be used and is exact for all possible circumferential modes, which is a unification of former results by other authors. A logical step is to approximate this solution by a series development since the shell is assumed to be thin compared to its radius.

The resulting expressions provide valuable insight into the elasto-static behavior, e.g. regarding the prevailing parameters, the influence lengths and the difference between membrane and bending dominated cases.

Next to this paramount advantage of the generic expressions, the solution allows easy implementation into a straightforward computer program in a stiffness method framework. In this calculation method, which is fast working on a personal computer, the stiffness matrix of complete shell parts is derived and several boundary conditions and ring stiffeners as well as surface and circumferential line loads are implemented. Distributed loading on the shell parts is accounted for through application of the inhomogeneous solution. To show the added value, numerical results are included.

KEYWORDS: Elastic thin shell, linear theory, full circular cylinder, Morley-Koiter equation, stiffness method.

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Fracture analysis of plate structures by spline finite strip method

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ABSTRACT: The finite strip method is a well-known numerical method in structural analysis and is one of the most efficient tools for the analysis of bridge structures due to its semi-analytical nature. The earlier finite strip method is restricted to regular prismatic structures, whereas today the method, in particular with the development of the spline finite strip, has been extended the applicability of the method to various complex problems, e.g. buckling and vibration of composite laminated plates, non-linear analysis of Midlin plates, double curved laminated shells, shear-deformable plates, etc.

The finite strip method was first introduced to fracture analysis several years ago using modified semianalytical Fourier expansions. By incorporating the Williams expansion in the spline finite strip displacement model, an effective crack strip for plane problems has been developed. As well the stress intensity factor, in this case, could be computed directly from this finite strip model.

In this paper, by using Tilley's anti-plane eigenfunction expansion and William's plane and bending eigenfunction expansions at a crack tip, a special crack strip can be developed for tearing mode; plane mode as well as bending mode of a plate structure in which the crack is assumed to be normal to the longitudinal direction of a strip. In this case, the stress intensity factor can also be computed directly from this finite strip model. A typical numerical example is given in the paper and compared with other numerical results to demonstrate the efficiency and accuracy of the method. By combining conventional spline finite strip with special crack strip, a new and efficient approach for fracture analysis of plate structures has been developed.

KEYWORDS: Finite strip method, fracture analysis, stress intensity factor, plate structure, spline function, displacement function.

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Finite element analysis of large openings in cylindrical shells

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ABSTRACT: Finite element analysis is carried out for cylindrical shell with large openings subjected to axial tension. By utilizing a parametric study, the paper investigates the effect of the size of the opening, on the stresses in cylindrical shells. It has been found that any increase in (a/R) ratio produces a correspondent increase in the stress concentration factor. This is particularly true for higher values of curvature parameter β. In all the cases studied, the membrane stress factor is more important than the bending one. Clearly, the high stresses occurred as a result of the existence of the opening in the shell is limited to small areas, and such a phenomena has only a local nature. However, it has been noticed that any increase in (a/R) ratio has a direct effect on the increase of the area of the local zone compared to the radius of the hole (a). Comparing the finite element results with those obtained from analytical solutions, the overall agreement between the two sets of results is found reasonably good. Furthermore, many models with reinforced openings are tested. It has been found that using reinforcements in the immediate area near the opening is more effective in reducing stresses. However, the efficiency of this method is reduced considerably when applied to larger openings or when the reinforced area becomes wider.

KEYWORDS: Shell, opening, reinforcement, stress concentration, cylindrical shell, curvature parameter.

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Stress concentration around circular holes in a finite plate using finite element method

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ABSTRACT: In this paper, a few of the important stress concentration problems commonly encountered in practice are studied by using the finite element method. The problems studied are: (i) variation in stress concentration factors (SCFs) due to variations in distance between holes in a plate having several circular holes, (ii) variations in SCF due to changes in edge-to-hole distance in a plate, and (iii) SCF in plates with several circular holes arranged in different patterns. A few of the results are compared with available analytical results. The results are useful for the design of plates with holes.

KEYWORDS: Stress concentration, stress analysis, FEM.

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Calculation of shear forces in plates and slabs using yield-line elements

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ABSTRACT: The yield-line element is a four-node rectangular plate-bending element used to model both elastic and inelastic plate behaviour. The formulation of the element is based upon a set of mixed unknowns to solve for bending moments and displacements. This paper describes the use of yield-line elements to solve for shear forces in isotropic slabs and plates. The results obtained for plates in single curvature are compared to exact solutions while the results for plates in double curvature are compared to available theoretical solutions and a displacement-type finite element. The solutions are shown to be exact for single curvature problems, which has always proven to be a powerful characteristic of yield-line elements. The solutions for double curvature problems are shown to be comparable to both the theoretical solutions and the displacement-type finite element.

KEYWORDS: Plates, slabs, yield-line finite elements, shear forces.

6.
Wind turbine structures

Analysis of the progressive damage behaviour of concrete wind-turbine towers

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ABSTRACT: The influence of thermal effects on the long-term durability of concrete structures is well-known, but consequences on the load-bearing behaviour in general do not occur. This holds true for structures under static loading conditions. In case of high-cycle dynamic excitation the degradation of the structural stiffness by cracking due to thermal effects may considerably diminish the ultimate load. This should be demonstrated by a pre-stressed concrete tower of a wind turbine. The fast development in wind energy with increasing capacities have lead to increasing dimensions concerning rotor diameter, generator size and tower height.

Until now most of the wind turbine towers have been made of steel. In future the increasing height will no longer enable to keep the tower's eigenfrequencies sufficiently far away from the turbine's frequency-range. Thus stiffer towers made of concrete are required. In general they will be designed with respect to a defined safety margin of their eigenfrequencies to the turbine's frequency of excitation, and then the dynamic structural response can be considered by a corresponding amplification factor. But in case of fracture and cracking the eigenfrequencies may change considerably, thus influencing the dynamic amplification and the ultimate limit as well. The theoretical background to model thus numerically will be presented and will be demonstrated at a pre-stressed concrete tower as a reference case.

KEYWORDS: Damage assessment, durability, FE-analysis, thermal loads, pre-stressed concrete tower, wind turbine.

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Optimization of a wind turbine tower structure

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ABSTRACT: Optimum design means search for better solutions, which better fulfil the requirements. The main requirements of up-to-date engineering structures are the suitable load-carrying capacity (safety), producibility and economy A structural optimization system is developed in which the safety and producibility is guaranteed by design and fabrication constraints and economy is achieved by minimization of a cost function.

This design system is now applied for the optimization of a wind turbine tower structure. The aim is to show the optimum design procedure for a 45 m high, slightly conical ring-stiffened shell tower with linearly varying diameter and step wise varying thickness. The shell can be approximated by three cylindrical parts of 15 m length, having constant average diameter and thickness. For the optimum design of a ring-stiffened cylindrical shell loaded in bending a cost minimization procedure is developed. Design constraints on shell buckling and on local buckling of flat ring-stiffeners are formulated according to Det Norske Veritas design rules.

The wind load acting on the shell tower is calculated according to Eurocode 1 Part 2–4. The wind force and bending moment acting on the top of the tower for a 1 MW wind turbine is given in the literature. To avoid the shell ovalization a domain of stiffener number is selected. In the constraint of shell buckling an imperfection factor is used, which expresses the effect of radial shell deformation due to shrinkage of circumferential welds.

The cost function includes the material and fabrication costs. The fabrication cost is formulated according to the production sequence and includes the cost of forming of shell courses into a near cylindrical shape as well as the cost of cutting of flat ring-stiffeners, cost of assembly and welding. The unknowns in an optimization procedure are the average shell thickness as well as the dimensions and number of ring-stiffeners.

KEYWORDS: Ring-stiffened steel shells, buckling of shells, structural optimization, wind turbine tower.

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Realisation of the inlet guide vanes—an integral part of the solar chimney

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ABSTRACT: Up to this point in time research on the South African solar chimney, proposed for a site in the Northern Cape, has addressed the structural integrity for the chimney structure, as well as air flow calculation, towards the optimal shape for the airflow channels. Not much work had been done on the realisation of the global structure, i.e. how the cardinal parts are optimized in an integrated structure. The inlet guide vanes (IGV's) lies central to such research efforts, being the main absorber and distributor of gravitational and lateral wind load of the chimney structure, while fulfilling the crucial role of channelling air and creating pre-swirl of the airflow onto the turbine blades. However, not much detailed research has been performed towards determining and characterising the many variables of the IGV's and integration with surrounding parts.

This paper reports on preliminary research done on these variables, ranging from structural integrity with regard to compressive, torsional and shear strength to economic feasibility. The outcome of this study will be a proposal as to what the optimal size of an IGV structure should be to bear the determined loads, while minimizing material cost/volume. Finite element methods will be used to create insight into IGV behaviour.

This study is valuable for researchers and designers of the solar chimney, serving as a reference for the design of the global structure.

KEYWORDS: Solar chimney, inlet guide vanes, alternative energy, sustainable energy, solar energy, solar tower.

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7.
Lightweight, space, cable and membrane structures

The new structural concept Tensairity: Basic principles

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ABSTRACT: Light weight structures are a challenge for the structural engineer and an important step towards a sustainable architecture. We present the new light weight structural concept Tensairity. In Tensairity, compression and tension are physically separated. Low pressure compressed air is used for pretensioning the tension element and for stabilizing the compression element against buckling. It can be shown that no buckling problem arises. This allows to use the material both for tension and compression to its yield limit. As a result, Tensairity girders can be by factors lighter than conventional beams. The technology is ideally suited for wide span structures and for deployable applications as temporary bridges, scaffolds or large tents. Prototypes, finite element analysis as well as experimental studies have proven the concept. In this paper, the basic principles of Tensairity are presented.

KEYWORDS: Tensairity, light weight, pneumatic structures, wide span structures, temporary buildings, temporary bridges, membrane, cable, airbeam, tensegrity.

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The new structural concept Tensairity: FE-modeling and applications

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ABSTRACT: The new lightweight structural concept Tensairity is based on a subtle interaction between cables, compression elements, membranes and low-pressure air. While the fundamental behavior of Tensairity is well described by a simple analytical model, detailed predictions rely on numerical analysis. We created and optimized a FE model based on a commercial software (ANSYS 7.1). Details of the model as meshing, element types and contact characteristics used in our non-linear large displacement analysis and transient dynamic analysis are presented. The model yields reliable results, which are backed up by experimental studies. Various types of Tensairity beams have been investigated elucidating the relation between form and stiffness in Tensairity structures. Calculations and design of the first Tensairity applications including a hall (exhibition centre Villa Erba, Cernobio, Italy) and a footbridge (Leamouth bridge competition, London, England) are presented demonstrating the maturity of the technology and the modeling.

KEYWORDS: Tensairity, finite elements, buckling, light weight, pneumatic structures, wide span structures, footbridge, membrane, air-beam, tensegrity.

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Mechanics of 2D flexible membranes

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ABSTRACT: Throughout their service life, building enclosures, both wall and roofing systems, are subjected to differential air pressures. This air pressure differential is influenced by changes in internal conditions (due to space use and occupancy, natural buoyancy, and the operation of mechanical equipments) and external conditions, especially wind. The building enclosure is an environmental separator and one important loading is this air pressure differential. Numerous walls and roof systems employ membranes that are not fully adhered; common examples being mechanically attached roofing membranes and housewraps in screen type exterior wall systems. This paper will address the issue of the performance of this type of membrane under differential air pressure loadings. In particular, the mechanics under suction will be developed and discussed.

KEYWORDS: Building enclosure, 2D flexible membrane, ballooning membrane, air pressure differential, the second order parabola.

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Numerical analysis of the dynamic behavior of cables under turbulent wind

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ABSTRACT: The research deals with the non-linear dynamic response of cables under steady and turbulent wind. A numerical procedure is described, which fully accounts for geometric and aerodynamic non linearities. In the procedure the cable is modeled using 3 nodes isoparametric finite elements. The aerodynamic forces are introduced according to the quasi-steady approach, retaining the complete non-linear form of drag and lift components. The methodology is applied to the oscillations of an iced cable in 1:2 internal resonance, subjected to a stationary wind flow as well as to a multi-correlated turbulent wind field. For the stationary case the numerical results are compared with those obtained by other researchers using an analytical model. The analysis of timehistories allows for some interesting considerations on the occurrence of self-excited oscillations and on effect of the turbulence structure on the cable response.

KEYWORDS: Non-linear dynamics, suspended cables, wind excitation, finite-element method.

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System identification of cable-stayed structure—practical investigation of cables

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ABSTRACT: The development of bridge construction has continued until now and new materials and technologies have been continually used—the limits of technical feasibility have been shifted more and more into the extreme range. Whereas we succeed in bridging increasingly long distances, at the same time numerous structural problems are encountered which have to be considered during the planning phase. The dynamic properties of the respective structure assume a special importance here.

Stay cables are excited by wind, rain, the combination of wind and rain as well as traffic as major sources. Out of many cables of a bridge usually only a few are subjected to vibration problems. Monitoring can identify those cables where for example damping is below a critical threshold value. Thus, adequate damping measures can be designed. The most important task for assessing cables in addition to the proneness to vibration is the determination of the current cable force by evaluation of the natural frequency. Earlier applied methods have only used a direct relation between cable force and measured frequency. Recent research has shown that this simple approach is only valid for the taut string theory and cannot be directly applied to bridge cables due to the effects of cable sag (cable weight) as well as bending stiffness which must not be neglected. From the research work a simple routine was developed which makes the determination of cable force possible in consideration of bending stiffness. Thus, the results of this assessment compared to the real cable force has led to an accuracy of ±1% in determination of cable forces. The paper is focused on the practical implementation of cable monitoring using ambient vibration data.

KEYWORDS: Cable-stayed structure, ambient vibration, cable force, cable damping, bending stiffness, natural frequencies.

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Coordinate calculation of hanging points for the main cable of suspension bridges

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ABSTRACT: The parameter equation is derived for the curve of the main cable of the suspension bridge with the hypotheses that the weight of the main cable is evenly distributed along the arc and other permanent loads such as the stiffened girders and decks are evenly divided along the horizontal length. A method is presented for determining the variables of the parameter equation through the boundary conditions and determining the hanging point coordinates of the main cable through varied parameters. A formula is derived for the non-stress cable of the suspension bridge as completed with integration method. With the principle that the length of nonstress cable for each span remains constant under non-load cable state of a completed bridge, the calculation method is established for determining the horizontal tension of the main cable under non-load cable state and the allowance for pre-deviation of the cable saddle. Then with the principle that the length of non-stress cable between hanging points remains constant under non-load cable state of a completed bridge, the coordinates of the hanging points are calculated for the non-load cable. The calculation result shows that the calculation method presented in this paper has the advantages of good suitability to programming, fast convergence and high precision, and is applicable to the calculations for the control of design and construction of suspension bridges.

KEYWORDS: Suspension bridge, main cable, parameter equation, hanging point coordinates.

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Mutually supported elements (MSE) in space structures

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ABSTRACT: The field of spatial structures covers a vast range of structural components and systems. New ideas and concepts are constantly developed in an attempt to improve efficiency in areas such as use of materials, configuration processing, analysis, design and construction. In this paper an innovative and novel type of lattice space structure system involving mutually supported elements is investigated. A circuit of Mutually Supported Elements (MSE) results in a three-dimensional space structure. MSE structures describe a family of spatial structures where the main elements support, and are in turn supported by one another. Some MSE structures have the appearance of being composed of interwoven elements due to this support arrangement. MSE space structures provide an aesthetic and convenient way of spanning small or very large areas without the need of intermediate vertical supports. Elements can be arranged to form two- and three-dimensional space structures. Typically, this arrangement of structural elements ensures that only two elements at any one time require to be connected to one another. This simplifies the connections considerably therefore giving this system potentially economic advantages over traditional space structure connection systems such as the Mero ball node joint system housing up to 18 threaded holes and used for example in the construction of geodesic domes. Whilst there is no theoretical maximum number of elements that may be used in a single MSE module, the minimum number required to create a closed module is three. This method of element support however, results in an eccentricity between the connected elements. The overall geometry and structural behaviour can therefore be of a complex nature. Previous work on the MSE system has been mainly concerned with configuration geometry and has been generally devoid of analysis in terms of overall structural performance. Some experimental and numerical modelling has been carried out at Coventry University. The initial findings of some numerical analysis have shown that the engagement window of an MSE module should be kept as small as possible in order to keep stresses in the structural elements low. MSE spatial structures are potentially suitable for use as temporary emergency shelters or falsework in the construction of permanent structures. Military applications are also possible. The aim of this paper is to explore and discuss the structural behaviour of some MSE space structures designed and constructed at Coventry University.

KEYWORDS: Mutually supported elements, space structures, structural behaviour.

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Analysis and experiment for self-erected hypar space truss

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ABSTRACT: This paper discusses a behavior of post-tensioned and shaped hypar space truss characterized by an economical fabrication and construction process. And the ultimate load test was performed with the hypar shaped space truss. This hypar space truss is post-tensioned at the bottom chords of one diagonal on the ground. Compared with conventional metal trusses, a characteristic of post-tensioned and shaped hypar trusses is that a simple post-tensioning process can complete the shape formation and erection. In this paper the essential characteristic of behavior for shape formation are discussed by a small-scale test model. Results of experiment and nonlinear finite-element analysis indicate that a planar rectangular layout can be deformed to a significant hypar shape by the proposed shape formation method in this paper. And the feasibility of the proposed method for furnishing of a hypar shaped space truss has been presented. Also a nonlinear finite element analysis method can be used in accurate predicting on the behavior of the space shape and the post-tensioning force of a hypar space truss. As a result, this shape formation method can offer economies compared to traditional construction methods involving the use of cranes and scaffolding.

KEYWORDS: Finite element method, nonlinear, post-tensioning, space truss.

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The bracings in the optimal elastic-plastic spatial grid structures

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ABSTRACT: The lower bound for the capacity of the load-carrying elastic-plastic spatial grid structures depends on large number of variables. However, if all the relevant variables are included in the optimisation problem, it cannot be solved given the computational power currently at our disposal. Therefore the analysis has to be limited to only a few variables, which have the strongest influence on the optimal choice.

The paper deals with selection of such variables. One of them is the choice of the system of bracings.

KEYWORDS: Decision variables, bracings, optimal choice, spatial grid structures, elastic-plastic analysis, vector of decision variables.

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The combined use of glass and steel together as a facade and roof cover together

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ABSTRACT: Glass and Steel are the strongest materials of building construction. The togetherness of these materials in the building envelope is bringing a very tasteful effect on human beings, living in or visiting these buildings. In the paper, three important built examples will be examined from the point of their facade and roof cover, having a structure of glass and steel together. The first one is from Luxembourg. The Luxembourg City History Museum by Conny Lentz (Luxembourg) and Repérages Architects (Paris) and Gehl, Jacoby & Ass.s.a.r.l. (Luxembourg) has full-height glass curtain walls for reception area and entrance area. The glass elevation, 12 m high and 14 m long, in front of the reception area is made from toughened safety glass (“Delodur”), 12 mm thick, using the “Planar” system of individual screw fixings. The second is from Germany. The Hotel Kempinski, Munich Airport by Murphy/Jahn (Chicago) and Schlaich, Bergermann & Partner (Sttutgart) has a 40×25 m transparent glass facade of the entrance elevation which is supported by pretensioned steel cables spanning between specially braced structures on both sides. At roof level, the vertical cables are attached to an arched beam with a tie consisting of several 46 mm. Diameter cables to prevent deformation. The facade beam is similar in section to the roof beams and is connected to the latter at the support so that a joint loadbearing effect is achieved. The third example which is Faculty of Law in Cambridge, England, by Sir Norman Foster & Parteners (London), and YMR Anthony Hunt Associates has a curved glass wall faces onto the northern facade is a vierendeel girder-spanning almost 40 m made of steel sections in a triangular arrangement on which teh glazing is mounted. The situation of glass and steel in these three examples will be examined from both structural point of view and also from architectural point of view.

KEYWORDS: Glass, steel, The Luxembourg City History Museum, The Hotel Kempinski Munich Airport, Faculty of Law in Cambridge, England.

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8.
Beam, arch, frame and box-girder analysis

The distribution theory for the analysis of Euler-Bernoulli beam with singularities

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ABSTRACT: The study of beams with singularities is significant to model real cases such as abrupt changes of the cross section, abrupt changes of the material, presence of internal constraints or else appearance of discontinuities due to fractures.

Analysis of beams showing physical or geometrical discontinuities along the beam span has been conducted in the literature by Yavari et al. (2000, 2001) and by Yavari & Sarkani (2001). However, in these cases integration is usually performed by seeking continuous solution functions over domains between discontinuities and imposing continuity conditions. Procedures based on integration over the entire beam span, however requiring enforcement of the continuity conditions, have been also proposed in the literature by Falsone (2002). As a result the computational effort depends on the number of discontinuities and no closed form solutions, have been proposed so far.

The problem of the integration of the static governing equations of the Euler-Bernoulli beam with discontinuities is studied in this work by means of a new approach within the context of the distribution theory. In particular, a single singularity of the flexural stiffness, modelled by a Dirac's delta distribution, has been considered first. The mathematical meaning of this model relies on the definition of the product of two Dirac's deltas introduced by Bagarello (1995, 2002), which is not defined by classical theories such as that, for example, proposed by Colombeau (1984). Furthermore, it is shown how the mathematical model provided by a Dirac's delta in the flexural stiffness corresponds to the case of presence of an internal hinge endowed with rotational spring. The expression of the rotational spring stiffness equivalent to the imposed singularity is provided explicitly. A generalisation of the proposed model together with the closed form solution to the case of multiple singularities is also presented.

Singularities of the flexural stiffness modelled by means of unit step functions are also described in the paper in order to show how abrupt variations of the cross section or the material can be accounted for. Numerical applications of the proposed closed form solutions show the correctness of the approach.

Finally it is shown how, starting from the analysis of a clamped-clamped beam, singularities at boundaries are able to modify the boundary conditions themselves. Such a procedure allows to provide closed form solutions without requiring the evaluation of any constant, the boundary conditions being described by suitable singularities.

The presented solutions, since both discontinuity intensities and locations appear explicitly, are relevant for the analysis of beams with uncertain parameters and also in inverse problems such as parameter identification.

KEYWORDS: Distribution theory, Euler-Bernoulli beam, Dirac's delta, unit step function, flexural stiffness singularities, closed form solutions.

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Moment-gradient factor for lateral torsion-flexure buckling of steel I-beams

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ABSTRACT: Lateral torsion-flexure buckling of thin-walled steel I-beams subject to flexure is one of the most important aspects which should be considered in design. Codes of practice deals with this matter by using the critical moment of a simply supported beam subject to two equal and opposite end moments and relate it to the critical moment of other loading cases using a moment-gradient factor which is also referred to as “the equivalent moment factor”. A numerical model based on the finite element technique is adopted to investigate the values of the moment-gradient factor for different loading configuration. The model is extended to investigate the effect of the load eccentricity, measured from the shear centre of the beam’s cross-section, on the critical moment which initiates lateral torsion-flexure buckling. Equations which consider the effect of load eccentricity from the shear centre are introduced and checked using the numerical analysis results.

KEYWORDS: Buckling, finite element, I-beams, lateral stability, moment-gradient factor.

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High-rise shear walls with outriggers at fixed and optimum locations

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ABSTRACT: This paper presents a simple method of analysis for preliminary design of outrigger braced high-rise shear walls subjected to horizontal loading. The shear wall has outriggers at two levels. One outrigger has a fixed location up the height of the structure whilst the second can be placed at an optimum location. This position will cause a maximum reduction in lateral deflection at the top of the building. A single diagram allows for a rapid assessment of the optimum location for the second outrigger. The suggested method of analysis for use in the initial stages of the design of an outrigger structure for a proposed tall building offers a simple and rapid means of locating a second outrigger at an optimum location up the height of the structure thereby allowing optimum dimensions for the individual structural members.

KEYWORDS: High-rise structure, shear wall, tall building, outrigger structure, optimum outrigger location.

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Critical cross-deck temperature distribution in box girder bridges in tropical city

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ABSTRACT: The climatic conditions in tropical countries are different from those in other climatic zones. Many factors affect the variations of cross-deck temperature distribution. Amongst them, the dominant ones include the intensity of solar radiation, the duration of sunshine, ambient temperature and wind speed. These environmental factors lead to seasonal and daily temperature changes in the bridge deck. The daily temperature variations cause temperature differentials across the depth of bridge deck. The cross-deck temperature distribution is non-linear. For simplicity and practical purpose, empirical curves are made available in codes for the design engineers. However, no curves are available for tropical climatic conditions, in particular in the city environment, in which the critical conditions could be more severe. Against this background, based on *in-situ* site measurements in a tropical city (Singapore), a finite-element numerical model is employed to calibrate the data, and then extended to estimate the extreme conditions of 50-year return-period.

KEYWORDS: Non-linear temperature difference, box-girder bridge, tropical climate, finite element model.

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9. Vibration and dynamic analysis

Ambient vibration testing and structural modeling of a cable-stayed bridge

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ABSTRACT: Theoretical and experimental investigation of an historic cable-stayed bridge is described in the paper. The investigated cable-stayed system, known as Carpineto bridge, was designed by R.Morandi and is placed on the freeway between Potenza and Sicignano (Italy). The bridge includes a main span, 181.0m long, with two cantilevers suspended by inclined stays and connected by a central simply supported drop-in girder. The structure is characterised by the adoption of pre-stressed concrete stay-beams, as it happens in other bridges designed by R.Morandi in the 60's, like the Wadi-Kuf Bridge in Spiac (Libya), the Magliana Viaduct in Rome (Italy) and the Polcevera Creek Viaduct in Genoa (Italy). The cable stays consist of pre-tensioned steel strands encased in a pre-stressed concrete shell; such unusual elements have made famous the bridges designed by Dr. Morandi in the bridge engineering community. The construction of the stays was carried out in successive steps. At the completion of the deck, the stays were made only of conventional tendons which carried the dead load of the cantilever girder. Successively concrete beams were cast in situ, in a segmental way, along the main tendons; the concrete beams were then pre-stressed by means of additional tendons. Finally, all the tendons were grouted so that the post-tensioned stay-beams supported almost all the live loads.

The unusual structural characteristics of the bridge, its infrastructural role and the existence of a twin bridge (which should probably be tested in the near future) provided strong motivations for dynamic testing. The experimental program of field tests was completed in three days and included extensive measurement of ambient vibrations induced by traffic. The most significant mode shapes and associated natural frequencies were determined in the frequency range 0–4 Hz by using the classical spectral techniques in the frequency domain and its improvement called *Frequency Domain Decomposition,* based on the singular value decomposition of the cross-spectral matrix.

The experimental investigation was complemented by the development of a three-dimensional finite element model based on as-built drawings of the bridge and accurate in-situ geometrical survey, so that the main assumptions embodied in the model were assessed through the comparison of measured and predicted modal parameters. The model

exhibits good agreement with the experimental data provided that geometric non-linearity was properly accounted for.

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Dynamic testing and analysis of a footbridge under walking-induced excitation in Podgorica, Montenegro

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ABSTRACT: A footbridge known to be lively under vertical pedestrian excitation was tested and it was established that it had a vertical natural frequency of 2.01 Hz and a very low damping ratio of 0.2–0.35% in this mode of vibration. These were the main contributors to its liveliness. A detailed finite element model was then developed and updated to match the measured natural frequency. Using the modal properties of this model, optimum properties of a tuned mass damper were established which would minimise footbridge response under pedestrian excitation.

KEYWORDS: Vibration serviceability, footbridges, vibration measurements, tuned mass damper, pedestrian dynamic loading, finite element modelling.

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Vibration serviceability of footbridges

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ABSTRACT: Vibration serviceability problems with footbridges continue to occur worldwide and to provide entertainment for engineers and members of the public. Experience in evaluation of one of a large number of footbridges in Singapore is reported, including evaluation of the effect of crowds on loading and response mitigation. The presentation will focus on a different bridge that was found to be susceptible to synchronous lateral excitation.

KEYWORDS: Vibration serviceability, pedestrian bridge, damping, human.

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Approximate method for response of structures subjected to explosion-induced ground motions

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ABSTRACT: Structures located near underground ammunition facilities may be subjected to ground motions generated by accidental explosions. These explosion-induced ground motions (EIGMs) have large amplitudes and high frequency contents, occurring within a short duration. EIGM characteristics can be segmented into two parts: the major shock duration (Phase I) and the ensuing duration (Phase II). Within Phase I, the structure undergoes a small displacement. Material-based modeling has shown that there is distributed damage from the higher-frequency modes of the structure. This paper proposes an approximate method which requires less computational effort than the material-based modeling. Under a short-duration triangular load, the change of velocity and displacement can be approximated using the proposed method. Idealizing an EIGM into a series of triangular loads, the proposed method provides preliminary estimates to the velocity and displacement responses at the end of Phase I, where a correction factor can be applied to improve the estimates. However, for MDOF systems, it is shown that while the displacement response is close to the exact solution, the forced-vibration velocity response can be better approximated as the derivative of the corrected displacement response.

KEYWORDS: Approximate method, ground shocks, shock response, underground explosions, short duration load, correction factor.

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The dynamic behavior of submerged floating tunnels under seismic and hydrodynamic excitation

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ABSTRACT: A numerical procedure is presented for simulating the dynamic behavior of submerged floating tunnels under environmental loading due to current, wind waves and seismic effects. A finite element is presented for modeling the anchor bars connecting the tunnel to the seabed; the model accounts for geometrical non-linear effects due to time varying axial load. The development of hydrodynamic loads acting on the tunnel and on the tethering system is then addressed along with the criteria for introducing three dimensional multiple-support seismic excitation; non-linear drag is retained in the analysis. Hydrodynamic and seismic loading are based upon the artificial simulation of the wave and seismic motion fields, both described through stochastic models. An example is finally given regarding the response of a 4680 m long tunnel.

KEYWORDS: Submerged structures, non-linear dynamic response, multiple-support seismic excitation, wave and current forces, random ocean waves.

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Free vibration analysis of a combined continuous and discrete structural system using the dynamic stiffness method

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ABSTRACT: Applying a transfer matrix approach, the dynamic stiffness matrix for a combined continuous and discrete structural system is developed in this paper. The particular case of a two-part beam-mass system consisting of two elastic beams and one rigid mass is considered to be the example of the proposed integrated structural system. The investigation is carried out using the Wittrick-Williams algorithm as the solution technique. Numerical results are obtained for a cantilever beam and discussed. Finally some conclusions are drawn.

KEYWORDS: Free vibration, continuous and discrete structural system, dynamic stiffness method.

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Consistent time-domain models for radiation damping

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ABSTRACT: Acoustic, fluid or solid-soil field problems are characterized by unbounded domains and thus by radiation damping caused by waves travelling outwards towards infinity. Typically such problems are described in the spectral domain either analytically or more often numerically; for example by using a boundary element approach.

However, problems in structural dynamics are characterized by bounded domains and by MDOFrepresentations in the time-domain; typically with non-linear effects included. High performance time-solvers are available in order to produce an overall-solution in space and time for these bounded problems.

The interaction of both types of fields, bounded and unbounded, demands for a total modelling in the timedomain especially for non-periodic vibrations.

This contribution further develops ideas from two papers [1], [2] published in 2001 and 2003:

First, the unbounded domain is solved in the frequency-domain according to an harmonic behaviour exp *(iΩt).* Then the dynamic stiffness K(Ω) coupling the interface forces $\hat{\mathbf{f}}$ and interface deformations $\hat{\mathbf{d}}, \hat{\mathbf{f}} = \mathbf{K}\hat{\mathbf{d}},$ is established and approximated by a rational representation with an additional asymptotic part K_∞.

$$\mathbf{K}(\Omega) = \mathbf{K}_\infty + \mathbf{Q}^{-1}\mathbf{P}, \quad \mathbf{K}_\infty = \lim_{\Omega\to\infty} \mathbf{K}(\Omega),$$
$$\mathbf{Q} = \mathbf{1} + \mathbf{Q}_1(i\Omega) + \cdots + \mathbf{Q}_M(i\Omega)^M,$$
$$\mathbf{P} = \mathbf{P}_0 + \mathbf{P}_1(i\Omega) + \cdots + \mathbf{P}_{M-1}(i\Omega)^{M-1}.$$

Finally this nonlinear formulation concerning the frequency is replaced by a corresponding linear form by means of introducing additional variables v.

$$(\mathbf{A} + i\Omega\mathbf{B})\hat{\mathbf{z}} = \hat{\mathbf{r}}, \quad \mathbf{z} = \begin{bmatrix} \hat{\mathbf{d}} \\ \hat{\mathbf{v}} \end{bmatrix}, \quad \mathbf{r} = \begin{bmatrix} \hat{\mathbf{f}} \\ \mathbf{0} \end{bmatrix}.$$

The corresponding time domain description

$$\mathbf{A}\mathbf{z} + \mathbf{B}\dot{\mathbf{z}} = \mathbf{r}, \quad \mathbf{z} = \hat{\mathbf{z}}\exp(i\Omega t), \quad \mathbf{r} = \hat{\mathbf{r}}\exp(i\Omega t),$$

can be coupled with the FEM-formulation of the bounded structure-part of the whole problem in classical manner. The full paper will contain details, recent improvements and typical results.

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KEYWORDS: Radiation damping, wave propagation, fractional dynamics, frequency-to-time transformation.

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Aeroelasticity and parametric uncertainty propagation: An hybrid approach

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ABSTRACT: Stability of the coupled system aircraft/aerodynamics is a key issue in civil airplane manufacturing. During the design stage of an airplane, many structural parameters are not clearly fixed or known, but nevertheless the final project must comply to the various international certification regulations. One popular approach to deal with this problem is to model the parametric uncertainties through random variables. Then one has to study the stability of a random parameter dynamical system. We present here the various steps developed at ONERA in order to construct an effective numerical procedure which can be utilized together with standard structural and aerodynamic codes by manufacturers. This procedure is based on Monte Carlo simulation. Two procedures have been developed. The direct simulation method randomly draws the values of the uncertain parameters directly in the finite element model of the aircraft, and performs a complete flutter calculation at each step. It yields exact statistics in the sense that no reduction is performed on the random parameters. But, although this method is straightforward, it is not applicable at the present time for the large d.o.f models which are currently used (≥300000 dof).

A second approach has been developed based on a projected simulation method. It necessitates the construction of an unique basis of projection. Results have shown that the mean modal basis, which seems a priori to be a good candidate, is not rich enough to restitute all the coupling behavior between the structure and the fluid. Moreover, this method is generally used in conjunction with a perturbation technique in order to represent the random parameter dependency of the generalized mass and stiffness matrices, valid solely for small uncertainties. We present an approach for extending the mean modal basis to a richer one. Moreover we show that polynomial chaos can be introduced in order to replace the perturbation technique with a representation capable of taking into account important uncertainties. The polynomial chaos coefficient are obtained by simulation.

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Sensitivity analysis of non-conservative eigensystems

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ABSTRACT: An expression for the derivatives of eigenvalues and eigenvectors of non-conservative systems is presented. Contrary to previous methods that use state space form (2N-space) to consider damping, proposed method solves the eigenpair derivatives of damped system explicitly. The computation size of N-order is maintained and the eigenpair derivatives are obtained simultaneously from one equation so that it is efficient in CPU time and storage capacity. The proposed expression is derived by combining the differentiations of the eigenvalue problem and normalization condition into one linear algebraic equation. The numerical stability is proved by showing non-singularity of the proposed equation, and the efficiency of the derived expression is illustrated by considering a cantilever beam with lumped dampers.

KEYWORDS: Sensitivity analysis, derivatives of eigenvalues, derivatives of eigenvectors, damped system, non-conservative system.

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Errors in numerical solution of equation of motion of lightly damped SDOF system near resonance

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ABSTRACT: This paper investigates the error which occurs when numerically integrating the equation of motion of a single degree of freedom system excited by a harmonic force near resonance. The Average Constant Acceleration method was considered in particular as it features in many finite element software packages. It was found that a considerable error in the calculated responses occurs in systems with low damping due to the well known phenomenon of period elongation. However, the error is reduced for systems with higher damping and/or when smaller time step is used. With regard to this, recommendations are given as to the time steps required to obtain solutions with a pre-defined level of accuracy.

KEYWORDS: Single degree of freedom, numerical integration, Newmark method, resonance, error.

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Train-bridge dynamic interaction

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ABSTRACT: If we want to take into consideration the dynamic effect of the moving vehicle during the test of structure we have some possibility to build up the model. We used three different models. The first one was the calculation with force groups. During the analysis we calculate the group force critical velocity and shown the large dynamic effect in this case. We have seen that the role of the structural damping is very important in results.

Using the second model we calculated by moving mass points. In this case the mass matrix in the dynamic matrix equation of the bridge was time-dependent. If we want calculate the effect of frequency independent structural damping we have to calculate the eigenvectors of undamped system. Using this eigenvectors we can apply the quasi-modal analysis. At this model the group force critical velocity was less, and the dynamic effect was higher.

The most complicated case if we calculate the train as moving dynamic system, when the mass, damping and stiffness matrices in the dynamic matrix equation of vehicle-bridge system will be time-dependent. Using the moving train model the critical force group velocity is less than in case of other models. The dynamic effect at velocity under the critical velocity is higher than was in case of moving forces or moving mass points. The results showed the important role of the dynamic characteristic and the velocity of the vehicle system. If the frequency ratio is near to the 1.0, the dynamic effect will be largest. But if the difference between the first frequencies is large, the dynamic effect will be less then in case of moving mass point model.

KEYWORDS: Train-bridge interaction, the effect of structural damping, quasi-modal analysis.

Analytical and experimental studies on free vibration of variable-arc-length beams

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ABSTRACT: This paper presents the free vibrational behavior of Variable-Arc-Length (VAL) beams, which have large displacement static equilibrium configurations. The variability in beam arc-length arises from one end of beam being pinned, and the other end being supported by a frictionless roller at a fixed distance from the pinned end. Using Lagrange's equation, the large amplitude, free-vibration, equation of motion is derived and simplified for small amplitude motion measured from the large static displacement configuration under beam weight. In addition to the finite element solution, the eigenvalue problem is solved using inverse iteration techniques to obtain the natural frequencies and corresponding mode shapes. Free vibration experiment has been performed to validate the obtained analytical results. A very good correlation between analytical and experimental results was obtained for a range of beam specimens.

KEYWORDS: Variable-arc-length beams, small amplitude motion, large static displacement, free vibration experiment.

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Responses' convergence for impact problems analyzed with different integration methods

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ABSTRACT: Semi-discretized equations of motion have fundamental role in structural dynamic analysis. Equations of motion together with sufficient initial conditions define initial value problems namely dynamic problems their responses express the dynamic behavior. These problems can be solved by different methods. In presence of nonlinearity, time integration is the most widely accepted approach for analyzing the dynamic problems. However the responses computed by the set of time integration methods are approximate and hence the numerical stability and accuracy of the attained responses should be studied and maintained. In order to attain to more reliable responses in time integration of nonlinear dynamic problems, the authors of this paper have recently proposed two independent methods for preserving responses' convergence in nonlinear dynamic problems. From another side of view, impact is one of the most strongly nonlinear behaviors, which is very important in some practical cases e.g. pounding effects in the study of seismic behavior of bridges and high-rise buildings. The two methods referred above are first reviewed in this paper. Then considering the nonlinear behavior of impact problems, the superior method together with a recent round-off reduction technique are used to define a better method for preserving responses' convergence toward less errors. Implementing the new method in the analysis of a simple impact problem with three different time integration methods reveals that regardless of the integration method, the presented method can preserve responses' convergence.

KEYWORDS: Dynamic analysis, time integration, nonlinear, impact, convergence, accuracy, error, (local) truncation error, nonlinearity error, iterative solution.

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Dynamic analysis of RC bridges

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ABSTRACT: This work is aimed at presenting a rational and detailed dynamic analysis of various types of RC bridges. The emphasis is to provide an evaluation of the 'impact factor', which is often considered to incorporate the dynamic effects in conventional analyses of bridges. After verifying the results from numerical formulation with theoretical results, a detailed parametric study is performed in this work to investigate some important details of the behavior of Deck Girder, Balanced Cantilever and Continuous Bridges based on dynamic analysis under the moving HS20 load. Various aspects of the dynamic response of RC bridges are studied, comparing with the conventional static structural analysis and changing the vehicular velocity, damping ratio and number of spans. The resulting effects on bridge deflection, bending moment and shear are observed.

KEYWORDS: Bridge, dynamic analysis, moving load, impact factor.

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Influence of the initial breather on the perturbed thin bar

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ABSTRACT: Considering Peierls-Nabarro force and viscous effect of solid, the dynamic response of onedimensional finite thin bar is researched under Neumann boundary conditions and harmonically driving. The Sine-Gordon type equation has been given to describe nonlinear wave propagating in this bar. When the initial condition is given as a single-hump Sine-Gordon breather, varying of spatial structures and long-time asymptotic behaviors of the bar with the amplitude of driving force and initial breathing phase is studied numerically. Power spectrum, Lyapunov exponent, Poincaré section, the time-displacement curve of the point in bar and the evolution of the spatial structure in time have been used to reveal spatial structures and temporal behaviors. When the amplitude of driving force is very small, the energy inputted from outside is also very small and the viscous effect of system is superior. The initial spatial structure would dissipate quickly and the initial phase of breather wouldn't influence the long-time asymptotic behavior. Along with increasing of driving force, the viscous effect, external driving and disturbance from initial condition all act on this dynamic system. With certain amplitude of driving force, the phase of initial breather influence the response of the system strongly. Periodic and chaotic character would appear with different initial phases. It is shown that the phase of initial breather is also an important factor to influence the dynamic behavior of the system under certain condition.

KEYWORDS: Sine-Gordon system, initial breather, chaotic, Neumann boundary condition, Lyapunov exponent.

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10.
Vibration and seismic control

A probabilistic method to assess the efficacy of smart damping technology

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ABSTRACT: Civil structures are traditionally designed to resist static loads. Civil structures are, however, subjected to a variety of dynamic loadings, including earthquakes, winds, waves, and traffic. These dynamic loads can cause severe and/or sustained vibratory motion, both of which can be detrimental to the structure and its material and human occupants. Structural control can mitigate these effects by absorbing and redistributing the energy introduced by dynamic loads. Passive, active and semiactive control strategies have been proposed and implemented in a number of civil structures. Smart damping technology, a type of semiactive control, assumes the positive aspects of passive and active control devices, providing similar increased performance as active control without large energy requirements like passive control. More efficient control strategies can be designed if engineers can more readably identify which controller is best applied for each application.

Civil structures are usually of unique and individual design and each application of smart damping control in civil engineering can be expected to provide varying levels of performance. Currently, the relative efficacy of smart damping control is determined by running numerous smart damping simulations. These simulations can require significant computation time and resources. Consequently, it is desirable to identify a quantitative measure to define the merit and applicability of smart damping technology which requires less computation time. Due to the random nature of the excitations on civil structures, a probabilistic approach to assess the efficacy of smart damping control is advocated.

This paper describes a probabilistic measure to define the merit of smart damping control for clipped optimal control strategies evaluating the probability of dissipative primary control forces. This paper proposes a control design method which employs this probabilistic measure to identify, for a particular family of controllers, the most promising primary controllers for clipped optimal control.

KEYWORDS: Structural control, smart damping, probabilistic measure.

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Dynamic properties of combined stayed cable/SMA damper system with coupled modes vibration

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ABSTRACT: The paper intents to investigate the vibration mitigation of a stayed cable incorporated with one shape memory alloy (SMA) damper, which dissipates energy through its super-elastic behavior. The ultimate purpose of this investigation is to devise the SMA super-elastic damper with super-elastic property to eliminate oscillation of the stayed cable.

Considering a stayed cable vibrates with first a few coupled modes under vortex shedding and parametric exciting etc, the motion equation of the stayed cable/SMA super-elastic damper system would be a coupled nonlinear multi-freedom motion equation. So, it is difficult to get the exact closure solutions of the additional equivalent modal damping ratio and frequency of the stayed cable/SMA damper system. In this paper, influence of parameters and locations of the SMA super-elastic damper on dynamic properties of the stayed cable/SMA damper system with multi-mode coupled vibration is analyzed by numerical method.

The responses of the stayed cable attached with one SMA super-elastic damper with different parameters at different locations subjected to harmonic excitation in plane are also calculated. The additional equivalent mode damping ratios of the first second modes are identified on forced vibration cases respectively.

The analytical results showed that the SMA super-elastic damper could mitigate the vibration of the stayed cable significantly and increase the frequencies appreciably of the stayed cable. At the same time, the excitation with the resonant frequency causes not only the corresponding mode vibration but also the other mode vibration, but the other mode vibration amplitude caused is much smaller than that of the resonant frequency mode vibration.

KEYWORDS: Stayed cable, stayed cable/SMA damper system, additional equivalent mode damping ratio, vibration mitigation.

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Performance of passive energy dissipation systems during near-field earthquakes

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ABSTRACT: Near-field ground motions are characterized by long-period pulses with high peak ground velocities. In this paper, a simplified analytical model using enveloped sinusoids is proposed for long-period velocity pulses in near-field ground motions. The objective of the proposed model is to represent dominant kinematic characteristics of ground motions, since only the most prominent frequency component of near-field ground motions affects the response significantly. The validity and usefulness of the proposed analytical model is demonstrated using ground motion records and response spectra of several near-field earthquakes. Passive fluid viscous dampers are widely used to protect structures from strong ground motions. However, it has been observed that the performance of passive energy dissipation systems varies widely during different ground motions. In this paper, the performance of passive viscous dampers is investigated using the proposed analytical model to determine the types of ground motions and structures for which these systems may be most effective.

KEYWORDS: Passive viscous dampers, near-field earthquakes, pulse excitations, supplemental dampers, structural response control.

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Parameter optimization of stay cable damper with fractional damping and stiffness

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ABSTRACT: To suppress vibrations of a stay cable, attaching damping devices to the cable near anchorages is one of the most effective and the most widely used methods. The dampers that have been implemented in actual bridges can mitigate vibrations to some extent, however, in the procedures of the parameter optimization of the cable-damper system, linear damper model is usually used, and the effects of the damper stiffness on the supplemental damping ratio are suggested negligible. With the result that, the actual efficiency of the vibration mitigation is generally overestimated. Therefore, this paper presented a passive damper with fractional damping, and carried out the parameter optimization of the cable-damper system, with taking account of the effects of damper nonlinearity and stiffness. The nonlinear damper model and the optimization method can improve the computation precision, and allow the optimal damping performance to be achieved over a wider range of mode than in the linear case. The results can offer a guideline for the optimal design of the cable-damper system.

KEYWORDS: Stay cable, vibration mitigation, fractional damping, damper stiffness, parameter optimization.

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Ensuring trouble-free structures for vibration

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ABSTRACT: The tools available to the Structural Engineer for modeling the vibration behaviour of structures has improved to excellent standards, but in practice many structures still experience vibration related problems, often relating to vibration of secondary or tertiary structural members or plating elements. Generally these vibrations are difficult to identify from structural modeling because their inclusion would lead to unwieldy models, and because they are very dependent on assumptions made in regard to member end conditions.

The effectiveness of various “rules of thumb”, assessment of individual members, and practical tips for eliminating vibration problems is explored. Simple equations are presented to define the fundamental natural frequencies of individual members. Most lateral and torsional vibration of secondary and tertiary members is related to resonance, so that these equations can be used to ensure that vibration of secondary and tertiary members is controlled.

KEYWORDS: Industrial structure, natural frequency, noise, vibration.

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Seismic reduction of eccentric structures using TLCD

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ABSTRACT: The installation of vibration absorbers on tall buildings or other flexible structures can be a successful method for reducing the effects of dynamic excitations, such as wind or earthquake, which may exceed either serviceability or safety criteria. Tuned liquid column damper (TLCD) is an effective passive control device by the motion of liquid in a column container. The potential advantages of liquid vibration absorbers include: low manufacturing and installation costs; the ability of the absorbers to be incorporated during the design stage of a structure, or to be retrofitted to serve a remedial role; relatively low maintenance requirements; and the availability of the liquid to be used for emergency purposes, or for the everyday function of the structure if fresh water is used.

This paper illustrates the vibration control methodology of tuned liquid column damper (tlcd) on eccentric structures, modeled as torsionally coupled multi-story shear structures, excited by multi-dimensional ground motions. Tlcds are set in orthogonal directions to control the lateral and torsional responses of structures. Based on the equations of motion for the control system, the main parameters that may affect the control efficiency are analyzed. The control effectiveness on the torsionally coupled seismic responses of high-rise building is verified by numerical computations. The multi-modes control method for eccentric structures using multi-tlcds (mtlcd) is also presented in this paper. A 24–story eccentric structure is controlled by different schemes for different modes. The result shows that the seismic response reduction for eccentric structures is better by controlling the first several modes than only control the first mode.

KEYWORDS: Eccentric structure, multi-dimensional ground motions, tuned liquid column damper (TLCD), multi-modes, multiple tuned liquid column dampers (mTLCD).

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Optimal multiple tuned mass dampers for suppressing floor vibration

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ABSTRACT: The optimal design of multiple tuned mass dampers (multiple TMD's) to suppress acceleration response of a typical floor system with closely spaced natural frequencies is investigated in this study. This is a particularly challenging design problem since the combined structure-TMD's system is highly non-proportionally damped and produces very complicated dynamic interaction among vibration modes. A new method to design multiple TMD's using nonlinear programming techniques has been presented. It is a very powerful method by which a large number of design variables can be efficiently handled without imposing any restriction before the analysis. The proposed method showed to be very well-suited for simultaneous searching optimal parameters and optimal placement of TMD's regardless the closeness of structural frequencies of the floor.

KEYWORDS: Multiple tuned mass dampers, floor vibration, closely spaced natural frequencies, nonlinear programming, optimal placement.

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Market-based semi-active tuned liquid column dampers for structural seismic control

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ABSTRACT: There are many decentralized control systems in non-structural engineering fields and an immediate example is the free market economies. In a free market system, scarce societal resources are distributed based on the local interaction of buyers and sellers who obey the laws of supply and demand, which is different from the centralized economies where the resources are distributed by the central government. The historically poor performance of centrally controlled economies is additional evidence of the difficulty associated with controlling a complex marketplace. In the free markets, what is optimally controlled is the price that is paid for goods or service. The complex control system can be simulated by market-based control (MBC), in which control devices and controlled structure are replaced by sellers and buyers, Hence the system is decentralized and the structure can be controlled effectively. In this paper, a novel control law for semi-active tuned liquid column dampers (TLCD), market-based control is presented. First, the equation of motion for structure-TLCD control system is established and the MBC semi-active TLCD control strategy is derived. The semi-active control strategy is illustrated through a one-story structure. A five-story structure is used to verify the effectiveness of the control method. The result is shown that MBC semi-active TLCD on-off control method can reduce the vibration of structure as well as saving energy and easily handling.

KEYWORDS: Market-based control, tuned liquid column damper, semi-active control, on-off control, response of structure, earthquake action.

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11.
Seismic response of structures & seismic design

Use of dampers to mitigate the seismic response of shear walls

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AB STRACT: This paper investigates the behaviour of multi-storey structures under simulated earthquake loads with friction dampers, viscoelastic dampers and combined friction-viscoelastic damping devices strategically located within shear walls. Consequently, evaluations are made as to how the damping systems affect the seismic response of these structures with respect to deflections and accelerations. In particular, this paper concentrates on the effects of damper types, configuration and their location within cut-outs of shear walls. The initial stiffness of cut out section of the shear wall is removed and replaced by the stiffness and damping of the device. Influence of parameters of dampers properties such as stiffness, damping coefficient, location, configuration and size are studied and evaluated using results obtained under several different earthquake scenarios. Structural models with cut outs at different heights are treated in order to establish the effectiveness of the dampers and their optimal placement.

KEYWORDS: Seismic response, dampers, finite elements, shear walls.

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An efficient seismic loading pattern for MDOF shear-building structures

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ABSTRACT: Shear building models of multi-story structures are considered in this study and are subjected to a group of severe earthquakes. It is shown that the strength distribution patterns suggested by the seismic codes do not lead to a uniform distribution and minimum amount of ductility, drift, and damage. A pattern is proposed that is a function of the period of the structure and the target ductility. If this pattern is used in the design it could result in a reduction of ductility (and drift) demands and a rather uniform distribution of deformations. An iterative approach is also developed to determine the design strength (and stiffness) pattern needed to achieve a prescribed ductility (or drift) distribution according to different dynamic characteristics of the structure and earthquake. Utilizing this approach, a performance-based design methodology is introduced. This approach is shown to be efficient in finding the optimum strength and stiffness distribution patterns.

KEYWORDS: Shear buildings, load pattern, ductility, drift, seismic, design, performance-based.

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Stochastic seismic response of structures with friction dampers

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ABSTRACT: The frictional damping elements has been proposed to be used for variety of structural systems, i.e, braced frames, concrete shear walls, and panel structures. Frictional elements have the advantage of being amenable to a particularly simple form of mechanical modeling and their response should be repeatable and fatigue resistant. The analysis of the dynamic behavior of structures under earthquake excitations is deeply complex problem due to several factors of uncertainty. This can be handled by using the random vibration theory for analysis of structures, where, the input ground motion is modeled as a random process. When applying the random vibration theory to structures having friction dampers, the problem becomes more complex because of the nonlinear behavior of the friction dampers. In this paper, the equivalent linearization technique is used to obtain the stochastic response of structures with friction dampers when subjected to random ground motion. The response is obtained in terms of Root Mean Square values (RMS), and the excitation is modeled as filtered white noise random process. The space state formulation is used, and thus, the non-linear behavior of the friction dampers is implemented in the analysis using differential model. The efficiency of the friction devices is investigated. The results show that the use of friction dampers, although affect only the structural stiffness, considerably reduces the response of structures. By increasing the bracing stiffness ratio R, the reduction in the RMS response is more for very stiff structures, and very flexible structures. Using friction devices with larger slip displacements, reduces the final RMS displacement of stiff structures. The effect is less for the case of very flexible structures. It is found that, using different filter parameters affect significantly the response of medium and very stiff structures. Thus, the filter parameters should be selected carefully to represent the real situation of the ground excitation.

KEYWORDS: Stochastic response, friction dampers, seismic forces.

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The chord angle demand of coupling beams under potential seismic loads in Hong Kong

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ABSTRACT: Coupled wall or core wall structures with coupling beams have been widely used to resist lateral wind loads in Hong Kong (HK). Coupling beams, in particular those with high shear loads, are often the most critical elements in low-to-medium rise buildings under potential seismic loads. In this study, beam rotation angles (also known as chord angles) were used to directly relate the displacement demand of coupling beams and the whole structure under seismic loads. Using the seismic load spectra developed by the Center of Earthquake Engineering Research in the Department of Civil Engineering of The University of Hong Kong, more than ten existing coupled wall structures, which cover wide range of building heights in HK, have been analyzed by ETABS. The maximum chord angle demands of coupling beams under high shear stress (>3 MPa) with different span-to-depth ratios were obtained. A simple chord angle demand prediction formula of coupling beam was proposed, when compared with its rotational capacity, the seismic resistant ability of existing coupling beams could be assessed.

KEYWORDS: Hong Kong, seismic, spectrum, soil site, rock site, inter-storey drift, coupling beam, chord angle.

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Sliding fragility of bench-mounted unattached scientific equipment

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ABSTRACT: In this paper, sliding fragility functions for different bench-mounted scientific equipment are developed using 32 ground motions of various seismic hazard levels propagated through a numerical model of a representative seven storey science building. Seismic fragility curves display the probability that a specific damage state has been attained given a set of earthquake motions (with a range of intensities). Coefficients of static and kinetic friction are considered as two independent random variables. The dynamic characteristics of various supporting bench systems are evaluated using shake table and hammer model test results and considered as a parameter for fragility curve development. It is observed from the fragility curves that neglecting uncertainties in the coefficients of friction and also ignoring bench amplification will underestimate the equipment vulnerability. It is also observed that variation of the supporting bench characteristics may significantly affect fragility curves.

KEYWORDS: Seismic fragility curves, sliding response, uncertainty, frictional behavior.

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A cost-based analysis of typical architectural and structural design faults in reinforced concrete buildings in Turkey

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ABSTRACT: Recent earthquakes in Turkey provided undesirable field evidence that most of the low story residential reinforced concrete buildings have very poor earthquake resistance. Structures collapse under the action of earthquakes, because they do not behave well when they are subject to ground excitation. Therefore designers must able to imagine the dynamic behavior of the structure.

Almost all buildings have architects who design by choosing the structural system. After the architectural design is finished, the structural engineer fits into the design the proper structural system. The architectural design faults negatively affect the structural behavior of reinforced concrete buildings. In Turkey, earthquake resistant design is considered to be under the responsibility of structural engineers. As a result, architects are not well informed about the effect of their design decision on the seismic performance of the buildings.

Due to the complexity of the earthquake phenomenon, the causes of a collapse are almost unique for every building. However many buildings have collapsed in a similar way during the earthquakes. Observations showed that these buildings shared some design characteristics, which negatively affected their seismic performance. These characteristics are called seismic design faults. Some of these faults are very common. This indicates that architects have a lack of knowledge about the concept of seismic behavior.

On the other hand, the cost of reinforced concrete skeleton of the buildings is insignificant over the total cost of building construction. Little changes in the cross-sectional sizes of the structural elements or re-adjustment of structural configuration do not change the overall cost of the building, without disturbing architect’s design considerations.

In this study, a classification of common seismic design faults is done in a comprehensible format for designers. The cost of small changes in the size and the shape of structural elements in accordance with this format are investigated with a cost-based analysis.

KEYWORDS: Architectural design, earthquake, structural analysis, natural disasters.

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Earthquake resistant design and code checking of reinforced concrete buildings using expert systems technology

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ABSTRACT: Earthquake codes contain a large amount of complex knowledge of past experience and regulations with numerous subsections, articles, tables, mathematical formulations, and cross references to address earthquake design problems. Earthquake codes of practice are periodically reviewed and updated to meet new knowledge and experience. Often, provisions of earthquake codes of practice become ambiguous during their development, as their authors strive for consensus. When the earthquake resistant design is completed the code provisions are applied in order to demonstrate that the design complies with all applicable earthquake code requirements. Designers have to deal with a large number of code provisions for each structure project and also need to deal with the gaps which exist within the code provisions. This paper is concerned with the investigation of the usefulness and benefits of the application of expert systems technology to earthquake engineering and earthquake codes checking. The methodology and system architecture for developing such expert system tools are also described. Brief description of a prototype expert system, which assists the design engineer in the interpretation and application of the UBC and CEB codes provisions during earthquake resistant design of reinforced concrete buildings, is outlined.

KEYWORDS: Earthquake resistant design, code checking, expert systems, knowledge representation.

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Damage analysis of masonry infilled RC framed structures

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ABSTRACT: A three bay ten-story reinforced concrete building frame was analyzed under strong ground motion to quantitatively evaluate the effects of distribution of masonry infill panels in elevation on the seismic performance of the frame. The nonlinear dynamic analysis of the masonry infilled frame model was performed under the EL-Centro 1940 North-South earthquake component accelerogram using the computational platform IDARC2D version 4.0. Two practically relevant cases of distribution of masonry infill panels in the structural elevation were considered for the dynamic analysis. The peak ground acceleration that was considered corresponds to Richter scale magnitudes of 7.6. The study quantitatively shows that distribution of infill panels in the elevation of a framed building structure may be a crucial factor in deciding the survival or collapse of the structure in the event of a severe earthquake.

KEYWORDS: Shear walls, masonry infill, earthquake, dynamic analysis, soft-storey.

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12.
Structural health monitoring and damage detection

Benefits of structural health monitoring: An example of an indirect benefit for bridges

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ABSTRACT: A specific static bridge test provides a direct, or individual, benefit for that structure itself; such a benefit is called 'individual' in the paper because it usually cannot be related to other structures. The term 'indirect benefit' or 'collective benefit' is used herein for the benefit identified by tests on one or few bridges, but which is available for the other structures as well. A re-assessment of the impact factor, or the dynamic load allowance (DLA), with the help of dynamic testing can provide indirect benefit for the evaluation of all existing bridges. It is demonstrated that the DLA, not given to direct measurement, is an interpreted entity, drops with increase in the vehicle weight. Since the values of DLA are always determined under vehicles carrying no more than the legally-permissible loads, a question is raised in the paper about the validity of these values for the much heavier design and evaluation loads corresponding to the ultimate limit state (ULS). It is recognized that the dynamic magnification of load effects above their static values takes place at an 'intermediate' strain rate, under which the strengths of most materials are at least 25% higher than the strengths determined at 'low' strain rates, or in 'static' tests. It is recommended that for the ULS evaluation by the Canadian Highway Bridge Design Code, the DLA should be reduced by at least 50%.

KEYWORDS: Bridge, dynamic load allowance, dynamic testing, structural health monitoring.

The state-of-the-art and application of intelligent health monitoring systems for civil infrastructures in mainland of China

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ABSTRACT: The intelligent health monitoring systems more and more become an technique for ensuring the health and safety of civil infrastructures and also an important approach for research of the damage accumulation or even disaster evolving characteristics of civil infrastructures, and attracts prodigious research interests and active development interests of scientists and engineers since a great number of civil infrastructures are planning and building each year in mainland China. In this paper, some recent advances on research, development and implementation of intelligent health monitoring systems for civil infrastructures in mainland of China, especially at Harbin Institute of Technology (HIT), P.R.China. The main contents include smart sensors such as optical fiber Bragg grating (OFBG) and polivinylidene fluoride (PVDF) sensors, self-sensing mortar and carbon fiber reinforced polymer (CFRP), shape memory alloys (SMA), wireless sensor networks and the experimental results on their properties; the basic functions and components of the intelligent health monitoring systems; the implementation of intelligent health monitoring systems in practical infrastructure such as offshore platform structures, hydraulic engineering structures, large span bridges and large space structures. Additionally, the relative research projects supported by the national foundation agencies of China are briefly introduced. Finally, the future trends of intelligent health monitoring systems are also pointed out.

KEYWORDS: Health monitoring; infrastructure; smart materials; intelligent structures; optical fiber Bragg grating sensors; smart concrete; shape memory alloy; long-span bridge; offshore-platform.

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Damage identification by monitoring of civil engineering structures

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ABSTRACT: The paper gives an overview of some important aspects of vibration monitoring. Instrumentation, system identification and different damage identification methods are commented. Afterwards some examples are given: damage identification of the Swiss bridge Z24 and of a prestressed laboratory beam. From these two examples interesting guidelines can be derived.

It can be concluded that damage identification by vibration monitoring has reached a mature stage. A crucial step is the prior filtering of the environmental influences. A prerequisite is that damage is accompanied by a sensible stiffness change. The sensitivity of the method can be boosted up by measuring also strains and so adding modal strains to the set of equations in the FE-updating process.

KEYWORDS: Vibration monitoring, FE-updating, damage detection, prestressed concrete, operational modal analysis.

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Substructure modal identification of large systems

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ABSTRACT: Structural identification deals with the inverse problem of identifying structural parameters such as stiffness coefficients based on the numerical analysis of input and output (I/O) data. Besides validating and updating mathematical models for structural systems, structural identification provides a means of nondestructive health monitoring and damage detection by comparing identified values of key structural parameters with the design values or previously identified values. Owing to rapid advances in computer and instrumentation capabilities, this subject has become a hot topic in the last two decades. Nevertheless, much research is needed to improve the feasibility and efficiency of structural identification methods. Noise in I/O measurement, incomplete measurement and ill-condition nature of algorithms are some challenges in the field of structural identification, particularly when the structural system size is large. In this regard, it is essential to keep the system size small. Furthermore, a soft computing approach is preferred such as the genetic algorithm (GA) method which is population based and has a higher chance of convergence in the global search compared to classical identification methods. In this paper, two novel strategies are exploited, namely (a) the substructural approach that physically divides the structural system into smaller systems, and (b) the modal method that transforms the physical problem into modal domain where the number of unknown parameters is greatly reduced. A numerical example of 100DOF structural system is presented to illustrate the proposed two methods, i.e. the dynamic substructure method and the substructure modal method.

KEYWORDS: System identification, structural dynamics, substructure, modal approach, genetic algorithm.

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Baseline finite element model of large span cable-stayed bridges for dynamic monitoring

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ABSTRACT: A baseline finite element model reflects the built-up structural conditions of the real undamaged structure. Structural health can be monitored when this model is compared against a model of the target structure. The paper is aimed at presenting an ambient vibration based procedure to establish a baseline finite element model of a long span cable-stayed bridge that was newly constructed. The bridge is the Qinzhou cable-stayed bridge over the Ming River, Fuzhou, China. Its main span length of 605 m is the longest in the world among the completed composite-deck cable-stayed bridge. The proposed procedure includes several tasks: field ambient vibration testing, finite element modeling and model calibration. The concrete deck stiffness, cable tension, large deflection and dead load are discussed in the modeling of the bridge. The calibrated finite element model will be a baseline model for the dynamic health monitoring of the bridge.

KEYWORDS: Finite element method, cable-stayed bridge, ambient vibration, structural dynamics, modal analysis, model correlation, structural health monitoring.

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Correlating modal frequency with temperature for a cable-stayed bridge using long-term monitoring data and support vector machine technique

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ABSTRACT: For reliable performance of vibration-based damage detection algorithms, it is of paramount importance to discriminate abnormal change in modal parameters caused by structural damage from normal change due to environmental fluctuation. This paper addresses the modeling of temperature effect on modal frequencies for the cable-stayed Ting Kau Bridge instrumented with a long-term monitoring system. Based on one-year measurement data from 45 accelerometers and 83 temperature sensors installed on the bridge, the correlation between the identified frequencies of the first ten modes and the measured temperatures at different locations are obtained. Then the support vector machine (SVM) technique is applied to establish regression models describing the temperature-frequency relationship. The modeling is conducted by maximizing the squared correlation coefficients of only testing data and both training and testing data, respectively. Emphasis is laid on examining different SVM parameters to achieve best generalization performance. The results show that the SVM models have good capabilities for mapping between modal frequencies and temperatures.

Structural damage location by combined analysis of measured flexibility and stiffness

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ABSTRACT: A damage diagnostic technique, based on changes in the measured flexibility and stiffness of structures, is presented. The objective is not only to detect the existence of damages but also to locate them. The modal parameters of structures are identified by using subspace identification approach and they are used to assemble the flexibility matrix written in dimension of the measured degrees of freedom. The corresponding stiffness matrix is obtained by a pseudo inversion of the flexibility. The damage location is realized by a combined evaluation on changes of these two measured matrices from reference state to damaged state. Since damage are located by the sensor position, no geometrical measurement is needed. When using output-only measurement data, an approximate mass-normalization of mode shapes is adopted, and an appropriate normalization procedure is proposed to locate approximately damages. Numerical applications are dealt with to examine the efficiency and limitations of the presented method.

KEYWORDS: Structural diagnosis, damage location, stochastic subspace identification, measured flexibility and stiffness.

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Construction of proportional flexibility matrix at sensor locations in ambient vibration for damage localization

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ABSTRACT: Structural damage detections based upon the changes of dynamic properties are major concern for structural health monitoring. In this paper efforts are made to extend the flexibility based damage localization methods, specially the Damage Locating Vector (DLV) method, to ambient vibration with incomplete measured degrees, where flexibility matrices are not available. The Proportional Flexibility Matrix (PFM) which is within a scalar multiplier to the real flexibility matrix is proposed. An algorithm to construct PFMs with arbitrarily scaled modal shapes in ambient vibration is presented. In the case of incomplete measured degrees, under the assumption that the modal masses don't change before and after being condensed to the partially measured degrees, the PFMs at the measured degrees are constructed. Finally an example of a 14 bays planar truss is given. The assumption made for incomplete measured degree case is testified to be true by this example. The efficiency of the damage localization using PFMs at partially measured degrees is demonstrated in this example.

KEYWORDS: Damage localization, flexibility matrix, proportional flexibility matrix, model condensation, damage locating vectors.

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Establishing fuzzy confidence limits for structural health monitoring using wavelet analysis

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ABSTRACT: The economic and safety incentives of using early damage detection in strategic infrastructure have added significant momentum to structural health monitoring (SHM) research worldwide. This article discusses the development of fuzzy confidence limits in a real time intelligent structural health monitoring system. Data processed from sets of distributed inertial sensors are used in a passive structural monitoring system. The system monitors the structural responses under unknown set of loads. The wavelet analysis is utilized to separate the different frequency components that may exist at the sensors' output without losing time information. Artificial intelligence techniques are used to extract features from the dynamic characteristics of the monitored structural system using healthy "clean" structural data. This allows the SHM system to perform pattern recognition at the different frequency components (different resolutions). Statistical analysis using means of Q-statistics is used to compare the real and the simulated signals. Damage in the structural system is identified when the Q-statistics exceed fuzzy confidence limits that represent healthy "normal" performance. The intelligent damage detection algorithm is demonstrated for detecting a simulated damage using finite element analysis in a reinforced concrete bridge due to cracking.

Baseline model evaluation for cable-stayed bridge

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ABSTRACT: On Korean cable supported bridges including cable-stayed bridges, long-term monitoring systems were employed to investigate the structural response of the bridges to the view of identifying the deterioration rate over a long-term period. To increase the accuracy of bridge state evaluation, it is prerequisite to establish baseline model calculating precise response. In design and construction stage, common structural analysis using finite element model calculates conservative response rather than accurate response. This principle usually guarantees structural safety in design stage but it is impossible to avoid differences between the analysis result and the real behavior of actual bridge in maintenance stage. Therefore the design model should be calibrated with measured data and the calibrated model representing undamaged state is the baseline model. To calibrate the design model for the bridge maintenance and to identify initial behavior of the bridge, static and dynamic loading tests on real bridges are needed. The initial loading tests to evaluate baseline models were performed before opening to the 7 public on two cable-stayed bridges in Korea. From the measured data the baseline models have been evaluated and used for maintenance works. Described in this paper are procedures and results of the initial loading tests and baseline model evaluation of the bridges.

KEYWORDS: Cable-stayed bridge, baseline model, model calibration, initial loading test.

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Long-term performance monitoring of a tall building under wind and seismic excitation

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ABSTRACT: Since 1995 a tall building in Singapore has been monitored with anemometers and accelerometers to identify the character of wind and seismic loading in a country not know for extremes of either type of loading.

Data so far show that dynamic response due to earthquakes is significantly stronger than that due to wind storms, and the observation provides lessons concerning design of less-high rise buildings for dynamic lateral load. Since 2002 a GPS system has been developed to track the low frequency and static movements of the building, with the aim to identify the relationship of static and dynamic wind-induced response and loading, an open question in Singapore where strongest wind-induced loads are due to storms characterised by highly turbulent winds. Results of the monitoring are presented.

KEYWORDS: Building, wind, earthquake, monitor, gps, code.

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Concrete bridge instrumentation for long-term and seismic monitoring

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ABSTRACT: This paper presents results of a long-term bridge monitoring program after nine years of data collection. The North Halawa Valley Viaduct on the Hawaiian island of Oahu was instrumented extensively during construction in 1994. The objective of the instrumentation program was to monitor the long-term behavior of the Viaduct. The instrumentation program was designed for an initial five year monitoring period, which was extended for an additional four years. The primary instruments used for concrete strain, span shortening and vertical deflection monitoring are described. Long-term response of the viaduct is compared with analytical predictions using a finite element computer program specially developed for use with segmental construction of bridge structures. Theoretical predictions based on the original design parameters do not agree with the measured response, particularly with respect to vertical deflections. Improved creep and shrinkage material properties were determined using recently developed creep and shrinkage models adjusted by means of short-term creep and shrinkage data. The modified material property data provides considerable improvement in the prediction of viaduct response. A procedure is proposed for prediction of upper and lower bounds for the long-term response of long-span prestressed concrete bridges. The results of this instrumentation project have been incorporated into the development of an instrumentation system for the seismic and long-term instrumentation of a new bridge to be built over the Kealakaha Stream on the seismically active island of Hawaii. The primary elements of this instrumentation system are presented.

KEYWORDS: Structural instrumentation, long-term monitoring, cantilever construction, box-girder bridge, creep, shrinkage, bridge deflection, prestress loss.

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Evaluating bearing capacity and damage of cast-in-place piles from dynamic field tests

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ABSTRACT: This study proposes to use Hilbert-Huang transform method to explore time-dependent dynamic characteristics from vibration recordings collected at the top of a pile subjected to an impacting load, and then to quantify the dynamic characteristics that are related to the bearing capacity, damage, and integrity of the pile. With the aid of field tests of three piles in Jiangshu Province, China, the study shows that the piles under investigation have the same estimated bearing capacity that is higher than the designed one.

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Health monitoring system for a self-anchored suspension bridge

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ABSTRACT: Automatic measurement of instrumented civil engineering structures is becoming more common for behaviour monitoring during construction in field as well as long-term monitoring for life time assessment. The considerations for deploying a proper monitoring system are appropriate instrumentation, reliable signal processing and intelligent information processing. This paper addresses general guidelines and suggestion regarding the main elements of structural monitoring as mentioned. This paper also presents a structural monitoring application considering these three issues on a self-anchored suspension bridge, Yongjong Bridge, which was constructed on the new freeway between Seoul and New International Airport in Inchon. Sensor and hardware instrumentation, signal transmission, signal acquisition and analysis are schematically described.

KEYWORDS: Health monitoring system, self-anchored suspension bridge.

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Investigation on structural damage detection based on mode varied quotiety

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ABSTRACT: Damage detection by using the dynamic system parameters in engineering structures has come an important research topic. There is an urgent need for the developing a direct, fast and inexpensive method to evaluate and localize damage using the change of dynamic parameters between the intact and damage states. This paper develops a method of identifying the location of structural damage in beams, which uses solely the mode shapes from the damage structure and does not require a prior knowledge of the undamaged structure. The developed damage algorithm is programmed with a finite element method and validated with experiments on slotted steel cantilever beam. The procedure is best suited to the mode shape obtained from the fundamental natural frequency. It is demonstrated that the developed damage index can estimate the presence of damage and locate the damage to a satisfactory precision.

KEYWORDS: Damage detection, strain mode shape, mode varied quotiety.

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Development of fiber Bragg grating sensors for monitoring civil infrastructure

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ABSTRACT: The concept of structural health monitoring has been subject of research over the last few years, particularly in civil and structural engineering where aging infrastructure has been of major concern. These studies have led to initiatives towards the development and deployment of new sensing technologies. Owing to the harsh environment found in the construction industry and the large size of civil structures such sensors should be robust, rugged, easy to use and economic. Fiber Bragg grating sensors are offering such a viable sensing approach with a number of advantages over traditional sensors which include, immunity to electromagnetic interference, light weight, small size, multiplexing capabilities, ease of installation and durability. This paper reports some results of a multi discipline research program on FBG sensors involving the School of Civil and Structural Engineering and the School of Electrical and Electronic Engineering at Nanyang Technological University. Novel FBG strain sensors have been developed and deployed on highway bridges to measure dynamic strain, static strain, and temperature. Results of these studies indicate that, if properly packaged, FBG sensors can survive the severe conditions associated with construction of civil infrastructure.

KEYWORDS: Fiber optic Bragg grating, structural health monitoring, fiber optic sensors.

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Application of smart materials in bridge structures: A state of the art

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ABSTRACT: From the past history of civil engineering structures such as Dams, Bridges, High-rise buildings, offshore platforms etc., one can see that they are all made of iron, steel, reinforced concrete and composite materials. The life of these structures have been minimized, because of the corrosion in particular and environmental effects (earthquake forces) in general. This paper reviews critically, the present day knowledge of Health Monitoring of Bridges, which is of global concern. In all parts of the world, Highways and Railways play a very important component in the transportation network. Risks or failures are associated with the damage or collapse of these bridges, which includes not only the human loss but also potential with reference to extreme economic implications. From the statistics, it can be seen that, in U.S. alone over 900 billion tons of commercial traffic is on highways and highway bridges. With reference to Indian scenario, one can see the tremendous progress in highways and railways with reference to construction of bridges and transportation. By taking world scenario, one can see the deformation of bridges nearly 20%. Deformation and destruction of bridges may be sustained due to continued use and misuse of the bridges (over loading), as well as catastrophic events, such as earthquakes. The failure of bridges can be seen from the recent earthquake occurred over a decade in USA, Kobe and Japan. The failure of the bridges to earthquakes remind us that, continued research to minimize such damage must be pursued. The maintenance of highway bridges is very much essential to safeguard lives and maintain a high level of service. Further, the failure of bridge leads to various causes where in the potential loss will far exceed that of rebuilding, repairing and retrofitting of bridges.

Hence, the main focus of this paper is to review critically, the development and implementation of health monitoring system for bridges to monitor for its performance continuously. The maintenance is through optical sensors, fiberglass-grading sensors and FRP materials. In general the overall concept should be based on real time sensing communication, computing and control.

KEYWORDS: Bridges, health monitoring, smart materials, actuators, sensors, fibers, grating, shape memory, vibrators, semiconductors.

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Non-linear constrained structural damage detection method using static data

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AB STRACT: A structural damage detection algorithm using static test data is presented in this paper. Change in the static response of a structure is characterized as a set of non-linear undetermined simultaneous equations that relates the changes in static response of the structure to the location and severity of damage. Damage is considered as a reduction in the structural stiffness (Axial and/or Flexural) parameter. An optimality criterion is introduced to solve these equations by minimizing the difference between the load vector of damaged and undamaged structures. The overall formulation leads to a non-linear optimization problem with non-linear equality and linear inequality constraints. Numerical results of a two-span beam and a 2D truss represent good ability of this method in detecting damages in a given structure.

KEYWORDS: Damage detection, structures, static test data, non-linear optimization.

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Finite element model updating of bridges by using ambient vibration testing results

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ABSTRACT: This paper presents a practical and handy finite element model updating method for real bridge structures using the field ambient vibration test results. The objective function considers the residuals of frequencies, Modal Assurance Criterion (MAC), as well as flexibility. The case study is a concrete filled tubular arch bridge whose dynamic characteristics were identified by field ambient vibration testing. The three-dimensional finite element model of the bridge is first developed according to the original blue prints. An eigenvalue sensitivity study is carried out to see the sensitive parameters to concerned modes. The objective function is minimized using the least square algorithm. The updated finite element model is able to produce natural frequencies in close agreement with the experiment results with enough improvement on MAC value of concerned modes still preserving the physical meaning of parameters.

KEYWORDS: Finite element method, model updating, ambient vibration, bridge engineering, structural dynamics, modal analysis, objective function.

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On the statistical processes for damage diagnosis of structures

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ABSTRACT: This paper presents two approaches for structural damage diagnosis through a statistical process. The first one involves an application of a process control concept. The Kalman model is constructed by performing data-driven stochastic subspace identification to fit the measured response histories of the healthy structure. Damage detection is based on the expectation that the Kalman model of the undamaged structure is not able to reproduce the newly measured responses of damaged structure. The second approach is based on an enhanced principal component analysis (PCA). It is assumed that in the absence of damage, structural responses remain approximately in the hyperplane defined by the principal directions of the initial responses. Both methods use directly measured signals as input data and are convenient for on-line monitoring. The proposed methods are compared on practical applications to show their consistency and efficiency.

KEYWORDS: Structural diagnosis, damage detection, Kalman filter, principal component analysis, stochastic subspace identification, novelty analysis.

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13.
Soil-structure interaction

Analysis of laterally loaded piles and sheet-piles embedded in elastic-plastic soil using the Winkler model

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ABSTRACT: An efficient method of numerical analysis of piles and sheet-piles subjected to transverse loads is outlined. In the approach, the soil is idealised as a linear-elastic—perfectly plastic material that in the elastic range can be modelled as a Winkler foundation. The direct stiffness method is used in the numerical modelling for piles/sheet-piles themselves, whilst for elastic soil the stiffness matrix is obtained from the potential energy of the Winkler medium. The computer program developed allows for both, elastic and elasto-plastic soil behaviour. Results of analysis of a sample problem are included for illustration.

KEYWORDS: Piles/sheet-piles, elastic—perfectly plastic soil, Winkler foundation, displacement method.

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Laterally loaded rigid piles in Gibson soil

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ABSTRACT: Design of laterally loaded rigid piles (including piers and drilled shaft etc.) has been relied on empirical expressions obtained from in situ full-scale tests or model studies performed in laboratory. To account for non-linear pile-soil interaction, centrifuge and numerical modelling were developed. However, the modelling requires too many soil parameters that are not often warranted in general design. Rigorous closed form solutions were developed for the case of a constant limiting stress, and soil modulus along the piles; and the case of a linearly increasing limiting stress, but a constant modulus. With only two soil parameters for limiting stress and the modulus, respectively, the solutions can well simulate non-linear responses of laterally loaded piles in comparison with numerical and experimental results. While other effects such as the (rigid) pile dimension may be included in the solutions themselves. Thus, these solutions should be useful for the pile design. However, in some cases, the limiting stress and modulus may vary in a different manner such as both linearly increasing (Gibson type) with depth.

To address the effect of this (Gibson) type variation, in this paper, new closed form solutions are developed, and presented in explicit forms that allow the following nonlinear response to be assessed readily: 1) the loaddisplacement relationship, and 2) the load-rotation relationship, due to the development of pile-soil relative slip. At the critical moment of tip yield, the magnitudes of maximum bending moment and its location, pile-head displacement were computed, which show the inconsistency in current estimations of pile capacity, and soil modulus.

KEYWORDS: Rigid piles, lateral loading, closed-form solutions, non-linear response.

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Long piles embedded in nonlinear sand subjected to horizontal loading—sensitivity investigations

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ABSTRACT: The paper deals with sensitivity analysis of nonlinear pile-soil system embedded in sand located below water table. The pile-soil system is subjected to lateral loading. The behavior of the pile is modeled by means of one dimensional beam element. The adjacent soil is simulated by means of $p-y$ model developed by Cox, Reese and Grubbs (1974). It is based on extensive field studies of natural size piles subjected to bending. This soil model enjoys high popularity among engineers and designers all over the world.

Depending on the lateral deflection, the $p-y$ sand model can unfold four physical phases. They are: linear elastic, nonlinear elastic, a by-linear elastic that passes into plastic flow. The material parameters involved in the full description of sand include coefficient of subgrade reaction k, submerged unit weight of soil γ', angle of internal friction ϕ, coefficient of active lateral earth pressure K_a of Rankine type and the width b of the pile. The behavior of the pile's structure involves the bending stiffness EI into constitutive relationship. All material strength parameters of the pile-soil system are taken as the design variables. The maximum kinematic quantities of the pile-soil system are subjected to sensitivity analysis assessment. They are investigated in the scope of variational calculus with aid of the adjoint system notion that demonstrates the path independent features.

The performance functional that involves the maximum generalized deformations is formulated based of the virtual work principle. The first variation of the performance functional caused by the changes of the design variables defines the sensitivity of the maximum generalized displacement due to the changes of the physical parameters of pile-soil system. They are expressed by means of sensitivity operators that are integrands of the spatial variables x. The graphical representation of sensitivity integrands visualize in practical fashion the effect of changes of the design variables on the variations of maximum generalized deformations.

KEYWORDS: Infrastructures systems, deep foundations, nonlinear sensitivity analysis, distributed parameters, sensitivity operators.

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Modal decomposition for calculation of soil-structure interaction

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ABSTRACT: The solution of soil-structure-interaction problem we can calculate in frequency domain. In the basic equations the structure with internal damping has a complex dynamic stiffness matrix and the soil region is represented by frequency dependent complex impedance matrix. Solution of large building analyzed by finite element method requires much computer time because the many degrees of freedom.

Calculating the modal amplitudes of the structure fixed at its base we can calculate the displacement vector of interface nodes and using this vector we will get the displacement vector of structural nodes too. This method is very comfortable, but we have to calculate the eigenvectors of a large system. In case of large systems, it is not possible to calculate all the eigenvectors but for practical application, it is not necessary either to have all the components. The necessary number of the eigenvectors is less if we break the total displacement amplitudes of the structure into quasi-static displacements introduced by the base response and dynamic displacements of the structural nodes. In the practical cases if the internal damping of the structure is proportional the calculation of the matrices will be simpler. We gave the formulas for this case.

During the numerical experiments we calculated the transfer functions of the absolute displacement for horizontal direction and the relative displacement to direct of axis and the orthogonal to axis of column at a high building. The transfer functions were calculated by direct integration and by modal decomposition using different number of eigenvectors. We have seen the differences of convergence at different value of frequency and the differences in case of absolute displacements, relative displacement to different direction. Using this algorithm the computer time can be reduced and we get a good possibility to solve the soil-structure-interaction problem in case of large system.

KEYWORDS: Soil-structure interaction, calculation in frequency domain, modal decomposition.

Stochastic dynamic response of embankment dams to deconvolved ground acceleration record

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ABSTRACT: The stochastic dynamic analysis of an embankment dam-foundation interaction systems subjected to deconvolved base-rock input model is performed for different shear wave velocity of the foundation rock in this paper. The values of shear wave velocity of the foundation rock are selected as 1000 m/s, 2000 m/s and 3000 m/s, respectively. Displacements and stresses obtained from the deconvolved base-rock input model are compared with each other and those of standard rigid-base input model.

KEYWORDS: Rigid-base, deconvolved base-rock, stochastic analysis, shear wave velocity, dam-foundation interaction, embankment dam.

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Contact subsoil FEM element for soil-structure interaction

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ABSTRACT: In the presented paper is designed the solution of soil-foundation interaction and plate contact FEM element. The subsoil model is as a linear elastic halfspace modified with soil structure strength coefficient following Standard ČSN 73 1001 taken into account.

For the stress-strain plate analysis is used the finite element method (FEM). The plate is modelled by means of isoparametric plate elements and Mindlin's theory with shear taken into account.

The original and universal method of contact stress solution by means of Jacobian transformation and numerical integration is derived. The stress state and settlement of halfspace can be calculated for arbitrary shape and plate contact stress. This is allowed by using 4- and 8- nodal points isoparametric contact elements with a general nodal load. Numerical integration is executed for arbitrary number of integration points by means of Gauss quadrature formulas. The limit depth and settlement is defined for each nodal point of isoparametric plate element and the contact function of element subsoil is calculated.

The element stiffness and subsoil matrix is calculated by the numerical integration. This non-linear interaction problem is solved by iteration method for desired precision of solution or number of iteration steps. In the interaction analysis one-sided bonds, reduced plate stiffness with cracks and influence of loading by surrounded structures can also be taken into account.

The results of numerical examples are compared to those obtained by other authors and other FEM systems.

This presented original solution of interaction fully respects the requirements of Czech standard ČSN 73 1001 and can contribute to design of European standard.

KEYWORDS: Soil-structure interaction, finite element methods, isoparametric elements, numerical integration.

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Soil-structure interaction in the seismic response of building frames

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ABSTRACT: The effect of soil condition on the elasto-plastic earthquake response of RC buildings has been studied by considering the effects of soil-structure interaction and soil amplification. In this study, idealized Reinforced Concrete buildings (2, 5 and 10-storied) are subjected to ground vibrations recorded during the Northridge earthquake in 1994. Surface foundations on soils of different shear wave velocities (representing stiff and soft soil respectively) are used as the substructure. The maximum forces and deformations are compared for different conditions of the foundation and the subsoil. The results show that the structural responses may be significantly affected if the effect of soil amplification and soil-structure interaction are also taken into account. The relative importance of soil amplification and soil-structure interaction depends on the structural stiffness compared to the stiffness of the foundation and the sub-soil.

KEYWORDS: Seismic analysis, soil-structure interaction, soil amplification, foundation stiffness.

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Analysis of a beam made of physical nonlinear material on nonlinear elastic foundation under a moving concentrated load

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ABSTRACT: A prismatic beam made of a behaviorally nonlinear materia $(\varepsilon_z = \frac{1}{E}\sigma_z + \frac{2}{27G^3} \cdot I_2 \cdot \sigma_z^3)$ is analyzed under a concentrated load moving with a known velocity on a nonlinear elastic foundation with a reaction [$q_e = -K_1 W(1+K_2W^2)$]. The vibration equation of motion is derived using Hamilton principle and Euler Lagrange equation. The amplitude of vibration, circular frequency, bending moment, stress and deflection of the beam can be calculated by the presented solution. Considering the response of the beam, in the sense of its resonance, it is found that there is no critical velocity when the behavior of the beam and foundation material is assumed to be physically nonlinear, and there are finite values for the deflection, stress and bending moment of the beam when $\eta^2 = \frac{\theta^2}{\omega^2} = 1.$

KEYWORDS: Physical nonlinear, moving load, Hamilton principle, Duffing equation.

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Behaviour of laterally loaded piles and sheet-piles embedded in elastic half-space with plastic zones

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ABSTRACT: The paper presents a relatively simple numerical analysis of laterally loaded piles/sheet-piles in soils that can be modelled as materials with linear-elastic—perfectly plastic behaviour. In the elastic stress range, the soil behaviour is defined by the behaviour of homogeneous, isotropic, elastic half-space. For the elasto-plastic soil-structure interaction, the soil mass is modelled also as a homogeneous, isotropic, elastic half-space, but with small pockets of plasticised material. The technique of analysis is a displacement-based approach in which the direct stiffness method is used for numerical modelling of piles/sheet-piles themselves. For the soil medium, the solution by Mindlin of the problem of a horizontal point-load acting beneath the surface is used to develop the flexibility matrix, whose inverse constitutes the original stiffness matrix of the soil. In the elastic analysis, this original stiffness matrix is combined with the stiffness matrix of the pile/sheet-pile to yield the stiffness matrix of the interacting system. For elastic-plastic interaction, a modified form of the soil original stiffness matrix is combined with the stiffness matrix of the pile/sheet-pile to obtain the stiffness matrix of the system. The developed ideas are implemented in a computer program, which can cater for both, elastic and elasto-plastic soil—structure interaction. Some results of analysis of a sample problem are included for illustration.

KEYWORDS: Piles/sheet piles, elastic—perfectly plastic soil, half-space, displacement method.

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14.
Tunnels, retaining walls and foundation structures

The sliding resistance of shallow foundations to coupled actions of axial moments and horizontal forces

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ABSTRACT: A method is derived to determine the sliding resistance of shallow foundations in their joints to the subsoil to coupled actions of horizontal forces H_x, H_y and axial moments M_z acting around the vertical z-axis. To this end ideal friction conditions between foundation and subsoil as well as the kinematics of rigid bodies are assumed. The governing equations are presented and possible displacement fields within the foundation joints are illustrated. The resultant moment and the resultant forces of the sliding resistance are ascertained from the displacement field and the distributions of vertical stresses and friction coefficient by integrating over the compressed part of the foundation area. One possible distribution of the resistance is graphically presented by an interaction surface. The method is applied to footings of rectangular shape. Therefore the developed integral equations are elaborated under further assumptions and simplifications and analytically solved. The solution is illustrated by a $H{-}M_Z$ interaction diagram. Finally, examples show the application of the diagram and the influences of axial moments on the sliding resistance. Due to the interaction only small additional horizontal forces can be allowed, if footings are already loaded by predominant axial moments and vice versa. This especially applies to small, compressed foundation areas, as the sliding resistance to axial moments (in contrast to the resistance to just horizontal forces) significantly depends on size and expansion of the compressed area.

KEYWORDS: Shallow foundations, axial moments, sliding resistance, interaction diagram.

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Application of sensitivity theory to cost assessment of composite layer

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ABSTRACT: The paper presents the application of the functional with moving ends to determine the equivalent thickness of a base layer of a flexible transportation system that guarantees the same performance as another transportation system, which is reinforced by a geogrid that is inserted into the base layer. The analysis employs the experimental data provided by the research conducted on the laboratory models. The performance of the unreinforced and reinforced systems are assessed by means of the application of the constant load of repetitive type that results in generation of cumulative permanent deformations. They form the basis for numerical investigations. The performance functionals (for the unreinforced and reinforced systems) used, are formulated based on the virtual work principle. They involve the suitable adjoint systems. In the problem explored, the primary systems demonstrate the ability to develop only permanent deformations. The stress-strain relationship caused by the single load application is described by the modified Hooke's law, which includes the modulus of permanent deformation. The irreversibility of permanent deformation implies that each repetition of a load is applied to different geometry of the system. The reinforced system is replaced by an equivalent system with thickened base layer, which is described by functional with moving boundaries. The laboratory determined cumulative permanent deformations allow the permanent deformations associated with each single load application for the original and the equivalent primary system to be defined. The difference of these deformations is equal to the first variation of the performance functional caused by the changes of the thickness of the base layer. First variation of the functional (the original and equivalent system) that is caused by the shifts of base's boundaries represent the sensitivity of the performance of the system due to the changes of the thickness of the base layer. The savings associated with the cost of the materials used is equal to the difference of cost of the base material required for thickening the base layer and the cost of the added geogrid.

KEYWORDS: Flexible pavements, geogrids, rutting, functionals with moving ends, sensitivity analysis.

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Single-layered pavement thickness inverse problems

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ABSTRACT: Field measurements can be used to determine the mechanical and physical properties of the materials of a layered structure such as soil sites, highway pavements and airport runways. The surface wave method, as an in situ non-destructive testing procedure, is used to derive the elastic properties and thicknesses of the component materials of the layers. The measurements are made of the differences in the phase of a wave of the Rayleigh type, received at two points at known radial spacings from the source of the wave. Pavements for highways or airport runways are usually constructed of cement concrete. Such pavements are treated as a single layer of constant thickness overlying a semi-infinite medium. The system is dispersive and all materials are assumed to be elastic, homogeneous and isotropic. Three types of inversion procedures; namely algebraic, numerical and approximate inverse procedures; have been developed and employed to determine the thickness of the upper layer using the data obtained from surface wave field measurements. To assess the effectiveness and reliability of the proposed inverse techniques, some real cases have been studied. The surface layer thicknesses of the cases measured in the field are compared with those calculated from proposed inverse procedures. Based on the comparisons made, the applicability of the techniques are examined and discussed.

KEYWORDS: Surface wave method, inverse problem, pavement layer thickness, Rayleigh wave, dispersion.

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Flexural analysis of retaining walls resting on elastic-plastic soil using the Winkler model

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ABSTRACT: A displacement-based method of bending analysis of reinforced concrete retaining walls resting on soils modelled as *linear-elastic—perfectly plastic materials* is outlined. The numerical modelling of the wall structure itself employs the direct stiffness method. The elastic behaviour of the soil underneath is assumed to follow that of a *Winkler foundation*. Hence, for the elastic stress range, the soil stiffness matrix is obtained from *the potential energy* of the Winkler medium. The elastic-plastic analysis employs an *iteration process* whose first step is the linear-elastic analysis. The computer program developed allows for both, elastic and elasto-plastic soil behaviour. Results of analysis of a sample problem are included for illustration.

KEYWORDS: Retaining walls, elastic—perfectly plastic soil, Winkler foundation, displacement method.

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Stability of underground works by improved Desai's theory

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ABSTRACT: A special coupling of physical and numerical modeling is established. Based on results from physical models material properties (constitutive relations) in numerical models are specified. Distinct state concept (DSC) and Generalized transformation field analysis (TFA) are used for determining nonlinear material properties of the rock in numerical models. Several physical models fulfilling geometrical and physical similarity have been prepared to get displacements at the tunnel face. These displacements are measured by special equipment and their values are substituted into the numerical models. Such a coupled modeling enables us to predict the behavior of tunnel structures, for example, very accurately.

KEYWORDS: Stability of tunnel face, distinct state concept, generalized transformation analysis, unified concept, coupled modeling.

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Stability analysis of a twin tunnel entrances in sloping ground surface conditions by 3D FEM

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ABSTRACT: In this paper, the stability analysis of a twin road tunnels located in a natural sloping ground surface is presented. In the entrance of western tunnel, two cracks were developed in first stage of excavation. It is expected that these cracks will affect stability of the tunnels during second stage of excavation. Therefore the entrance of the tunnels were simulated through finite element method using ANSYS program as a three dimensional model. The behavior of rock mass in the analysis was assumed to be elasto-plastic based on Drucker-Prager criteria. This analysis shows that the region will be unstable during the second stage of excavation at least the first 12 m from tunnels entrances. Such instability is more likely to occur as an overall slope failure which passes through the floor of the tunnels. This failure will be independent to the internal support system of the tunnels. To solve the problem and to provide stability of the tunnels, it is suggested to reduce the overburden of the western tunnel entrance.

KEYWORDS: Stability analysis, tunnel, natural sloping ground surface, 3D FEM, ANSYS.

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Observed and simulated behaviour of a geogrid reinforced wall structure

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ABSTRACT: A full scale, 4.8 m high geogrid reinforced wall was constructed to study and evaluate the performance of this reinforced soil wall system. The behaviour in the field after construction was monitored by incorporating extensive instrumentation including inclinometers, strain gauges, pressure cells, piezometer tubes and surface settlement markers. This paper gives some results of the measurements, describes the behaviour of the reinforced wall and compares the performance with predicted or calculated values obtained using the finite element method of analysis.

KEYWORDS: Reinforced soil structure, retaining wall, geogrid, instrumentation, finite element method.

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Behavior of square footings on double reinforced soil

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ABSTRACT: Many attempts have been carried out along years aiming to increase the soil bearing capacity. It is really an important target to geotechnical engineers. To contribute in this goal, twenty-three laboratoryloading tests on square-footing model resting on reinforced sand were conducted. The use of geosynthetic as an inclusion to modify ground characteristics is increasing annually. The development in the subject is going through many aspects, one of these is the placement and orientation of geosynthetics. So the study aims to make a comparison between single and double reinforcing layers on the bearing capacity ratio (BCR) of a footingsoil system. Moreover, the study aims to illustrate the improvement achieved by two-reinforcing layers on the bearing capacity of sand. It was found that the (BCR) increased with a value varied from 1.48 to 2.25 for single reinforced soil, to a value varied from 1.92 to 4.40 for double reinforced soil. For double reinforced soil the most effective depth of the upper layer was almost 0.25B irrespective of the depth of the lower reinforcing layer. The most effective spacing between the two reinforcing layers was almost 0.25B. Finally, it was established that the location of the upper layer is more effective than the lower one.

Bending behaviour of long retaining walls on elastic-plastic soil modelled as elastic half-space

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ABSTRACT: The paper presents a displacement-based method of flexural analysis *of long*, reinforced, concrete, retaining walls founded on soils idealised as *linear-elastic—perfectly plastic* materials. The soil behaviour in the elastic stress range follows that of homogeneous, isotropic, elastic half-space with rough surface. The same soil model is used for the *elasto-plastic* soil-structure interaction, however, the medium in this state is assumed to possess *small pockets of plasticised material.* The direct stiffness method is used in numerical modelling of wall structures themselves. The soil stiffness matrix is obtained from the flexibility matrix, which in turn, is developed with the aid of the *classical* solutions by Boussinesq and Cerrutti for vertical and horizontal point-loads acting on the half-space surface. This stiffness matrix is used for both elastic and elasto-plastic solutions. This follows the assumption that the plastic zones are small enough to have negligible effect on the overall, elastic behaviour of the foundation. However, for elasto-plastic solutions, the stiffness matrix of the foundation is modified to allow for the development of distinct displacements of the base-plate and the half-space. A further modification of the soil stiffness matrix precludes the presence of tensile contact stresses between the soil and the structure. The developed ideas for the elastic and elasto-plastic soil-structure interaction are tested in a computer program. Results of analysis of an illustrative problem are included.

KEYWORDS: Retaining walls, elastic—perfectly plastic soil, half-space, displacement method.

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15.
Loading on structures

Integrated computation of wind actions on large structures

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ABSTRACT: In the present paper, competences of frequency-domain approach for integrated computation of major wind actions on structures are outlined. It will be demonstrated, that these could all be analysed based on the same framework of spectral analysis and normal mode summation. The integrated analysis code, used as demonstrator, is put to practice in several medium to very long-span cable-stayed bridge projects. As wind-tunnel experiments and monitoring are done in parallel, rich set of conclusions is obtained. One of the main benefits the approach are reliability, overall efficiency of simulation, and possibility to extract equivalent static wind loads for design purposes.

The hart of the associated numerical code is simultaneous buffeting and flutter analysis algorithm, which is non-iterative in nature. It employs technique analogous to flight-flutter testing of air-crafts. The normal mode summation is used to reduce size of the problem, resulting two important properties: 1) analysis efficiency in large problems and 2) link to third party finite-element codes used for modal analysis.

The calculation model for vortex-induced vibrations is versatile to take into account the key properties of the phenomenon. The excitation process is modelled as band-limited white noise, in which the bandwidth is dependent on vibration amplitude and longitudinal turbulence, while the load variance is assumed to be invariant. The model for local (signature) turbulence applies spectral analysis essentially in same form, as the simplified buffeting models do. To evaluate typical design parameters, this action of wind needs more research.

The static response and divergence analysis are modelled through normal-mode approximation of static displacements. Although theoretically compromising some accuracy, the implied uncertainties are on a small level in comparison, e.g., to uncertainties in aerodynamic input parameters. Here, the divergence analysis using general-purpose finite element codes is in most cases not feasible, as load magnitude will be dependent on deformation of the structure.

KEYWORDS: Wind, wind load, structures, bridges, buffeting, vortex shedding, flutter, divergence, signature turbulence, frequency domain.

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Development process and components of a wind disaster model for South Africa

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ABSTRACT: At the 2001 SEMC a paper was presented, in which the background to the wind damage and disaster in South Africa was given and a development of a comprehensive risk model was postulated. This process has been completed and its components were presented in a series of papers at various international venues. The current paper presents an integrative overview of the process and summarises the components of the model, affecting the amount of damage. Initially the highlights as well as motivation for, the basic philosophy of the model are presented. Various wind-related and land developmental factors are discussed in the context of the South African conditions. These include: the geographical distribution of strong wind events, information on their foot-prints and rate of occurrence, data on the distribution of land development, its density, distribution of asset value and vulnerability of built environment.

KEYWORDS: Wind, damage, risk model, South Africa.

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Field load testing of a non-composite concrete slab on steel girder truss bridge

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ABSTRACT: Many of the older steel truss bridges in the United States have inadequate structural capacity according to current load standards. One portion of a steel truss bridge that is frequently problematic from a load rating point of view is the floor system. Older bridges of this type were normally constructed with non-composite steel-concrete deck systems. To provide further insight into the structural behavior of the bridge deck system, field load tests were conducted on a steel truss bridge to measure the actual response to known truck loads. The measured response can help determine a more realistic load distribution and determine the degree of unintended composite action for older bridge decks not designed compositely. This paper presents the results of a field load test conducted on a steel truss bridge in Goliad, Texas.

KEYWORDS: Bridge load, test, truss bridge, bridge load rating.

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Monitoring traffic loads and traffic load effects on the New Arstaberg Railway Bridge

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ABSTRACT: This paper describes the instrumentation of a railway bridge at Årstaberg in Stockholm. The bridge is of the integral type structure, made of reinforced self compacting concrete, and was opened for traffic in July 2003. The main objective of the instrumentation is to study actual traffic loads and traffic load effects on railway bridges. Some very early results are presented and the feasibility of the measuring system is discussed.

KEYWORDS: Bridge, rail, traffic load, load effect, moving load, dynamic, monitoring, bridge weigh-inmotion, strain transducer, field measurement.

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Examples of some parameters influence on bridges behaviour under moving loadings

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ABSTRACT: The paper presents numerous own comparisons of bridges behaviour under moving loads of different types. There are investigated displacements and global behaviour in space and in time, bridges under loading of different vehicles as cars, trains, aircrafts, moving with some different velocities e.g. 0 (static), 36, 360, 3600 km/h, without dumping. The vehicles are having different mass approximately: 1t, 10t, 100t, 100t. There is possible to consider different number of wheels and vehicles moving with constant and variable velocity, too.

The paper gives certain continuation of author's presentations during large conferences: I ASS 2002 in Warsaw and ICSSD 2002 in Singapore. This time examples concern the bridge, where very important is proportion of vehicle and bridge masses. The computations were performed by Finite Differences Method applied in 3D-Time space. Results and diagrams were elaborated by commercial program EXCEL. In previous papers were investigated similar tasks for other freely supported beam and aircraft on air-belt placed on elastic foundation.

The beam considered in the paper is freely supported with the length 1=100 m, Figure 1 and made from steel with density ρ=7.85 g/cm^3. Its hypothetical cross-section is rectangular, with dimensions of middle line 4×18 m. The beam is divided on 10 sections with the length of a=10 m each. The internal points of beam division are numbered from 1 to 9.

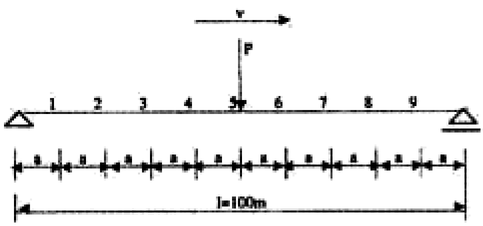

Figure 1. Concentrated force on freely supported beam.

The thickness of the cross-section walls is δ=6.570647606 cm what give for static loading by concentrated force P=10000 kN (mass about 1000 t) deflection of bridge equal w=10 cm. The area of the cross-section is A=28910.84947 cm^2. Moreover, mass of bridge section with the length 1 cm gives own mass equal μ=226950.1683 g.

KEYWORDS: Dynamics, moving load, bridges behaviour, vibrations, analysis, comparative results.

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Highway bridge live loading assessment using a modified Gumbel distribution

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ABSTRACT: In recent years there has been growing interest in non-destructive field-testing and monitoring of bridges to determine representative structural models and to assess their load carrying capacities. This has been made possible by technological developments in data acquisition hardware and software, sensors and data interpretation procedures. The advantage of field-testing and structural monitoring over traditional assessments based on standard axle loads is that realistic structural systems and live loading models are used. The resulting live loads integrate site specific conditions including traffic volume, bridge natural frequency and damping, proximity to heavy industry, road alignment, vehicle suspension, traffic barrier design, speed environment, traffic mix. This paper explores the use of the modified Gumbel distribution to estimate live load using structural monitoring data. The candidate structure is a bridge identified by the Land Transport Authority (LTA) of Singapore for strengthening due to its strategic location.

KEYWORDS: Gumbel distribution, structural monitoring, bridge assessment, bridge live loads.

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Considering continuous support conditions in moving force identification

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ABSTRACT: A method is presented to identify moving forces on a continuous bridge. The bridge is modeled as a continuous supported Bernoulli-Euler beam and the boundary value problem of the beam is solved to get the exact mode shape functions of vibrating beam with inner supports. The bending moment responses are used to study the inverse problem in identifying moving forces on a bridge. The SVD (singular value decomposition) is used in the solution to study the inverse problem. Two time varying forces moving over the bridge are simulated to evaluate the method. White noise is added to simulated bending moment responses to study the effect of noise in moving forces identification problem for different numbers and arrangements of sensors. Results obtained from simulation study show that the method is effective in identifying moving forces and acceptable results can be obtained.

KEYWORDS: Moving forces identification, bending moment responses, time domain method.

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A comparison between crane induced load effects from SABS and Eurocode

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ABSTRACT: A comparison between crane load models in the Eurocode prEN 1991–3 (CEN TC250/SC1 2002) and the South African code of practice on loading on buildings (SABS 0160:1989) indicates that the South African load models are over-simplistic. This suggests the need for an assessment of the South African provisions for loads induced by cranes. The adoption of the Eurocode crane load models into the South African loading code is currently under consideration. The implications of this with regard to load situations provided for, design effort and structural cost are investigated. It is shown that the application of Eurocode load models requires a more extensive design effort but results in more economical crane support structures.

KEYWORDS: Overhead traveling cranes, crane load models, SABS 0160:1989, Eurocode prEN 1991–3.

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Precast concrete terraces under static incremental loading: A laboratory investigation

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ABSTRACT: The paper describes an experimental investigation of a set of L-shaped precast concrete terrace units subjected to static incremental loading to assess their structural performance and estimate their stiffness. A series of loading-unloading tests were carried out on *uncracked* (as delivered from the factory) and *cracked* (after the first complete loading-unloading cycle) units. The variation of parameters, such as displacements and strains, with the applied load was recorded and presented graphically. The reduction in stiffness of the units due to cracks was then estimated from these graphs.

The predominant mode of failure was found to be due to gradual propagation towards the top of cracks starting from the soffit (tension zone) and around the symmetry line (where maximum bending occurred). The strain distribution with depth for the vertical "beam" part of the terrace unit was predominantly linear, with tension at the bottom and compression at the top. However, a large portion of the horizontal part of the unit *(slab)* followed closely the behaviour of the beam, to give tension rather than compression at the top. This could have important implications for the design of the units. Their deformed shape was considerably more complex than that assumed in the initial design, with downward displacements combined with rotation about a longitudinal horizontal axis and warping at the free slab corners.

A series of finite element models were developed, depicting closely the true behaviour of the units, to assist the study of the structural aspects that otherwise would not be easy to identify (such as, the formation of a "bowl" at the central region of the units). It was concluded that the present methods and procedures of evaluating and designing precast concrete terraces were not sufficiently comprehensive. Further tests are required, combined with more rigorous analytical work and the establishment of benchmarks, in order to substantially minimise the uncertainties surrounding their performance in service.

KEYWORDS: Laboratory, tests, grandstands, terraces, stress, strain, displacement, stiffness.

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16.
Structural safety and reliability

Optimizing structural safety levels on the basis of lifetime utility objectives of the individual

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ABSTRACT: It is widely accepted that life cycle cost optimization (LCCO) based on the sound principles of decision analysis yields civil engineering designs that are optimal from the point of view of safety and economy. LCCO allows us to design infrastructure providing a balanced solution between what we can afford to pay for structural safety, and what we should afford to pay for acceptable safety. But in finding an optimal compromise between the two conflicting objectives of safety and economy, a decision analytical framework such as LCCO requires stakeholders to agree on a wide range of consequences or "costs" that are, generally speaking, not easy to quantify. We are referring mainly to indirect economic losses such as consequences related to death, maiming, injury, loss of longterm income, emotional distress, loss of valuables and social disruptions.

The approach taken in the present paper is based on the idea that an analysis of ultimate limit state failures is related to the lifetime utility of the individual. Using this approach, the key aspects of life that humans consider valuable can be viewed as an attribute of a lifetime utility function.

In this framework, questions regarding the acceptability of loss of life and life quality can easily be addressed using straightforward decision analysis tools. The method is illustrated by using a few simple examples to suggest that traditional design objectives, such as uniform lifetime reliability and equal safety levels for all possible hazards, are not necessarily optimal and, in some cases inappropriate.

KEYWORDS: Lifetime utility, consequences of failure, life cycle cost optimization, design safety levels.

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SARA: An advanced engineering tool for reliability assessment of concrete structures

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ABSTRACT: The software system SARA—Structural Analysis and Reliability Assessment—is presented. The authors combined efficient techniques of both nonlinear numerical analysis of engineering structures and stochastic methods to offer an advanced tool for assessment of realistic behavior of concrete structures from reliability point of view. The nonlinear finite element analysis is used for realistic prediction of structural response and its resistance. The utilized software ATENA based on elite constitutive models for concrete is well established for computer simulation of structural behavior, damage and failure. The stochastic engine of the SARA system is the probabilistic program FREET—Feasible Reliability Engineering Efficient Tool. This software package for statistical, sensitivity and reliability analysis of engineering problems was designed with focus especially on the computationally intensive problems like nonlinear finite element analysis, which do not allow performing thousands of samples. A special type of numerical probabilistic simulation called Latin Hypercube Sampling (LHS) makes it possible to use only a small number of Monte Carlo simulations for a good estimation of the first and second moments of the limit state function. Statistical correlation between random variables is adjusted by stochastic optimization technique Simulated Annealing. Sensitivity analysis approach based on nonparametric rank-order statistical correlation with Spearman correlation coefficient or Kendall's tau is employed. Cornell's reliability index is estimated from the limit state function. The feasibility of the SARA system is documented on numerical example of statistical failure simulation and reliability evaluation of existing concrete bridge structure. The presented approach is going beyond the boundaries of design codes and can lead to considerable cost saving as the reliability requirements can be targeted more precisely.

KEYWORDS: Reliability assessment, concrete structures, computer simulation, nonlinear finite element analysis, stochastic methods.

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Safety index calculations for a continuous reinforced concrete beam

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ABSTRACT: The goal in design is toward a small risk of failure since the risk of structural failure can never be totally eliminated. This paper presents the results of the estimation of the failure probability of a three-span continuous reinforced concrete beam designed to BS 8110 (1985) and subjected also to random loading as well as material and geometrical variability. The results have shown (i) the inconsistency in the design requirements of BS 8110 (1985) and (ii) some critical issues that should be re-appraised in the prediction of the performance of continuous reinforced concrete beams.

KEYWORDS: Continuous reinforced concrete beam, variability, design requirements, probability distributions, safety index.

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Durability-design of reinforced concrete traffic infrastructure

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ABSTRACT: Highway traffic infrastructure in Hungary includes a considerable number of reinforced concrete girder bridges. Continuous growth of public traffic and the increasing environmental pollution makes the durability-design of such structures an important approach to economical and efficient design processes. Deterioration processes, such as creep, aging or corrosion of reinforced concrete, and chemical reactions, such as carbonation, have significant influence on the bearing capacity of these structures. These adverse processes result in changes of stochastic parameters of material properties and structural sizes. Structural safety is a suitable measure that can be used to track changes caused by different deterioration processes. Requirements in respect of durability can be expressed by a specified level of safety. An appropriate method for solving complex mechanical problems involving uncertainties is the stochastic finite element method (SFEM). To obtain an appropriate simulation tool for the durability-design, the SFEM has been combined with a method for calculating reinforced concrete beams subjected to compression, multiaxial bending and torsion. The finite element method is used for the calculation of the structural members. The post-cracking behaviour of structural concrete in combined stress-state is described by a method based on discretized space truss model. The implemented method is capable of comparing globally acting forces with structural resistance at system level and evaluating the safety of reinforced concrete beam structures. The value of safety evaluated in a certain point time can be used to determine the adequacy of the structure.

KEYWORDS: Reinforced concrete, durability-design, traffic, infrastructure, safety, simulation tool.

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Parametric sensitivity analysis of modal failure of a glued thin-webbed beam

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ABSTRACT: A performance prediction and evaluation procedure of a glued thin-webbed timber beam based on the design point method (DPM) of reliability theory is presented. The Eurocode5 (EC5) design requirements illustrated by Solli (1995) form the basis for establishing the stress thresholds for varying failure modes of a composite I-beam. Under uncertainties in design variables the critical parameters responsible for weakening or strengthening of the beam are highlighted and compared for all modal failures. The results of the analysis also reveals that, if the ratio of flange to web height augments, the various stress controls except that of the shear stress in the web, enhance the performance of the beam.

KEYWORDS: Thin-webbed timber beam, failure modes, uncertainty, probability distributions, performance level, variable sensitivity.

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17.
Structural optimization and computer-aided design

Effect of some parameters on the optimum height of planar CHS trusses with parallel chords

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ABSTRACT: The optimum design of planar trusses is shown in this study by means of two novel and interrelated constrained gradient-based optimization techniques, namely the Leap-frog method and the Dynamic-Q method. In the optimisation the height and the cross-sectional dimensions are optimised using circular hollow sections (CHS) for minimum volume. The effect of several truss parameters, such as loads, number of fields, has been investigated during the optimization. Using the optimised height, significant mass and cost savings can be achieved in the design stage. This is in contrast to the current routine and design practice in which the truss height is taken proportional to the span length, and which does not give an optimal solution with minimum mass.

Results obtained by the method for the five field and eight field cases illustrate the fact that the optimal $\omega=h/a_0$ ratio varies in a non-linear manner between 1.12 and 1.75, depending on the load. It is also clear, that an increase in a_0 results in an increase in the optimum volume and mass of the truss. Also, the volume appears to be linearly proportional to the loading. If the loading is the same, the optimal ω is larger for the smaller nodal distance (a_0=2000), with the corresponding h even smaller than that for the greater nodal distance (a_0=4000). Thus it can be concluded that the routine design practice of simply taking the truss height proportional to span length, is not to be recommended, since it does not give a minimum mass design within the specified constraints.

The two algorithms used in this study, gave almost identical results for the 48 continuous optimization runs performed in producing the results. This gives confidence in the results obtained.

KEYWORDS: Structural optimization, tubular trusses, gradient-based optimization, approximation methods.

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A variational method for structural topology optimization

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ABSTRACT: In this paper we present a variational method to address the topology optimization problem—the phase transition method. A phase-field model is employed based on the phase-transition theory in the fields of mechanics and material sciences. The topology optimization is formulated as a continuous problem with the phase-field as design variables within a fixed reference domain. All regions are described in terms of the phase field. As an order parameter, the phase-field model makes no distinction between the solid, void and their interface. The Van der Waals-Cahn-Hilliard theory is applied to define the variational topology optimization as a dynamic process of phase transition.

KEYWORDS: Topology optimization, phase field model, phase transition method, regularization method, interface evolution.

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Minimum cost design of a column-supported oil pipeline strengthened by a tubular truss

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ABSTRACT: A column-supported oil pipeline is considered. When the distance between supports is in anywhere larger than the regular span length, a question arises whether a larger pipe should be used or the original pipe should be strengthened. The aim of this study is to answer this question by comparing the costs of the two possibilities. Therefore a strengthening welded tubular truss is proposed and optimized.

The truss is constructed from a central vertical column and two diagonals. The strengthened pipe and the truss form a statically indetermined structure in which the member forces depend on their dimensions. Thus, a systematic optimization process is necessary to find the unknown member dimensions, which fulfill the design constraints and minimize the cost.

The unknown force in the vertical column is derived using a deflection equation. The original pipe is designed considering the self mass, the mass of oil in the pipe and the internal pressure of 64 bars. The strengthening welded tubular truss is optimized taking into account the design constraints on member stresses and truss geometry as well as a cost function.

The cost function includes the costs of material, cutting and grinding of strut ends, assembly, welding and painting.

In the stress constraint of the vertical column a lateral force is considered acting on the truss node to avoid the lateral buckling. Therefore the column should be checked for compression and bending.

The optimization is performed using the Rosenbrock's hillclimb direct search method complemented by a discretization to obtain available circular hollow sections.

The results show that the optimum truss height is determined by the geometric constraint prescribing the minimum inclination angle of diagonals. The cost comparison shows that the strengthened pipe is much cheaper than the larger pipe without strengthening.

KEYWORDS: Oil pipeline, structural optimization, welded steel structure, tubular truss.

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Integrated engineering workflow: Structural industrial environment

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ABSTRACT: Most structural engineering consultants stop technological innovation with three-dimensional computer aided design (3D CAD) and utilise it as an effective way to create drawings as a construction deliverable. To utilise 3D CAD fully and effectively as an integrated engineering solution, the consulting engineering practice needs to re-engineer its traditional workflow.

Intelligent three-dimensional (3Di) models raise the level of sophistication of the engineering information, which can extend the use of 3D CAD beyond the traditional use of creating 2D drawings. 3Di modelling changes the way that engineering work is done and changes the work product. The model and database contain information that is 'nearer to fabrication and construction' and this reduces or eliminates the need for intermediate and repetitive deliverables, review processes and clash checking. This in turn reduces the time schedule, cost and opportunities for user error i.e. it reduces re-work resulting from engineering documentation errors and omissions. The key differentiator of 3Di delivery compared with traditional methods is the ability to implement multi-disciplinary concurrent engineering with integrated data integrity.

This paper endeavours to introduce the integrated workflow concepts through a selected case study. The case study will highlight the potential yield gains if business redefinition concepts are applied with good technological innovation and structural business process experience.

KEYWORDS: Business redefinition, integrated engineering workflow, three-dimensional computer aided design.

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Recalculation of construction elements based on drawings

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ABSTRACT: In the case of renovation or reorganization of buildings problems often arise concerning the availability of a digital model for the existing building. This problem makes the structural redesign of these buildings difficult and very expensive. For existing buildings often only paper based drawings are available. Based on this analogous information a recognition process is performed in order to re-engineer the construction elements of buildings. Commercial algorithms and software tools are available to convert a digitised paper based drawing into a vector plot. These vectorisation systems however did not prove in practice to be suitable for the recognition of constructional objects within the drawings. In this paper a medial axis approach to convert digitised drawing data into lines and curves with topological information is presented. Based on this topological information the semantics of the drawing objects is recognised and is translated into construction elements. The theoretical background and the practical use of the developed algorithms are explained in detail. Within the numerical simulation system FEAPpv the construction elements are recalculated. This approach is applied to a realistic example of ground-floor plan and the recalculation of a ceiling. All methods explained in this paper are realized within a software tool based on JAVA. Although the ground floor drawing presented in this paper is a small example, all algorithms have proven to be fast enough to deal with more complex building projects. This tool closes the gap between paper based drawings and numerical recalculations.

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Civil engineering education in MENA countries with special reference to structural analysis & design

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ABSTRACT: The paper is an outcome of a reflection exercise on the main trends, role, and challenges faced by civil engineering educators in Middle-eastern & North African (MENA) countries. It is designed to address questions stemming from the problems like: What constitutes structural analysis and design skill related education for an undergraduate CE curriculum? What do employers expect from a CE undergraduate? How should the courses be developed? How can we better addresses the needs of a relatively large number of CE students who in all probability do not foresee the possibility of pursuing further studies in structural engineering? Some results from an on-going comprehensive survey of professors teaching civil engineering in general and structural engineering in particulars in case study MENA countries to determine the content of structural analysis and design courses that should be included as a requirement in a civil engineering curriculum are outlined. Summary of general observations, views and suggestions with respect to civil engineering education in general and enriching required courses in structural engineering in particular to meet the challenges of change and development for MENA countries situation are given.

KEYWORDS: Civil Engineering Education, MENA countries, structural analysis & design, comprehensive survey, general observations, views, suggestions.

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18.
Numerical methods, formulations & modelling

On the robustness of the Q4 membrane element

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ABSTRACT: Post treatment of assumed stress membrane finite elements through penalized equilibrium is discussed; for elements of irregular geometry, it is shown that enforcement of penalized equilibrium in the limit results in complete loss of stiffness in higher order deformation modes.

For the displacement based Q4 membrane finite element with bi-linear interpolation, elemental parameters are then introduced to soften the higher order deformation modes, and render the element bending-exact.

KEYWORDS: Penalty formulation, Q4 element, higher order deformation modes, bending-exact.

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Inverse FEM I: Load and response estimates from measurements

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ABSTRACT: Could we use the finite element method to estimate the distribution and history of wind pressures on a structure, based on strain and acceleration measurements? Could we estimate plastic strains in weld “hot spots” from remote strain measurements? In other words, could FEM form the base for a versatile and efficient structural monitoring system?

We no longer have a proper boundary value problem: for a given degree of freedom, we might know neither displacement nor load, or we might know both. Further, such inverse numerical problems are “ill posed”: small response measurement errors easily lead to huge errors on estimated force.

“Tikhonov regularisation” solves such problem by introducing a quadratic “cost” on the deviation of estimates from measurements (strain, displacements, etc.), as well as a quadratic cost on unknown external loads. The cost is written a function of displacement degrees of freedom, and external force degrees of freedom. The cost is minimized under the constraint of equilibrium. In this paper, Tikhonov regularisation is used to formulate an inverse finite element method (iFEM). This results in an enlarged system of algebraic equations with loads and displacements as unknowns.

This approach gives well-behaved estimates of the curvature and soil contact forces in an offshore pipeline on an uneven seabed, a case that defeats other methods. Extensions of the theory to more general structures, non-linear and dynamic problems and further discussions are presented in three companion papers.

KEYWORDS: Structural monitoring; state estimation; load estimation; Tikhonov regularisation; finite element methods.

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Force-hybrid formulation for the frame element with lateral deformable supports

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ABSTRACT: This paper presents a new frame element for the nonlinear analysis of beam on soil foundations. The governing differential equations of the problem (strong form) are derived first. Then, the force-hybrid frame element (weak form) is formulated to solve for the numerical solution of the problem. Tonti's diagrams are employed to conveniently represent the equations governing both strong and weak forms of the problem. Finally, a numerical example is used to show that the force-hybrid element is much more accurate than the classical displacement-based element. The nonlinear frame model proposed in this paper has practical applications in modeling the soil-pile structural system, geosynthetics/fiber-glass reinforcement of foundation soils, etc.

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Local finite elements refinement strategy for concrete structures using modified isoparametric elements

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ABSTRACT: A special isoparametric element is developed for local finite element refinement to solve the problem in the transition region, without any need of a special elements subdivision. The proposed element allows variable positions of the interior nodes. The concept of the isoparametric element in the finite elements methods is based on using the same shape functions to describe the elements geometry as well as the displacement within the element. The interpolation functions must satisfy at least the C^0 continuity, where the C^0 continuity means that the function itself is continuous and C^m continuity means that functions derivative up to the order of m are continuous. The quality of the finite element solutions greatly depends on how finite elements are subdivided. In general the finer the mesh and/or the higher the order of the used element the more accurate the obtained result.

For the local refinement in the FEM there are basically two different strategies that is h-method and p-method. By the h-method the elements themselves are geometrically refined; by the p-method the spaces of interpolation function are enriched. In this study the h-method will be considered.

There are different ways for local refinement using the h-method, the most used and practical one is the element subdivision, by which the element is simply divided into smaller ones keeping the original element boundary unchanged. Such a process generates as many hanging nodes; (or in some literature, referred to as slave nodes or irregular nodes) at the interior boundary between different levels of refinement. One of the important aspects is how to deal with such hanging nodes, which hang normally between two regular nodes.

It is clear that one of the problems in local refinement using quadrilateral elements comes from the treatment of the elements in the transition region. The objective of this paper is to solve the compatibility problems in the transition region for finite element refinement using a new developed isoparametric element without any need of a special elements subdivision. The proposed element allows variable positions of the interior nodes not only on the edge of the element but also outside the element. A singularity of the Jacobean matrix and numerical problems will not occur if the condition that no two nodes one above the other positioned, is kept. The new element formulation is tested and used in the analysis of structural concrete problems.

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Testing and multibody analysis of transport aircraft's landing gear

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ABSTRACT: The research on the most effective methods of aircrafts' landing gears design as well as the evaluation of the gear's condition during utilization period and possibilities of extending its durability are the subject of numerous studies, including the ones by leading worldwide aviation companies and national scientific centers. It is indicated in these studies that numerical analysis of the strength of the construction elements of the examined aircraft's part (beside experimental research) is a necessary stage of proper methodology of aviation research, in particular in programming and reliability evaluation and development of methods of increasing durability in case of solutions already used in practice. In this paper experimental and numerical research of transport airplane's landing gear are discussed. Chosen issues of the experimental research of the gear, conducted in cooperation with the Laboratory of Landing Gears of the Institute of Aviation in Warsaw are presented. The results of static research of the gear and results of the drop-station trial used to simulate touchdown phase are discussed. Furthermore, tensometric measurements of the strains of main elements of the gear are presented. Basing upon those, reduced stress have been calculated to describe effort of the basic elements of the gear's force structure. Effort of these elements of the gear has also been numerically analyzed using MES. Multi-stage methodology of numerical analysis and discrete models used has been described. Chosen results of the numerical analysis for the maximum load of the gear considered, corresponding to an aircraft's 3-point landing at maximum decline speed allowed have been compared to experimental research's results. The numerical model of landing gear proposed by authors bases on mathematical model which was applied to obtain dynamic characteristic of chosen parts of the unit and perform multibody simulations. The analysis presented in this paper is the first part of wider considerations concerning numerical assessment of landing gear life.

KEYWORDS: Landing gear, tensometric measurements, simulation, mathematical model, FEM, multibody.

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Inverse FEM II: Dynamic and non-linear problems

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ABSTRACT: The inverse finite element method (iFEM), as discussed in a companion paper for linear-quadratic static problems, is here extended to dynamic problems, using the iterative "sweep method" (Bryson and Ho, 1969) popular in optimal control theory. While the method was originally designed to decide what controls to apply to steer a dynamic system into a target state, it can be used to estimate what forces did act to steer a dynamic system into a measured state.

In the present paper, the method is applied to estimate the curvatures and the hydrodynamic forces in a marine riser subjected to wave load, on the base of displacement measurements. While this approach is gives superior estimate quality in presence of strong measurement noise, it remains limited to problems with few degrees of freedom.

iFEM is also extended to "non linear-quadratic problems" where the structure is non-linear and measurement errors, or prior estimates of external forces are non-Gaussian. This is done by iteratively solving an incremental problem that is linear-quadratic. Besides the obvious generalisation that this provides to non-linear structures, this also gives a useful probabilistic interpretation of iFEM input and output: iFEM provides a maximum likelihood estimator.

The method is applied to estimate the loads and state of a frame structure, when the loads have caused a member to buckle. The load and state are satisfactorily estimate, despite the absence of direct measurement of the buckling.

KEYWORDS: Bayesian estimation; non-linear structural analysis; dynamic structural analysis; sweep method; finite element methods.

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Computation of localisation in earth pressure problem using cohesion-softening model

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ABSTRACT: Localisation in passive earth pressure problem has been modelled using cohesion-softening Mohr-Coulomb soil model. Results from fixed-mesh finite element analyses confirmed the mesh-size dependency characteristics when standard continuum theory is employed and indicate that the convergence of load-displacement is possible when very small elements are used. The development of failure plane has been studied and results show that the convergence of load-displacement response is related to the successfulness of failure plane being correctly captured during the analysis. For rough wall, results show that there exist variation in the extent of the log spiral part of the failure plane and it is depending on dilation angle used and softening parameter values.

KEYWORDS: Cohesion-softening, earth pressure problem, failure mechanism.

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Discrete element method analysis of a bearing capacity experiment

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ABSTRACT: The Discrete Element Method (DEM) simulates the non-linear, dynamic behaviour of discontinuous systems, such as fractured rock and soil, at the level of the individual block or particle. A critical and often overlooked requirement for DEM to become more widely accepted and utilised in engineering practice is the development and simulation of well devised experiments to validate the method. This paper presents such a comparative study. The bearing capacity of an experimental system composed of 3860 steel cylinders within a rigid steel frame subjected to a rate controlled, centralised load is compared with two-dimensional DEM simulations and a classical closed form solution. The friction parameter required for the DEM simulation was determined experimentally. Comparisons between the experiment and the simulation are undertaken based on the load-displacement behaviour of the loading platen and the surface profile of the failed particle arrangement. Insights into the failure mechanisms are given using the DEM analyses.

KEYWORDS: Discrete Element Method, bearing capacity, experimental validation.

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The development of mathematical and finite element models for the analysis and design of a new light weight rail track system, LR55

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ABSTRACT: The paper describes the development and validation of a mathematical model for the analysis and design of the LR55 track system. The model is validated experimentally using full-scale laboratory tests on a physical 6 m long track model. The Main components of LR55 track system are: low profile steel rail, elastomeric pad and concrete trough. LR55 track system is invented as a solution to overcome the drawbacks of the existing light rail track systems due to its main characteristics and unique features.

A special purpose one dimensional finite element computer program was developed to solve the LR55 track system, which has been modelled as multiplayer beams on elastic foundations. Non-linear analysis due to loss of contact between the concrete trough and the track base, i.e. track base separation can be performed. A constant or variable track base modulus along the track can be specified too. Four static and non-destructive tests were carried out on a full scale 6 m long track model, including the case of 1m collapsed foundation simulation by applying a single point load at the centre of the track model up to the pre-assigned maximum value. The test results compared well with the theoretical solution using one dimensional finite element analysis. The theoretical optimum design of the prestressed concrete trough section, satisfying the serviceability and ultimate states requirement of the current British Standard, BS 8110.

KEYWORDS: Rail track, concrete trough, one dimensional finite element model, non-linear analysis.

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Implications of finite element formulation in optimal topology design

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ABSTRACT: This paper illustrates the effect of finite element formulation on optimal plate and shell topologies. Results are presented for three plate formulations, namely the Discrete Kirchhoff Quadrilateral element, and two Mindlin-Reissner based elements, one with selective reduced integration on shear and the other with an assumed natural shear formulation. These plate elements are then combined with either a standard displacement based Q4 membrane or an element with drilling degrees of freedom, to form flat shell elements. Two example problems are used to numerically investigate the effects of element type on optimal topology. The SIMP method is employed to perform the topology optimisation.

KEYWORDS: Plate, shell, element formulation, topology optimisation, SIMP.

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A new construction and technology for tyres of vehicles and testing equipments for fatigue tests

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ABSTRACT: The contents of the paper point out the necessity of combining the theoretical and experimental approaches in the investigation of tyre load in vehicles.

The article deals with the loading condition analysis of the manipulator frame for off take tyres by the working load. The model of the manipulator was created in software AutoCAD. The kinematics and dynamics analysis was made in software Working model 3D. The loading condition analysis were made with help of Cosmos M software.

The model of the tyre disk was created in software AutoCAD and Cosmos M. There are calculated the first ten eigen frequencies disk in this article with help of the software Cosmos M.

The models are planar and they model the cross-section of the tyre enabling the consideration of the bottom load and the internal pressure in the tyre, as well as the influence of the lateral force.

The steel cords reinforcing motor vehicle tyres are unevenly loaded in time as the tyre is in operation and in contact with road surface.

The conditions for conducting and evaluating experimental test that would model the considered loading of the steel-cord-reinforced tyre have been defined.

KEYWORDS: Manipulator, Working model 3D, disk, natural frequencies, fatigue, experimental tests, reliability.

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Inverse FEM III: Influence of measurement data availability

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ABSTRACT: In the inverse finite element method (iFEM), given a finite element model of a structure and imperfect displacement measurements, the external loads acting on the structure can be assessed. The basic idea behind iFEM is the optimization of a quadratic cost function of the difference between the measured and estimated values, with a high cost corresponding to a high precision of the measurement.

In the first part of the paper it is shown how the iFEM theory was extended to accommodate for strain measurements on a slender beam through the construction of costs matrices to express the costs associated with the estimation of the response.

The second part of the paper deals with the influence that the measurement set-up has on the quality, or reliability of the estimates. To what extent does the combination of strain gages etc. and the precision of these measurements allow to capture the response of the structure? A numerical method was developed that identifies what combinations of external loads and response are likely to occur without being detected for a specific measurement set-up.

An example consisting of a structure with both displacement measurements and strain measurements being taken, is presented. It illustrates how the sensitivity study method can be used to plan a more effective measurement set-up.

KEYWORDS: Inverse finite element method, sensitivity study, strain measurements, experimental planning.

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Inverse FEM IV: Influence of modelling error

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ABSTRACT: The inverse finite element problem allows finding the external forces and the complete response of a structure, given a finite element model of the structure and imperfect measurements of its response. The theoretical basis of iFEM is described in two papers submitted to SEMC by Philippe Mainon.

Testing of the inverse Finite Element Method was initially done under the assumption that the model used in the iFEM analysis behaves exactly as the structure on which the measurements are taken. In practice however, the model (represented by a stiffness matrix, and where adequate, damping and mass matrices) will not match the real structure exactly.

Sources of modelling error include errors due to discretisation, and uncertainty on the characteristics of the structure, including structural damage.

The paper discusses the performance of iFEM in terms of assessed external loads and assessed stresses, in the presence of localised and/or distributed model errors.

The influence of modelling errors was investigated as follows: Measurement data was simulated by creating a FEM model of the structure considered, computing “measured” values and adding adequate noise to the “measurements”. Errors was then added to the FEM model to obtain the inaccurate iFEM model. This approach gave a great liberty to explore different structures and scenarios. It also had the benefit of being much easier to carry out and less time consuming than the generation of real measurement data.

In addition to the test cases with simulated measurement data, real measurement data was also obtained from experiments on a damaged beam.

The investigation concludes that iFEM is stable in the presence of modelling errors. Distributed model error give rise to distributed error in the assessed external loads. The output of iFEM in the presence of localised error (damage) is such that it can be used to detect discrepancies between the model and the real structure.

KEYWORDS: Inverse finite element problem; modelling error; sensitivity study; defect detection.

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19.
Composites, ceramics and material modelling

A multi-scale modeling approach for concrete-like composites

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ABSTRACT: The overall mechanical behavior of heterogeneous materials is strongly conditioned by their micro-structural details. This paper introduces a multi-scale modeling approach for concrete-like composites. Besides its adequacy for the homogenization of concrete-like material structures, it is capable of representing the randomness of the corresponding overall continuum mechanical variables, based on local homogenization. It is demonstrated how the randomness of macroscopic concrete-characteristics can be controlled. Associated parameters are derived.

KEYWORDS: Concrete, effective material constants, equivalent homogeneous continuum, finite element method, heterogeneity, homogenization, multi-scale modeling, randomness, representative volume element.

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Finite element modelling of thermal transport in ceramic matrix composites

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ABSTRACT: Ceramic Matrix Composites (CMCs) are considered to be possible replacement for metallic superalloys in high-temperature parts of aeroengines. Increased operating temperatures from 900–1200°C, for coated superalloys, to above 1300°C for CMCs have the potential to achieve higher thermal efficiencies and lower emissions. Such applications require good thermal properties for heat transfer in CMC engine components. Compared to metallic alloys, a deficiency of CMCs is the degradation of thermal transport properties due to internal damage. An ability to predict thermal transport in CMCs is therefore a primary requirement at the design stage. The presence of damage, and cracks can be introduced in either manufacturing or in service. Damage during manufacturing occurs as a result of the different thermo-mechanical properties of the constituent materials, which during cooling introduce thermal gradients, thermal stresses, localised failure and hence damage. This manifests itself after cooling as micro-porosity, which reduces the thermal transport properties of the composite. The driver for this research is the need to describe this porosity and predict, through FE modelling, its degrading effect on thermal transport.

The thermal modelling of CMCs requires a number of factors to be taken into account such as the architecture of the composite, the properties of constituent material, and the influence of defects. A complex weave model of a plain weave CMC has been presented by Sheikh et al [i]. This model is 3-dimensional, and represents a relevant development towards the modelling of complex composites architectures. The model included the effect of directionality in thermal transport by introducing the individual properties of fibre and matrix. It was deficient, however, in that the influence of initial porosity was not taken into account.

Another paper [ii] set the following developmental modelling strategy, which takes account of these factors:

i. categorise manufacturing or initial porosity;
ii. create an ability to numerically model it; and
iii. subsequently, further develop this to a point where growth and coalescence of initial porosity due to applied loadings and thermal strains can be accurately predicted; and, in addition, couple this with the degradation of mechanical and thermal properties.

The abovementioned paper [ii] concentrated on the identification and classification of initial/manufacturing porosity, and introduced four different classes, each of which will be discussed later. In addition, extensive measurements were taken from micrographical evidence to quantify each of the four classes of porosity. This paper addresses how, for each porosity classification, finite element analysis techniques can be used to quantify the effect of each class of porosity on the spatial heat transport properties assessed at the level of a micro Unit Cell. In the analysis, care has been taken to accurately model porosity volume fractions and characteristic defect lengths. However, thermal properties determined using one model are included in subsequent models. It is in this way that the synergy between different classes of porosity are assessed.

KEYWORDS: CMCs; Porosity; FE modelling; Thermal Transport Properties.

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Numerical determining of residual stress concentrations at graded ceramic-metal interfaces on the example of a valve of combustion engine

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ABSTRACT: There were considered ceramic coatings established on a steel substrate. Numerical investigations were made with the use of FEM based software MSC Nastran. For the needs of investigations in microscale a micromechanical model was developed. The coating in this model was considered as Functionally graded material with properties changing smoothly accordingly to the linear function from the pure alumina on external surface to the metal substrate. In preliminary results there were visible very high stress concentrations, which were of the values much higher than strength of both ceramic and metal phases. In the distance of barely several grains there were observed strong gradients of stresses which took the extreme values from the calculated stress range.

In macroscale a model of coating established on an internal combustion engine valve was taken into considerations. It was modeled as 3-layered graded material. Calculations were made with the use of the two models. The edge of the top surface of the first model was sharp and of the second one—rounded. Obtained results showed out characteristic distributions of stresses especially for the axial component. The model with sharp edge produced higher values of radial and circumferential stresses than the model with rounded edge. But axial stresses were higher for the model with rounded edge.

Concentrations of tensile stresses originated in substrate material just under the boundary of substrate/coating separating surface.

The shape of edges of coating and the modeled mechanical part are of great meaning for distribution of axial stresses and may decide about durability of coating itself and subsequent durability of the protected mechanical part.

KEYWORDS: Graded material, ceramic coating, combustion engine valve, FEM modelling.

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Manufacturing processes for engineered cementitious composite material

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ABSTRACT: Engineered cement-based composites (ECC) have superior mechanical properties in tension. Through engineering tailored ingredient proportions, this class of materials exhibits tough behaviour in tension, as opposed to brittle behaviour of normal concrete. Like in fibre reinforced concrete and cements (FRC), crack bridging in the matrix is performed by fibres. The superiority of ECC to FRC lies in the strain-hardening, or increased tensile resistance beyond the initial cracking strain. To exploit ECC commercially, it must be tailored for industrial fabrication processes. These processes influence the material directly, through fibre orientation and modification of fibre-matrix interfacial properties, as well as indirectly, by the required adjustments to the mix ingredients and proportions. This paper addresses these issues. Standard casting and vibration, pipe spinning and extrusion processing of ECC are discussed. Required mix adjustments for these processes are elaborated, illuminating the different mix designs for optimal performance of products from the different processes. Evidence of production specific orientation of fibres is presented. The influence of the processes on the mechanical properties is discussed at the hand of results of standard laboratory tests.

KEYWORDS: Cement-based composites, fibre reinforced cements, fibre alignment, strain-hardening.

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Computational and experimental modelling of creep behaviour of Engineered Cement-based Composites

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ABSTRACT: ECC (Engineered Cement-based Composites) have evolved over the past decade to become a ductile cement-based composite. It consists of short, randomly distributed polymer fibres in a cement based composite. These fibres increase the toughness of the material by bridging the cracks that form under tensile stress in the matrix. This mechanism results in multiple cracking, which leads to increased structural resistance upon further deformation, also known as pseudo strain hardening. Still, very little is known about the timedependant behaviour of ECC. This is an important issue, as the time-dependant behaviour can lead to the unexpected failure of a structure. In this paper, strategies are reviewed for the efficient numerical analysis of the time-dependant behaviour of ECC. The phenomenon of creep is investigated on the macro-scale and attention is drawn to the importance of non-proportional creep, also referred to as non-linear creep. An analytical example of creep fracture is elaborated to demonstrate the importance of incorporating non-linear creep to accurately predict life expectancy of ECC structures under sustained load. The final aim of this project is, however, to predict the time-dependant behaviour of ECC using a multi-level numerical analysis. This multi-level model will incorporate the heterogeneous meso-level into the homogeneous macro-level.

KEYWORDS: Cement-based composites, fibre reinforced cements, creep, computational modelling.

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20.
Damage mechanics and modelling of materials and solids

Irreversible thermodynamics theory for damage mechanics of solids

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ABSTRACT: The entropy production is a non-negative quantity based on irreversible thermodynamics and thus can serve as a basis for the systematic description of the irreversible processes occurring in a solid. In this paper, a thermodynamic framework has been presented for damage mechanics of solids materials, where entropy production is used as the sole measure of damage in the system. As a result, there is no need for physically meaningless empirical parameters to define a phenomenological damage potential surface or a Weibull function to trace damage evolution in solid continuum. In order to validate the model, predictions are compared with experimental results, which indicates that entropy production can be used as a damage evolution metric. The theory is founded on the basic premise that a solid continuum obeys the first and the second laws of thermodynamics.

KEYWORDS: Conservation laws, irreversible thermodynamics, damage mechanics, entropy production, thermo-mechanical coupling.

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Consideration of internal damage in the computational design process of reinforced concrete structures

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ABSTRACT: The failure of reinforced concrete elements is often due to an interaction of different damages. Apart from mechanical loads, reinforced concrete structures are also subject to environmental physical and chemical loads. However, often only the mechanical loads are taken into account to calculate the changes in the load bearing behavior. Nowadays, the physically and chemically induced damage to concrete fabric (e.g. occurring due to attack by freeze-thaw cycles) is usually considered as a problem of durability of the concrete surface only. In general, the influence of such damages on the load bearing behavior is not considered. The presented research project aims to provide a basis, on which physical and chemical loads can be included in the design process of reinforced concrete structures by means of appropriate material models which include deterioration aspects. As an example for physical and chemical deterioration mechanisms, freeze-thaw cycle loads together with the absorption of capillary water have been chosen and analyzed. This deterioration mechanism causes an internal damage of the concrete microstructures, which can be quantified by the ultrasonic measuring technique. The freeze-thaw induced micro cracks in the cement paste create a relatively homogenous damage, which is suitable to be formulated in terms of deterioration coherences.

In a first step, the variation of concrete elastic modulus and also of the bond behavior due to the applied freeze-thaw cycles is monitored and analyzed. The results of these studies, the deterioration parameters, are then implemented in a computational model, developed at the University of Waterloo, Canada. The program generates the moment-curvature relation of bending and axially stressed reinforced concrete structures. The model is based on a layered analysis of the cross section, where the bond behavior is particularly considered. The moment-curvature relation computed with the model are compared with data obtained from various tests with freeze-thaw damaged beams.

KEYWORDS: Internal damage, computational design process, reinforced concrete structures, freeze-thaw damage, physical and chemical loads, microscopic cracks, modulus of elasticity, bond behavior, bending behavior, load bearing behavior under deterioration aspects.

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Constitutive models for cracking in concrete dams: A literature review

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AB STRACT: Cracking in concrete dams raises concerns regarding dam safety. Dams are generally subj ected to complex stress states that can best be analysed with the finite element method (FEM). Strength-based constitutive models were initially used in the FEM but they failed to accurately predict the behaviour of cracked concrete. Developments in the field of fracture mechanics have shown a significant improvement in accuracy. Many analytical methods have been proposed during the last decades but none have been introduced into standard design procedures. A review of available constitutive models is presented together with a review of past investigations on cracking in dams. Recommendations for future research are also made.

KEYWORDS: Cracking, constitutive model, concrete dam, fracture mechanics, crack initiation, crack propagation, fracture process zone, strain softening, finite element method, criteria.

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A non-local elasto-plastic model to simulate the behaviour of concrete and reinforced concrete elements

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ABSTRACT: The paper presents results of FE-calculations of the behaviour of concrete during both an uniaxial plane strain compression and uniaxial plane strain extension. In the first step, an elasto-plastic model with a linear Drucker-Prager type criterion using isotropic hardening and softening and non-associated flow rule was used. However classical FE-analyses of the behaviour of materials with softening are not able to describe properly both the thickness of localisation zones and distance between them. A non-local approach was applied in a softening regime to capture realistically localisation of deformations. A modified non-local model (Brinkgreve's formulation) was adopted wherein a non-local plastic measure included a local and non-local part. To simplify calculations, plastic strain rates were approximated by total strain rates. The characteristic length l was incorporated via weighting function in the form of a normal distribution function. Numerical calculations were performed for meshes with a different number of elements and with a various alignment. A concrete specimen was subjected to compression and extension. To induce shear zone, different imperfections were assumed (different number, different spacing, different location). The effect of a non-local parameter and characteristic length on the width of the shear zone was examined. The thickness of the shear zone was found to be proportional to the characteristic length and non-local parameter.

It turned out that the thickness of the shear zone during extension was smaller by 30% than during compression. The FE-calculations showed that the modified non-local model caused a full regularisation of the boundary value problem. Numerical results converged to a finite size of the localisation upon the mesh refinement. The results of a classical non-local theory (Bazant formulation) suffered partly from the mesh sensitivity.

KEYWORDS: Concrete, elasto-plasticity, finite element method, localisation, non-locality.

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Predicting creep in concrete frames subjected to nonuniform temperatures

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ABSTRACT: Creep in concrete structures subjected to nonuniform temperatures can cause forces and stresses within the structure to change over time. Although the redistribution of stresses that occur is often detrimental to the structure, it is seldom considered in analysis and design, perhaps because of the significant numerical effort required in conducting a time-dependent analysis. The first part of the paper presents an example to explain some fundamental behavioural characteristics of creep under nonuniform temperatures while the second part presents the theory for a simple one-step method to determine the long-term (steady-state) forces caused by creep. The proposed method uses a temperature-transformed section (TTS), which aids in the analysis and explains why forces in statically indeterminate structures tend to change over time.

KEYWORDS: Creep, concrete, nonuniform temperatures, steady-state, temperature-transformed section.

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Changes of material characteristics of concrete under freeze-thaw loading

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ABSTRACT: The paper presents the damage of concrete and its dependence on different strength grades of plain concrete under the action of load and freeze-thaw cycles and analyzes changes of material characteristics of concrete in compression. The loss of compressive strength of concrete specimens subjected to loading were determined. Experimental results show that material characteristics of concrete specimens are strongly influenced by the damage process of freeze-thaw cycles, which is of great importance to durability of concrete under comprehensive conditions.

KEYWORDS: Freeze-thaw loading, stress-strain diagram, cube compressive strength.

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Damage and microstructural change in geophysical materials under high compression and shear

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ABSTRACT: The paper deals with recent developments in studies of the mechanics of progressive breakdown of structure in geophysical materials. Ice has been used as a reference material in experimental studies. The breakdown of structure has been found to occur under high stresses comprising both hydrostatic pressure and shear. The change in structure includes extensive microcracking and recrystallization at lower confining pressure and recrystallization together with other softening processes at higher confining pressures. The latter include pressure melting. The softening process at higher confining pressures leads to a cyclic failure process in interaction between a mass of the material and an indenter or structure. The breakdown process in the material comprises two phases in time. During the first part of the process, the microfracturing and recrystallization lead to a fine-grained material, similar to the mylonites of geological experience. After this, an evolution of the softening process within the fine-grained material occurs. Computer analysis of the material, including interaction with indenters, has been conducted using the methods of damage mechanics. The paper will include a review of damage mechanics, and the development of state variables describing the material will be outlined. These include two pressure-dependent functions that describe the process of softening under stress as related to prior stress history. These constitutive models have been calibrated against experimental results and have been included in a numerical (finite element) model of the interaction process against rigid indenters. The results of these simulations have been compared to medium scale experimental results. The results demonstrate the localization of damage into a layer of microstructurally modified material. The softening at high confining pressures, when accompanied by shear stress, has been found to be a key element in the layer formation and the consequent ejection of crushed materail. The properties of the layer are different—by several orders of magnitude—from that of the parent ice, and vary both in time and space. This has been replicated in the finite element simulations, as well as the localization of the layer itself.

21.
Plastic analysis and non-linear modelling

A linearization technique for nonlinear systems

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AB STRACT: In most case it is very difficult to solve the equations governing the motion of nonlinear structural systems in close form. Therefore, methods providing approximate solutions have to be used. Numerical methods are generally adopted. They require high computational efforts and provide solutions including both the transient and the steady part of the response. To reduce computational efforts a/o when only the steady part of the response is of interest, some others mathematical techniques providing approximate solutions can be utilized. These techniques are based on a variational approach or on an approach where the solution is expanded in series. The method to be used is chosen considering the type of nonlinearities, the type of excitations and the complexity of the structural system. The equivalent linearization method (ELM) is one of the above mentioned mathematical techniques. It provides not only an approximate solution but also a linear system equivalent to the actual one. The equivalence of the linear system and the actual one is obtained by minimizing with respect to the unknown equivalent parameters a function defining the difference between them. In this study the accuracy of the ELM in predicting the response of nonlinear structural systems is evaluated. This is done by comparing the obtained solutions with those obtained using the Newmark integration method. A good accuracy of the proposed method in evaluating the peak values of the response is noticed in the case of a single degree of freedom system characterized by a softening behavior and of a nonlinear two degree of freedom system. Both systems are excited by a sinusoidal acceleration applied to the ground.

KEYWORDS: Nonlinear structural systems, equivalent linearization, nonlinear structural response.

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Plastic yielding of pipe specials under internal pressure

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ABSTRACT: A series of pressure tests was undertaken on a number of full size pipe specials for a high-pressure slurry pipe line. The tests were undertaken as a check on the results of a series of finite element analyses of the specials. However, the tests showed that it is not possible to model a pipe special accurately. Geometric imperfections in the pipe fabrication result in changes of geometry under pressure that are unique to each article and cannot be modeled because they cannot be predicted except in a qualitative way. Also, when a pipe is formed from mild steel by cold rolling, the rolling strain-hardens the steel. Welding of the seam of the pipe anneals the steel in the vicinity of the weld, as does the welding of the fittings or the fabrication of pipe specials. After fabrication, one has a strain-hardened steel pipe or pipe special with annealed seams.

Yielding under pressure converts the entire article, seams and all, to a strain-hardened, more geometrically perfect article that then functions elastically during its working life.

The experimental evidence for these conclusions will be presented.

KEYWORDS: Pipe specials, pressure testing, strain hardening, yielding.

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Computation of sensitivity in thermo-elasto-plastic structures

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ABSTRACT: Having efficient computational means for realistic assessment of the nonlinear response of thermo-elastic-plastic bodies subject to thermo-mechanical loadings is, crucial for solving many engineering problems. Sophisticated FEM-based algorithms have therefore been developed to this purpose. A natural extension of the analysis capabilities has been the developments in the parameter sensitivity area for the mechanical problems. The so-called design sensitivity analysis (DSA) consists in computing variations in response quantities with respect to parameters entering the theory. In the last decades DSA has attracted considerable attention in the field of solid and structural mechanics and also thermal problems, but little work has been published on it in nonlinear thermo-mechanical problems. There exist several approaches to solution of sensitivity problems, e.g. the DDM, the adjoint system method and the control volume method.

In the paper a design sensitivity of thermo-elastic-plastic structures is considered. The continuum approach and resulting finite element formulations are described. Sensitivity is obtained by an incremental load approach for non-linear response analysis. Kinematic and isotropic hardening in thermo-elasto-plasticity are discussed. The control volume approach is to analyse shape and non-shape design. The direct differentiation method is adopted to obtain the design sensitivity expression for the response variables.

Analytical examples demonstrate the developed sensitivity procedure. The design sensitivity formulas are discretized to implement it into a computer program with isoparametric finite elements. Numerical examples are presented to calculate the design sensitivity.

KEYWORDS: Finite elements, sensitivity analysis, thermo-elasto-plasticity.

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Comparison of some plastic flow surfaces using a finite element elasto-plastic computer programme

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ABSTRACT: In this paper, the author presents comparative analysis in the performance of *Botkin, PisarenkoLebedev* and *Geniev-Balandin* plastic flow surfaces. A number of various existing structures are used in the analysis. The above surfaces are incorporated in the finite element models used for the calculations. The computer application programme used in the calculations incorporate the elasto-plastic algorithm model based on the associated rule of plasticity and the Von-Mises maximum principle.

In the analysis, care is taken to accommodate the effect of singularity at the corners of the surfaces. The performance of the above models is compared with corresponding models incorporating the classical plastic flow surfaces; namely: *Mohr-Coulomb, Tresca* and *Drucker-Prager* surfaces. Different engineering materials are incorporated in the study for the identification of the suitability of application with one or the other of the given surfaces. Specifically, models involving soil masses and cement concrete are emphasized.

Suitable Recommendations are formulated as to their applicability to approximate *in-situ* conditions.

The author is indebted to Sida/SAREC of Sweden and to the Faculty of Technology of Makerere University for providing funds for the research; without which, the execution of the research would not have been possible.

KEYWORDS: Comparative analysis, structures, finite elements, elasto-plastic algorithm, plastic flow surfaces.

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Determination of load-carrying capacity of perfectly plastic structures by a series of linear-elastic solutions

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ABSTRACT: Determination of the load-carrying capacity of perfectly-plastic structure using linear programming or related methods still requires large computer times, a method based on a series of linear-elastic solutions is suggested in the paper. In each calculation step, the Young's modulus is reduced according to a stress relaxation parameter. The sum of all stress relaxation parameters of the structure is defined as an error index. The convergence result is obtained when the error index is within the error tolerance. The method is developed for obtaining estimates of load-deflection curves, stresses and strains on the way to final collapse. A numerical experiment indicates that the algorithm is effective and reliable.

KEYWORDS: Finite element, algorithm, collapse load, perfectly plastic materials.

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22.
Impact resistance and crashworthiness

Rockfall impact on protection galleries

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ABSTRACT: Rockfalls are one of the most prevailing natural hazards in the mountainous regions in Switzerland. Concrete protection galleries are used to protect the local infrastructure and lifelines against these potential rock impacts. Cushion materials are laid on these galleries to absorb the rockfall impact energy, which is one of the main input parameters in the design of the protection gallery. An attempt has been made to reduce the impact energies by placing a better damping material on the gallery. The high rock impact energy ranges are difficult to model at the laboratory scale. Field tests are generally avoided due to the high costs involved and also due to the singularity of the potential tests. The prototype energy levels can be achieved at the laboratory scale with the help of a geotechnical centrifuge. An instrumented model of the protection gallery is rotated under high g levels, thereby increasing the unit weight of the material. With the help of appropriate scaling laws, the prototype energy levels can be achieved. This paper focuses on the determination of the impact force of a rockfall of a specific energy and the forces induced in the gallery. The maximum acceleration values of the rock and deflection of the galleries are compared for different energy ranges and cushion materials. The test results are later compared with numerical modelling using the finite element program LS-DYNA.

KEYWORDS: Rockfall, protection galleries, centrifuge modelling, soil dynamics, impact.

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Performance of thin-walled frusta energy absorbers in structures under impact loads

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ABSTRACT: Over the past several decades increasing focus has been paid to the use of energy absorption techniques in protecting and improving the performance of structures subjected to random and unpredictable loads such as impacts, explosions and seismic loads. One such area of application is the crashworthiness of structures where the energy during an impact event needs to be absorbed in a controlled manner. This has led to considerable research being carried out on energy absorbers, devices designed to dissipate energy during an impact event and hence protect the structure under consideration. Energy absorbers have found use in a wide variety of crashworthiness applications such as automobiles and trains, highway barriers and at the base of lift shafts. Thin-walled frusta are a relatively new type of energy absorber used to protect structures under impact loading such as in crashworthiness applications. Frusta are tapered thin-walled tubes and can be circular, square or rectangular in cross-section. This paper presents the pertinent results of a recent study on the energy absorption response of rectangular frusta under axial quasi-static and dynamic impact loading. Quasi-static experiments were used to validate a numerical model, and close correlation was achieved. A parametric study was carried out using the validated model, the primary variables being impact velocity and mass, and frusta wall thickness, number of tapers and semi-apical angle. The simulations showed that the quasi-static initial peak load decreases with increasing semi-apical angle and number of tapers. Due to inertia effects and material strain rate sensitivity the mean load was an increasing function with impact velocity and wall thickness, whereas it was independent of the mass of the impacting projectile.

KEYWORDS: Frusta, energy absorption, axial impact, numerical simulations, crashworthiness.

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Three-dimensional barrier impact response modeling (BIRM3D)

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ABSTRACT: With the present-day computing capability, conducting three-dimensional simulations of vehicular crash dynamics on a notebook PC has become very feasible. A different approach from the conventional finite element (FE) method has been developed in an attempt to reduce computer runtime. The chassis, engine, axles, and wheel-hubs of a vehicle are modeled with 8-node rigid solid elements. The solid elements are used for distributing the mass or the inertia effect of the vehicle. The vehicle's exterior surface is modeled with 4-node shell elements. The shell elements are used as contact surfaces to determine contact and frictional forces. The crush characteristic of the vehicle is modeled by two-node truss elements inserted between the solid and shell elements, with various stiffness properties. However, the stiffness of solid and shell elements are ignored in the analysis. Nonlinear structural responses due to the inelastic material effect and large deformation of these truss members are taken into account. During impact, the vehicle exerts forces on the contact faces of the barrier. These impact and frictional forces between the vehicle and barrier produce structural deformation in the barrier as well as the vehicle, which dictate the resulting vehicle trajectory. The contact forces are solved according to the compatibility between vehicle crushing and stiffness characteristics of the truss members. Forces between the vehicle tires and the pavement are also included in the vehicle trajectory calculation. An explicit, step-by-step solution scheme is used for this transient dynamic problem. No inversions of large matrices are necessary at each time step in this algorithm. Validation examples using crash test data and data from the literature are presented to demonstrate the accuracy and efficiency of the developed algorithm.

KEYWORDS: Colliding contact, rigid, deformable, penetration, crushing, separation, unloading, non-convex.

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Axial crushing behavior of partially aluminium foam-filled hat sections

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ABSTRACT: The axial crushing behaviors of partially aluminium foam-filled single hat sections and double hat sections were investigated. First, the empty single hat and double hat sections were quasi-statically compressed, and the superfolding element lengths *(2H)* were measured. Then, different lengths of aluminium foam fillings were adopted, which were the full filling length *l,* partially filling length *l-H* and *l-2H*. The axial crushing behaviors of the non-filled, partially and fully foam-filled hat sections were compared. The tests results showed that, (1) aluminium foam-filled hat sections became more stable and weight efficient than the non-filled ones; (2) the aluminium foam-filled double hat sections gave more special energy absorption (SEA) than the single ones; (3) partially filled hat sections had lower initial force than the fully filled ones, the hat sections with filling length of *l-H* had the maximum SEA.

KEYWORDS: Aluminium foam, hat sections, axial crushing, special energy absorption (SEA).

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Finite element analysis of a rollover protective structure for a Komatsu 630E dump truck

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ABSTRACT: Rollover protective structures play a vital role in protecting the operators of large earthmoving machines which are commonly used in the rural and mining sectors. These structures typically consist of a moment resisting steel frame that is required to withstand the impact forces sustained by the vehicle during a rollover and provide a survival space for the operator during such an event. Recent advances in analytical modelling techniques have made it possible to model accurately the response behaviour of these types of structures to the impact loads that they will sustain during a rollover. This paper is concerned with the response behaviour of a rollover protective structure (ROPS) fitted to a Komatsu 630E dump truck using nonlinear finite element analysis techniques. The first stage of this analysis has involved subjecting the ROPS to static loads about the lateral, vertical and longitudinal directions of the ROPS. Further research will involve subjecting the ROPS to dynamic impulse loads and implementing the use of an energy absorbing device in the structure to optimize the level of energy absorption and improve operator safety. Results obtained from the analytical modeling phase will be presented at the conference.

KEYWORDS: ROPS, energy absorption, yielding, impact, FEA.

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Dynamic response of a projectile perforating multi-plates concrete target

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ABSTRACT: By means of the limit-density theory, the cavity-expansion theory and the stress-wave theory, in terms of some phenomenon of experiments and tests, focusing on the time history process of penetration, we presented and explained a series of assumptions. The analytical penetration equations are established which are derived from the mass conservation, momentum conservation and energy conservation.

In this paper, we consider that the scabbing is caused by the reflection of attenuation wave on the free surface. After reflection of stress wave on free surface, the original compress wave will change to tensile wave. The material will damage one time when the resultant stress is greater than the limit tensile strength of the material. Finally, the principles of scabbing on the back of target plate are analyzed and illustrated. To study effectively, in addition to theoretic analysis, an experiment analysis on the process of projectile perforating multi-plates target was made. In order to record the striking load effectively, in the experiment, we choose the on-board storage system and the accelerator which can record high G striking load. Accelerator is piezoelectricity film sensor that can endure high load. The storage system is RAM. Furthermore, the dynamic responses especially the deceleration curves of a projectile are analyzed and calculated by means of computation and experiments when it perforates continuously several concrete target plates (multi-plates concrete target). From the results of experiment and calculation, the results from analytical analysis are in good agreement with those from experiment.

KEYWORDS: Projectile, multi-plates target, concrete, penetration, scabbing, dynamic response.

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23.
Brick and masonry structures

Analyses of resistance and safety of the stone bridge structure in floods

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ABSTRACT: Long-term monitoring of the stone structure of Charles Bridge and numerical analyses show that a number of mechanical failures, origination and development of cracks, which occur in the stone structure and individual stone blocks, are mostly caused by non-force effects of temperature and moisture changes. Some structural interventions performed within the large repairs of Charles Bridge (the concrete slab etc.) had a negative impact on the bridge structure behaviour and contribute to its gradual mechanical degradation.

The numerical analysis of characteristic alternatives of calculation models of the bridge structure showed a negative spacing impact of the concrete slab. The numerical analysis of the response of the stone bridge structures to the effect of the bridge pier rotation proved origination of the state of stress causing severe damage to the arch bridge structure which might be followed by its total destruction. The analysis showed that the concrete slab raises the entire state of stress in all its components, thus decreasing the resistance and safety of the stone bridge structure of Charles Bridge during floods.

KEYWORDS: Charles Bridge, numerical analysis, mechanical degradation, resistance and safety.

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Response of brick masonry under cyclic biaxial compression-tension

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AB STRACT: Thirty two sand plast (a forum of calcium silicate) brick masonry panels were tested under cyclic biaxial compression-tension. Four principal stress ratios were considered in which the bed joint orientation with the tensile force was 0°. Masonry under cyclic loading exhibits three distinct cyclic stress-strain curves: envelope curve, common point curve and stability point curve. The stress-strain curves were drawn on a normalized coordinate system. Stress-strain envelope curve and stress-strain common point curve were obtained from test data and were expressed mathematically by an exponential formula. The stability point curve, however, could not be established.

KEYWORDS: Masonry, cyclic loading, compression, tension, envelope, common point, stability point.

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The lateral load carrying capacity of wall ties used in cavity wall construction in the Western Cape

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ABSTRACT: This paper reports on testing to compare the relative positives and negatives of the Butterfly Tie and the Crimped Tie as regards to water transfer, tensile and compression strength, based on the Australian Code (AS 2699–1984) requirements. It is believed that these requirements are more comprehensive than the South African requirements.

The Butterfly Tie is being actively promoted in cavity wall construction in South Africa. The NHBRC (National Home Builders Registration Council) compels contractors to use the Butterfly Tie and it is also prescribed by SABS 28 (1986) and SABS 0164–1 (1980), even though there is an anomalous statement in the specifications. The Crimped Tie is not promoted in cavity wall construction mainly because of a lack of information regarding characteristic strength and its resistance to water transfers.

The following tests, based on the Australian Code, were carried out on both the Butterfly Tie and the Crimped Tie: (i) tests for water transfer (ii) tests for compression and tensile strengths using couplets and (iii) tests for compression and tensile strength using ties only. Although the testing showed that the Butterfly Tie and the Crimped Tie fulfilled the requirements of the Australian Code, there were negative aspects relating to the Butterfly Tie. It is recommended that serious consideration be given by the South African Bureau of Standards to include the Crimped Tie in its Code of Practice for cavity walls.

KEYWORDS: Butterfly Tie, Crimped Tie, Cavity Walls, Load-sharing, Resistance to water transfer, Compression & Tension, Drips, Brick Couplet, Blotting Paper, Australian Code (AS 2699–1984).

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Time dependent movement of masonry mortar

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ABSTRACT: The purpose of this study is to assess the basic characteristic of the strains of masonry mortar, involving shrinkage and creep which is concerned with the time-dependent behavior. Relatively, little is known about creep and shrinkage in mortar compared to the knowledge about creep and shrinkage of concrete. As a result, there is a need for a greater understanding on mortar movement behavior so that the designer can account for its effects. In this study, specimens of masonry mortar for the experimental work were prepared with six (6) different mix proportions and the water/cement ratio was determined from the dropping ball tests. They were 6 no. of 100 mm cubes and 7 no. of 265×75 mm cylinders for each mix proportion. Then, they were cured in water at 20°C and 100% relative humidity. In term of strength, cubes and cylinders were tested for 7, 14 and 28 days respectively. The specimens for creep were loaded at the age of 14 days and shrinkage was started simultaneously. The work has been carried out in a controlled room at 20° C and 65% relative humidity, and readings were taken over a period of approximately 70 days. It was found that for the mortars included in this investigation, the estimated ultimate value of shrinkage and specific creep were 2104 to 2596×10^{-6} and 272.10 to 6177.42×10^{-6} per MPa, respectively. Thus, it can be seen that there can be significant changes in long-term deformation due to a change in mortar type, which should be taken in account in design.

24.
Historic structures and structural assessment

Structural assessment of an historic masonry bell tower

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ABSTRACT: Investigations on structural safety of ancient masonry towers have received increasing attention in recent years probably as a consequence of some dramatic events which occurred like the sudden collapse of the Civic Tower in Pavia in 1989.

The dynamic behaviour of a masonry Bell Tower is examined by using both experimental and theoretical methods. The investigated Tower is adjacent to the Cathedral of Monza (a town about 20 km far from Milan, Italy). The Tower, made from solid brick masonry, was built between 1592 and 1605 on a design by Pellegrino Tibaldi. The walls of the Tower, 74 m high and 1.40 m thick, show passing-through, large and potentially dangerous vertical cracks on the West and East sides, which are slowly but continuously opening.

In order to assess the structural condition of the Bell Tower, an extensive investigation was carried out in situ by using non-destructive and slightly destructive techniques together with laboratory tests and analytical calculations. On site investigation included an accurate geometrical survey together with a survey of the crack pattern; successively flat-jack tests and sonic pulse velocity tests were carried out in order to estimate the stress level under the dead load and the damage extent and distribution. Recently, full-scale dynamic tests have been conducted to measure the dynamic response of the Tower at 20 different locations, with the excitation being associated to environmental loads and to the bells ringing. The most significant mode shapes and associated natural frequencies were identified by spectral analysis of recorded data. The fundamental mode of the Tower, with a natural frequency of about 0.59 Hz, involves dominant bending in the E-W direction with significant bending participation in the opposite N-S direction as well. Notwithstanding the nearly symmetric shape of the Tower, the identified modes of the system generally show coupled motion in the two main E-W and N-S directions; thus, the experimental modal analysis suggests either a significant interaction between the Tower and the Cathedral or a non-symmetric stiffness distribution (as the one which has to be expected basing on the crack distribution).

In the theoretical study, vibration modes were determined by using a 3D finite element model. Experimental modal data were then used to

assess and verify the assumptions adopted in formulating the model. Specifically, a good match between theoretical and experimental modal parameters was obtained when relatively low stiffness ratios were used in the model for the zones of the Tower which are most damaged.

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Simplified 2D analysis of existing R/C buildings for seismic vulnerability assessment

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ABSTRACT: Natural disasters, such as earthquakes, teach many new lessons to researchers. Although these lessons are too costly, future losses might be minimized as the building codes are updated based on the new information. Changes in the codes leave a large number of existing buildings under question. Various studies have been conducted to evaluate seismic performance of existing buildings using a number of structural parameters as variables. Building performance and structural parameters obtained from many existing buildings in Erzincan, Dinar, and Marmara earthquakes provided valuable information. This paper aims to give a short summary of methods that already exist and discuss basic steps for possible improvements in seismic vulnerability assessment methodology by integrating additional parameters extracted from simplified two-dimensional (2D) structural analysis. The stiffness and mass matrix generation steps are explained. 2D building model has two translational degrees-of-freedom (dof) in the horizontal plane and one rotational dof in the vertical direction.

KEYWORDS: Seismic, building vulnerability assessment, earthquake, analysis.

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The use of new codes to qualify existing structures: A case study

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ABSTRACT: The use of safety factors to account for uncertainties during the design stage is unsuitable for reassessing an existing structure, especially with a structure that had been in operation for some years. The blind application of the new-design approach to reassess an existing structure without consideration of risk assessment and the judicial use of load factors may lead to unnecessary costs to the owner/operator, as demonstrated by a case study.

The inherent conservatism in using codified load factors is generally justified when weighed against increased reliability, as its effect is generally limited to a relatively small increase in material and fabrication costs. It is also justified due to the uncertainty associated with a new design. However, this approach may lead to impractical, unnecessary and expensive requirements if applied to an existing structure. Strengthening an existing structure generally involves significant cost due to the possible need for plant shutdown to effect the strengthening with consequent loss of production as well as the costs associated with fieldwork and difficult to access areas.

A proposed generic methodology for the assessment and re-qualification of an existing structure is presented. Firstly, the reason for the requirement to re-qualify the structure must be established and due consideration should be given to the consequence of failure. Secondly, a risk analysis should be carried out, which would enable an assessment the appropriateness of the codified load factors. The risk level is evaluated by estimating the potential severity of harm and the likelihood of harm. When considering these two factors, the adequacy of risk control measures already implemented should be reconsidered in view of the relevant legal requirements and codes of practice. When considering the likelihood of harm, factors such as the number of exposed personnel, the frequency and duration of exposure, potential failure of services, machinery and safety devices, exposure of elements, use of personal protective equipment and unsafe acts should be taken into account. Once the risk level is assessed, action alternatives can be investigated before the structural analysis takes place. The risk can be treated using elimination, reduction or acceptance process or a combination. For an existing

structure, which may have been designed to a previous edition of the relevant code, a sensibility check of the resulting capacity of the members should be done.

A real life situation is shown as a case study, in which the application of the proposed approach resulted in considerable savings while maintaining the inherent reliability of the structure implied in the codes.

The paper concludes that:

1. The assessment of an existing structure involves a higher level of engineering expertise than that of designing a new structure if excessive costs are to be avoided.
2. The uncritical application of design codes to an existing structure in operation may lead to unnecessary cost.
3. The re-qualification of existing structures that do not satisfy “new design” code requirements should be considered with a wider perspective before recommending actions such as strengthening or abandoning the structures.

A study on damage scenarios for residential buildings in Dhaka city

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ABSTRACT: The main purpose of this study is to obtain the damage scenario for residential buildings in the occurrence of a destructive earthquake (EMS Intensity VIII) in the city area of Dhaka, Bangladesh. A special concern for seismic vulnerability in Dhaka is caused by the fact that although Bangladesh National Building Code was developed in 1993, it is not strictly enforced till now. A building inventory is important for building damage estimation due to earthquakes, and also for earthquake disaster risk management. For the first time, a building inventory for the city of Dhaka was developed. This involved development of a questionnaire format for the inventory, selection of eight wards among existing ninety wards of Dhaka, conducting survey of 3668 buildings (about 1.5% of the city) samples by the methods of interviews and visual inspection. Their results helped to understand the nature and characteristics of the existing buildings of the city, and were utilized for earthquake disaster management planning. This building inventory together with the existing census data were then used for damage estimation of buildings.

KEYWORDS: Earthquake hazard, building inventory, scenario earthquake, fragility curve, damage estimation.

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Stability and strength check on a minaret using generalized finite element package, ANSYS

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ABSTRACT: A generalized finite element analysis has been performed to investigate the stability of a reinforced concrete minaret, which otherwise would have been difficult using the conventional analysis and design procedures as stipulated in the code of practice, such as ACI. It has been found that the columns of the minaret are not safe for the dead load alone in terms of strength resistance. When wind analysis was added, its serviceability condition did not pass the code criteria. Columns are not also safe for combined dead and wind load in terms of strengths.

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25.
Timber structures and connections

Load-carrying capacity analysis of timber joints using mechanical fasteners

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ABSTRACT: In this study several engineering timber joints were analyzed from the load-carrying capacity point of view, such as joints with split-ring connectors, nail-plate joints and also some dowel-type joints. We analyzed these joints through numerical and experimental methods. Three-dimensional finite element models were applied and contact elements were used in order to model the connection between the wooden material and the steel mechanical fastener. The main point was to determine the stress distributions in the wood near to the mechanical fastener, and draw conclusions for the failure according to the knowledge of these distributions. In addition, biaxial failure criteria were considered for the calculated stresses so that we could consider the failure and obtain the load-carrying capacity values numerically. In order to draw conclusions, the obtained results were compared to experimental results as well. The experiments were carried out at the Structural Laboratory of the Budapest University of Technology and Economics. The load-carrying capacity of these joints was also determined according to the European Standard for calculating timber structures (Eurocode 5). So the loaddependent behaviour of three different joint types (split-ring connector joint, nailed joint and nail-plate joint) was obtained through the above described three ways (FEM, analytical (EC5) and experimental). The study summarizes the calculation methods and compares the results of each. The biggest problem of such connection types is the consideration of the anisotropy of the timber. Of course all of the three methods intend to take into account the anisotropic behaviour of the wood as precisely as it is possible. The differences in the obtained results can stem from the consideration of the material anisotropy and from use of different safety levels.

KEYWORDS: Timber joint, split-ring connector, dowel-type joint, nail-plate joint, biaxial failure criteria, strength anisotropy.

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Development of a new connector for double and triple-layer timber space grids for lightweight roofing applications

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ABSTRACT: This paper reports on the development of a new connector for double and triple-layer space grids in timber, intended for medium-span lightweight roofing applications. The origins of the connector date back to 1995, when it was first proposed by the first Author as the 14FTC-U Timber Space-Truss Connector, and subsequently tested under laboratory conditions over the three years that followed. Unlike connectors for timber space grids proposed by earlier investigators, or the proprietary connector systems that are available for constructions in steel and aluminium, the 14FTC-U connector features a central core of wood in the form of a cuboctahedron or its variants, upon whose faces are attached U-shaped metal brackets that take the timber members. Thus the connector unit is predominantly wood, giving it considerable aesthetic advantages over its all-metal counterparts. While promising, the structural performance of the original connector was not adequate for practical application, hence a programme of further development was embarked upon. As reported herein, recent improvements of the connector have culminated in a structurally viable unit that has been successfully employed in a prototype double-layer timber grid.

KEYWORDS: Layered space grid, double-layer grid, triple-layer grid, connector, timber space grid, Space-truss connector, timber structure, lightweight roofing application.

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Flexible shear connectors in composite timber beams and columns

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ABSTRACT: This paper discusses the strength and stiffness behaviour of flexible shear connectors. Standard nails of 3.5 by 75 mm were chosen as connectors. The emphasis was placed on the relationship between the shear stiffness and the timber density. With the pure shear test the shear stiffness of the connectors were determined. The relationship between the connector stiffness and the density was investigated. The results were compared with the equation in the European Code 5 (EC5) of practice. The relationship between the shear stiffness and the frequency of occurrence was used to simulate multiple shear connectors. From the simulations a model was created to predict a reliable value for the ultimate limit state.

KEYWORDS: Shear, composite, timber, stiffness, connectors.

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The development of the Malaysian codes of practice for the structural use of timber with emphasis on timber joints

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ABSTRACT: The earliest Code of Practice for the design of timber structures in Malaysia, the MS 544 was introduced in 1978. The code, which was not updated or revised for 23 years, was still using the Imperial Units, contained misprints and errors and perceived to be very conservative. The first revision of the MS 544 was finally made and circulated in September 2001. The main purpose of this paper is to introduce the changes and additions in the revised code using the part of the code which dealt with mechanical joints i.e. Code of Practice for the Structural Use of Timber, Part 5 (MS 544:2001: Part 5) as an example. The data from various research and test results performed locally were incorporated into the revised code. In this paper a discussion on how timber joints tests data were analysed and incorporated in the code, is also highlighted. The materials in the revised code were also sourced from several codes such as the AS 1720.1 and BS 5268 Part: 2. The main changes and additions in the revised code include changes in timber grouping and joints classification, changes of units from Imperial to S.I. units, design guideline for coach screw and design of rotational joints. The code generally discussed the structural use of mechanical joints on Malaysian timbers based on the principles of engineering design. The new code also discussed the updated methods and guidelines required to design nailed joints and their basic load derivations.

KEYWORDS: Code of practice, timber joints, nailed joints, basic load, rotational joints.

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Shear resistance and stiffness of 75 mm nails in timber members

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ABSTRACT: This paper discusses the strength and stiffness behaviour of flexible shear connectors. (Nails) The emphasis is placed on the relationship between the shear stiffness and the timber density. The shear tests were done with a pure shear test setup. The relationship between the elastic shear modules of the connectors and other physical properties was investigated. A formula for the shear stiffness of multiple connectors was developed.

KEYWORDS: Shear, resistance, nails, timber, stiffness, connectors.

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26.
Steel structures (general) and composite construction

Strength and ductility of high-strength steel members

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ABSTRACT: Modern steel making techniques have enabled production of high-strength steels, which are being in structural constructions. The mechanical characteristics of such steels are very much different from those of mild-carbon steel. This investigation concerns with the behaviour and performance of high-strength steel elements, members and structures. The Finite Element Method based study considered the strength and ductility of I-shaped stub column sections, and short beam sections. The stub columns were subjected to uniform displacements and the short beams were subjected to uniform rotations until complete collapse. The objective is to establish the effects of material stress-strain relationship characteristics on the strength and ductility of structural members. A wide range of flange and web slenderness was selected in order to establish the effects of cross sectional compactness on the section strength and the section ductility. It was observed that the available ductility tends to increase as the flange and web slenderness decrease.

KEYWORDS: Strength, ductility, high-strength, steel members, finite element analysis, flange slenderness, web slenderness.

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Design of cold-formed steel compression members for local buckling effects at elevated temperatures

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ABSTRACT: Since cold-formed steel structures are increasingly used in a range of applications, the importance of fire safety design of cold-formed steel structures has been realized by both researchers and designers. Despite this, the structural behaviour of cold-formed steel members at elevated temperatures is not well understood because past research on fire safety design of steel structures has been mainly focused on hot-rolled and heavier steel structures. Hence adequate design rules are not available for cold-formed steel structures.

This paper presents the details of an investigation into the structural behaviour of cold-formed unlipped channel compression members subject to local buckling of their stiffened web elements at elevated temperatures. The critical buckling stress formula and the conventional effective width design rules for local buckling were simply modified by considering the degradation of mechanical properties. The modified rules were then used to predict the local buckling stress and ultimate strength at elevated temperatures. To verify the suitability and accuracy of these modified rules, laboratory tests and finite element analyses were conducted on a series of lipped channel members at elevated temperatures. Experimental and numerical results indicated that the modified design rules considering the reduced mechanical properties are adequate for low strength steel members whereas they overestimated the strength of high strength cold-formed steel compression members. It was also found that the theoretical buckling stress formula including the reduced elasticity modulus can be used to determine the local buckling stress of both low and high strength steel members at elevated temperature.

KEYWORDS: Cold-formed steel structures, local buckling, elevated temperatures, effective width, finite element analysis, experiments, mechanical properties.

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Cyclic response of cold-formed hollow steel bracing members

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ABSTRACT: The earthquake resistance of many building structures is provided by steel bracing members. RHS and CHS members are often employed as bracing members for structural as well as aesthetic reasons. This paper describes an experimental study of the response of fixed-ended steel SHS and RHS members to monotonic and cyclic axial loading. Twenty-one short specimens made from cold-formed steel grade S235JRH sections with an aspect ratio of three were tested under displacement-controlled monotonic loading. Eighteen longer specimens with normalised slendernesses between 0.4 and 3.2 were tested under cyclic axial displacements of increasing amplitudes. In both sets of tests, three cross-sectional geometries were employed: 20×20×2.0 mm SHS, 40×40×2.5 mm SHS and 50×25×2.5 mm RHS. The objective of the short specimen tests was to relate tensile material strength and section resistance. The observed results are compared to design provisions of Eurocode 3 and AISI. The objective of the tests on longer specimens was to determine their likely behaviour under strong earthquake loading. The steel hollow brace members exhibited stable hysteresis behaviour up to local buckling, and then showed considerable degradation in strength and ductility depending on their slenderness and b/t ratios. First-cycle buckling loads are compared with design loads predicted by international steel specifications. The effects of section and member slenderness on the strength, ductility, and energy absorption capacity of the braces are examined.

KEYWORDS: Bracing members, buckling capacity, cold-formed, cyclic loading, ductility, hollow steel sections, tests.

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Residual stresses in steel sheets due to coiling and uncoiling

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ABSTRACT: This paper presents the results of recent research which forms part of a larger study on the theoretical prediction of residual stresses in cold-formed sections. The paper is concerned with residual stresses that arise from the coiling and uncoiling process experienced by steel sheets before they are cold-formed into shapes. In this paper, an analytical closed-form solution is presented for these residual stresses, in which the coiling and uncoiling process is modelled as an elastic-plastic plane strain pure bending problem with the steel assumed to obey the von Mises yield criterion and the Prandtl-Reuss flow rule. The accuracy of the solution is demonstrated by comparing its predictions with those from a finite element simulation. Numerical results from the analytical solution are also presented to illustrate the effects of coiling curvature and yield strength on the residual stresses.

KEYWORDS: Residual stresses, cold-formed sections, plastic bending, coiling, uncoiling, flattening, finite element simulation.

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Structural behaviour and design of profiled steel cladding systems subject to local failures

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ABSTRACT: The common profiled steel cladding systems used in Australia and its neighbouring countries are made of very thin (0.42 mm), high strength steel (G550 with a minimum yield stress of 550 MPa) and are crestfixed. However, these claddings often suffered from local pull-through failures at their screw connections during high wind events such as storms and cyclones. At present, steel design codes do not provide guidelines for the crest-fixed steel roof or wall claddings. Past research has shown that European and American recommendations for steel roof claddings cannot be used as they are for thicker, deeper and softer steel claddings fastened at the valleys, which are mainly subjected to gravity loading rather than wind uplift. Therefore at present the design of crest-fixed steel claddings in Australia is entirely based on laboratory testing. Although testing produces a reliable assessment of their, it is often time consuming and expensive. This situation inhibits the innovative design and advances in the steel cladding industry.

Since the local pull-through failures in the less ductile G550 steel claddings are initiated by transverse splitting at the fastener holes, analytical studies have not been able to determine the pull-through failure loads accurately. However, an appropriate splitting criterion has been developed recently using a series of full scale experiments of crest-fixed steel claddings. A finite element model of crest-fixed trapezoidal steel cladding using shell elements has then been developed that included the new splitting criterion and advanced features such as contact simulations, residual stresses and geometric imperfections. The improved finite element analyses were able to model the pull-through failures associated with splitting as evident from the comparison of their results with the corresponding full-scale experimental results. Parametric studies considering the effects of material properties and geometric parameters of the two common trapezoidal roofing profiles were undertaken using finite element analyses. Design formulae for the local failure load of these trapezoidal profiles were then derived for optimization purposes and to simplify the current design method.

KEYWORDS: Profiled steel claddings, screw connections, local pull-through and dimpling failures, finite element analyses, experiments.

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Design method for steel structures based on reliability theory

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ABSTRACT: In this paper, the stability design method based on the reliability theory for steel structures is developed. System resistance factor of the limit load is suggested to simplify the steel structure stability design. The only one of nonlinear analysis is needed in order to verify the steel structure stability. For the determination of the limit load second-order inelastic static analysis is carried out using the general purpose *code ANSYS*. Material and geometric imperfections is considered in the structural analysis. The Monte Carlo simulation on the response surface is applied for statistical study of the steel structure limit loads. Minimizing the computational effort can substantially be carried out under the constraint of sufficient accuracy. This paper deals with the error and the corresponding cause of the effective length method by means of parameter study of three examples and proves design method for steel structures based on reliability theory.

KEYWORDS: Steel structures, reliability, stability design.

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Fatigue of girders with undulating webs under moving local loading

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ABSTRACT: Economical steel girders with sinusoidally predeformed webs commonly used in Central Europe are described. A review of their static and fatigue resistance based on tests and theoretical analysis performed at CTU in Prague are presented. Results of extensive static tests with local patch loading are shown, statistically evaluated in accordance with Annex Z of Eurocode 3 to determine characteristic and design resistance values and supplemented with parametrical study based on finite element geometrically and materially non-linear analysis with imperfections. Extensive tests dealing with fatigue of undulating webs under cyclic shear and cyclic steady local patch loading are summarised and resulting fatigue resistance discussed. Finally latest tests simulating moving local crane loading are described in which cyclic and moving strain pattern in the undulating web under the loading was reached through special testing rig. Evaluation of the new tests and theoretical analysis of local yielding are performed using ANSYS software. In the end some recommendations for practical design concerning fatigue of the girders with undulating webs are presented.

KEYWORDS: Cyclic loading, fatigue, fatigue category, statistical evaluation, steel undulating web.

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I-girders under eccentric patch loading: A review of experimental researches

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ABSTRACT: The paper analyses the problem of thin-walled I-girder loaded (over flange) by patch or concentrated load that has a certain eccentricity regarding the web plane. It is rather complex problem of elasto-plastic bending with geometric non-linearity noticeable even at low extent of loading. Researches done so far show that behaviour, collapse form and ultimate load of thin-walled I-girder subjected to eccentric patch load depend on geometric parameters (girder's dimensions and their ratios), load eccentricity and the manner of load applying (line or laterally distributed load). However, "clear border" between behaviour of centrically and eccentrically loaded girders has not yet been defined. Namely, collapse form of the most (but not all!) eccentrically loaded girders is quite different from the collapse form of centrically loaded girders. The following question is still without quite precise answer: *under what circumstances do the eccentrically loaded girders lose carrying capacity the same way as centrically loaded girders*, or *to what extent of load eccentricity is the collapse form of the same character as that of centrically loaded samples?* A review of experimental researches performed at the Faculty of Civil Engineering, University of Montenegro, in the years of 1998/99 and 2001, as well as comparison with previous similar researches (performed in the USA and Czech Republic), are presented in the paper, as an attempt to get closer to the answer to the question mentioned above.

KEYWORDS: Structural engineering, steel structures, thin-walled girders, patch loading, load eccentricity, collapse form, ultimate load, comparative parameters, experimental research.

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Instability-induced rigging failure

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ABSTRACT: A wide variety of rigging arrangements is used to accommodate the dictates of specific site conditions when heavy equipment is lifted into position on plant structures. In planning for these rigging operations, there are certain instability conditions that must be avoided. The dangers were highlighted in an incident in which a mill shell with a mass of some 70 tons fell from its rigging cradle during installation. The paper describes an analytical procedure by which the stability of similar rigging arrangements can be investigated. Using these procedures to ensure stability, a second mill shell was successfully lifted and replaced.

KEYWORDS: Instability, mill shell, rigging, slings.

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Sensitivity of composite girders to variations in the modulus of elasticity of concrete

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ABSTRACT: Pronounced variations in the modulus of elasticity of concrete inevitably occur due to stochastic material dispersions or systematic influences from the composition of concrete. In calculations of steel-concrete composite girders they are usually neglected and fixed, average values—ascertained only from the concrete strength—are assumed. In the paper the sensitivity of composite girders to deviations from these average values is investigated for the serviceability state, taking into account the time-invariant and the time-variant behaviour of concrete.

The predominant factor of influence on the modulus of elasticity of concrete is the rock type of the aggregate particles. Compared to values given in design codes deviations up to about 50% may arise (sand stone, basalt), while the strength remains almost constant. On the contrary, the creep coefficient is approximately independent upon the choice of the rock type, as elastic deformations change to almost the same extent as creep deformations.

The dependencies of area, second moment of area as well as reduction coefficients (modelling the effects of the time-variant increase of creep strains at different loading types) upon the modulus of elasticity of concrete are derived and graphically presented for composite sections typically used in composite bridges. To this end geometric parameters of the sections are varied in wide ranges. The sensitivities of normal stresses, shear transfer between steel girder and concrete slab as well as resultant inner forces are investigated and illustrated for a representative example. Finally the influence of the construction sequence is shown and recommendations are given for practical applications.

Composite sections show a robust structural behaviour. Moderate under- or overestimations of the modulus of elasticity of concrete do normally lead to negligible deviations in calculations of section properties, shear transfer or resultant inner forces. However, attention should be paid to pronounced, unintended overestimations, as the calculated values of the stresses in the steel girder close to the neutral axis as well as the creep deformations can get significantly wrong. Especially composite girders that are supported during placing of concrete show this sensitivity.

KEYWORDS: Composite girders, modulus of elasticity of concrete, sensitivity, aggregates.

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The effects of shear connectors on plate-reinforced composite coupling beams

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ABSTRACT: Experimental studies on the newly proposed design of plate-reinforced composite (PRC) coupling beams have been carried out. Results reported previously have shown that this design can offer coupling beams with ductile performance under seismic loading, and high strength and stiffness under elastic loading. This paper presents further experimental study on three coupling beam specimens that investigated the importance of shear studs on the plate/reinforced concrete composite action. Three PRC coupling beams of span/depth ratio *(l/h)* 2.5 were tested under reversed cyclic loading. Each of them contained a vertically embedded steel plate, where one was welded with shear studs both in the beam and in the wall regions, while the other two contained shear studs in one of the two regions only. While the shear studs in the beam span would only slightly increase the beam capacity, those in the wall regions would contribute much to the improved inelastic beam performance.

KEYWORDS: Coupling beam, composite, shear stud, steel plate, seismic design.

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Effects of fabrication technique on behaviour of steel columns

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ABSTRACT: Fabricated structural steel sections are made from plates, where first the flanges and the web pieces are cut to length and size, and then welded together to form the sections. Besides traditional saw cutting and flame cutting, modern structural steel fabrication techniques include plasma cutting, water jet cutting, and laser cutting. The first part of the paper establishes the process differences associated with these cutting techniques, and then identify the advantages and disadvantages associated with them. Different fabrication techniques result in different Heat-Affected-Zones, which translate into different residual stress patterns and geometric imperfections. These imperfections affect the strength of particularly the intermediate length columns. The second part of the paper presents the residual stress results from three pilot tests. It is noted that precision gage holes for mechanical strain gauge may be made with drill press-electrical drill assembly. Water-jet cutting provides faster slicing of sections. The paper discusses the research needs and future plans.

KEYWORDS: Fabrication, plasma cutting, flame cutting, heat-affected zone, residual stresses, column strength, experimental.

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27.
Steel frames

An investigation into pallet rack structures under sway

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ABSTRACT: This paper describes an investigation into the sway of portal frames under a combination of point loads normal to the ground and with proportionally increasing side loads.

A mirror arrangement of two portal frames lying horizontally was tested. The frames were tied together by a tension jack which applied point loads on the beam near to the joints. One of the legs of each portal frame was shimmed so that the load applied by the tension jack had a sway component normal to the columns of the portal frames. This sway load was proportional to the vertical load in the columns. The amount of shimming was varied to give different ratios between horizontal and vertical loads. The arrangement was such that after an initial load the frames came away from any ground support and were completely free to sway without any frictional effects.

During each test three cycles of loading and unloading were performed before the frame was taken to its ultimate load. Joint deflections were recorded using of displacement transducers. The moments at the joints were experimentally determined by use of strain gauges attached to the loading beam.

Initially the bending moments on both beam-to-column joints had the same sign. The percentage of side load applied to the structure was chosen so that due to the non-linear PΔ effects reversal of bending moments occurred in one of the joints during the test. The beam and column components of the frame were numerically modelled using stability functions. The beam-column connections were semi-rigid and the experimental momentrotation curves were incorporated into the connection behaviour. As plasticity of the connection occurs at early stages of loading, and the elastic unloading curve is distinct from the loading curve, the moment-rotation curve was modelled using a tri-linear loading curve and a bi-linear unloading curve.

KEYWORDS: Pallet racks, steel structures, sway, non-linear analysis, portal frames.

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Methods of analysis for design of semi-continuous frames: Current practice and future developments

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ABSTRACT: The paper summarizes the current progress in the development of methods of analysis for design of frames with semi-rigid joints. Three groups of methods of analysis are presented in details. The first one consists of simplified second order plastic-hinge methods for calculations of member internal forces in inelastic semi-continuous frames subjected to moderate sway deformations. Methods of this group use a set of notional loads in the first order plastic-hinge analysis. The second group of methods presented in the paper refers to general second order methods of analysis. Finally, more general methods for advanced analysis and design are presented. They use the second order analysis and the concept of refined plastic-hinge that allow for the combined effects of joint stiffness degradation and distributed plasticity along the member length as well as across the member sections. These methods are based on a two surface degradation model or on a spring-in-series model. In the former, two element end springs representing the joint flexibility are used and combined with the introduction of two stiffness reduction factors representing the effect of member inelastic deformations, and applied to direct flexural terms of the element stiffness matrix. In the latter—two element end springs are used in order to represent the effects of joint flexibility and member yielding. An illustrative example is presented. Conclusions regarding methods of analysis used currently in design of sway frames and regarding their future developments are drawn.

KEYWORDS: Steel frame, semi-rigid joint, inelastic deformations, geometric nonlinearity, method of analysis, method of design.

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Effect of connections on steel frames at elevated temperatures

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ABSTRACT: Connections between the structural members of steel frames are key components of these structures. Rising temperatures leads to structural collapse at critical temperatures due to the variation of mechanical properties of steel, but the national building regulations of most countries provide only limited guidelines to engineers on the factors to consider for structural behaviour in the event of a fire. This paper investigates the effects of high temperatures on some connections between beams and columns of steel frames. The changes in the structural stiffness due to elevated temperatures could then be incorporated into the standard analytical methods and models for determining the structural stability of the frames. The analysis of connection behaviour at enhanced temperatures can lead to a more accurate determination of the critical loads (that lead to failure) and an improved design of connections in order to delay structural collapse for steel frames under fire conditions.

KEYWORDS: Steel frames, connections, fire engineering, elevated temperatures, stability behaviour.

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An investigation into the factors affecting the accuracy of beam-end connector tests in pallet rack structures

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ABSTRACT: The cantilever test is often used to determine the moment-rotation relationship for the semirigid connection occurring in pallet rack structures. However, research at Oxford Brookes University has shown that if measurements of the rotation of the connection are made by using displacement transducers attached to the beam, the flexibility of the beam must be taken into account in order to obtain the true moment-rotation relationship. This paper describes the results of a theoretical and experimental investigation into different methods of measuring rotation and derives correction equations involving beam flexibility in bending and shear to get adjusted moment-rotation relationships. The results of the investigations show that if measurements are made on the beam that the influence of flexibility and shear lead to corrections of approximately 2% and 1% respectively If, however, the transducers are attached directly to the beam-end connector then only a shear correction of approximately 1% needs to be made, beam flexibility having almost zero influence.

In order to determine the moment in a beam-end connector in a pallet rack frame the paper also discusses the use of a series of strain gauges attached to the surface of the beam in conjunction with a finite element model of the beam section. Four strain gauges were attached at different distances from the connection and when the force was applied to the end of the stub beam the strain corresponding to a given moment was determined. A best fitting straight line was then obtained to get the moment at the connection corresponding to a given strain in the gauge. An example of the use of this technique is described in the experimental investigation of a pallet-rack frame under sway.

KEYWORDS: Pallet racks; cantilever test; moment-rotation curves; steel structures.

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28.
Steel connections

Fatigue of composite tubular joints for high-speed railway truss bridge

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ABSTRACT: The structural performances of composite tubular K-joint leading to real truss bridge construction of high speed Shinkansen train are presented. The experimental studies on improving the fatigue performance of welded steel tubular joints by upgrading the structural joint details and improving the weld toe profiles were carried out on ten tubular K-joints under repeated constant amplitude load. The behavior of all joints were examined through the analyses and the tests. The results suggest that concrete filled tubular joints are able to improve the fatigue strength substantially compared to unfilled joint.

KEYWORDS: Composite tubular K-joints, fatigue strength, stress concentration.

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Virtual experimental model of endplate connections

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ABSTRACT: Endplate connections are extensively used and have some advantages over fully restrained connections used in steel building structures. They are designated as partially restrained connections and possess more ductility without much loss in moment carrying capacity. The moment-rotation behavior of endplate connections has been investigated both experimentally and numerically. Some researchers have attempted to use limited test data to develop empirical equations for the moment-rotation curve of an endplate connection. Such mathematical models can be developed if moment-rotation data is available for a large number of connections that cover the possible range of variations of all relevant geometric and force related variables. In practice, a large number of such variables affect the moment-rotation behavior of a connection. Moreover, these variables can vary over a wide range to design connections with different capacities. It is too costly to obtain such data by physically testing for all possible designs of connections. On the other hand, if a computer program can be calibrated against results recorded from physical tests for selected cases and its predicting capability be demonstrated, then it could be used as a tool to simulate the behavior of any given connection in lieu of actual physical tests. Then a combination of limited physical testing and more computer simulations will be the most judicious approach to develop mathematical models that describe the moment-rotation behavior of endplate connections.

Based on the above motivations, a 3D finite element model of an 8-bolt, extended, and stiffened endplate connection has been developed. The program includes the capability to model the pre-tensioning of the bolts, fracture initiation and its growth, and load-dependent boundary conditions between the column flange and the endplate. Current available commercial software does not incorporate all of these features. The results predicted by the analysis were compared with experimental data available for thirty connection geometries. The comparison shows a good match between the test and analysis results.

KEYWORDS: Finite element, endplate, cyclic loading.

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Simulation, computation and fatigue tests of welded joints between high-strength fine-grained steels and structural steels

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ABSTRACT: The subject of this paper is the numerical simulation of temperature fields during MAG welding and of the fatigue behaviour of a variety of mismatch welded joints, which was carried out in the research project "Innovative constructions for the mechanical engineering and steel construction by combination of new steel materials". The investigations concentrated on combinations of structural steels with high-strength fine-grained steels in the welded joint.

The required details for thermal simulation comprise two steel grades as well as boundary conditions. The insufficient material basis for the weld was identified as the major problem for the thermal simulation of temperature field of welded joints. The procedure and the results of the thermal computation of the temperature field using FEM are described.

The specimens with K-welds, fillet welds and butt welds have been arranged into fatigue classes (FATclasses). This was carried out with respect to the nominal-, structural- and notch-stress approaches. Several ways of modelling the welds with finite elements are introduced and compared.

The structural-stress approach in particular requires the definition of principles for calculating the hot-spot stresses. On the other hand, the determined fatigue class for hot-spot stress site is valid only for the finite element modelling concept used. Currently, there are a many ways of modelling the weld for this approach, leading to different stress results.

A high degree of accordance was obtained between the measurements of temperature time history and of the fatigue behaviour on the one hand, and the results of numerical computations on the other. Subsequently, it can be assumed the material dates used represents reality quite satisfactorily. Experimental investigations however are still important for the verification of calculations.

KEYWORDS: Numeric simulation, high-strength fine-grained steels, temperature field, material properties, MAG-welding, fatigue behaviour, hot-spot stresses, structural stress model, local stress model, cruciform joint with K-weld.

Welded HSS truss connections

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ABSTRACT: Sixteen full-scale truss connection specimens, consisting of hollow structural section (HSS) members forming either T or N configurations, were held at a prescribed axial compressive load applied to the lower chord member while axial load applied to the vertical member was gradually increased to the ultimate connection capacity. The ratio of vertical member width to chord member width, b1/b0, varied between 0.67 and 1.0. Modes of failure included localized large deflections of the flange face and sidewalls of the compression chord. It was found that reduction in capacity due to a member of a connection being intentionally offset from the central plane of the truss by as much as 17 percent of the width of the chord member, was either marginal or negligible.

KEYWORDS: Experimental, hollow structural sections, truss connections, offset member, structural evaluation.

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Strength of gusset plates in welded steel structures

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ABSTRACT: The design of gusset plates is normally carried out on the basis of the technical beam theory or other assumptions proved safe by experience. This design procedure has proved its usefulness by the length of life and use of existing structures, and is to some extend justified in simple loading cases.

A different approach is taken in the paper where upper and lower bounds are derived for the yield load assuming a perfect plastic material and Tresca's yield condition. The theoretical results are supported by a few numbers of tests. The paper deals mainly with the case of a single member welded into a cut out in a gusset plate, but also the case with two members is addressed. A FEM-analysis of a gusset plate with two members is reported and compared to the theoretical results.

KEYWORDS: Gusset plate, steel structures, plasticity, limit analysis.

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The deformation capacity of the H-section beam considering brittle fracture

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ABSTRACT: After the Northridge and Hyogoken-Nanbu Earthquakes, it was observed that brittle fracture occurring at the beam-to-column connections were a significant cause of steel structure collapse. This phenomenon constitutes a serious structural defect problem. Preventing the occurrence of brittle fracture will not only save the human life but will also preserve structure function. After these earthquakes, extensive experimental and analytical researches were initiated in Japan. Accordingly, recommendations for improving seismic design criteria to achieve better performance of steel structures, particularly for the beam-to-column connections, were compiled in *Recommendation for Design of Connections in Steel Structures.* However, this publication only recommends the ultimate strength of the beam-to-column connections, but did not comment on the rotation capacity. In well-designed steel frame structures, inelastic deformation under severe seismic loading is confirmed in beam plastic hinges located near the beam-to-column connections. Thus, rotation capacity of the plastic hinge and resilience of the connections are essential for good plastic behavior and expected energy dissipation in steel frame structures.

This paper investigates the rotation capacity of the beam-to-column connections which is defined by the degradation of strength or the initiation of the ductile crack at the scallop tip by using detailed finite element analysis. From this investigation, three important results were found:

First, Semi-Complementary-Energy-ratio is an available material index to evaluate the rotation capacity of beam-to-column connection defined by the degradation of strength.

Secondly, in the case of considering a ductile crack at the beam-to-column connections, it is important to take into account both width thickness ratio and the ratio of plastic section modulus of the web on the H-beam (Z_{wp}/Z_p).

Finally, the regions of width thickness ratio, whose rotation capacity of beam-to-column connection is defined by the initiation of ductile crack, are indicated in this paper. The region will extend when Z_{wp}/Z_p is large.

KEYWORDS: Steel frame structure, moment resisting frame, beam-to-column connection, rotation capacity, material property, semi-complementary-energy-ratio, collapse mode, ductile crack, width thickness ratio.

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Specialist steelwork connection design in South Africa: Good and bad practice

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ABSTRACT: The paper is aimed at raising the awareness of South African Engineers, Detailers, Contractors and any other associated party with regard to the latest South African Codes of practice and the contractual requirements regarding steelwork connection design and detailing. Firstly, current practice is discussed, followed by the latest contractual requirements. Examples of some specialist connection design approaches as well as some problematic approaches are presented which reinforce the comments made with regard to contractual issues. This paper highlights current issues relating to connection design practices in South Africa in context with recently issued codes of practice and related experience obtained during both local and overseas projects.

KEYWORDS: Connection design, Structural Steelwork, Gusset buckling, Two-way bending, Yield-line theory.

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3-D finite element modelling of flush end-plate bare-steel connections at elevated-temperatures

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ABSTRACT: This paper describes a finite element model developed to establish the moment-rotation characteristics of flush end-plate bare-steel connections at elevated temperatures using a general purpose finite element software ABAQUS. The connection components were modelled using three-dimensional brick elements while the contact between the components was modelled using coulomb friction. Material non-linearity was considered for steel members and the connection components. Degradation of steel properties with increasing temperatures was taken according to EC3 recommendations. Simulation results were compared with results from experimental tests conducted on flush end-plate connection in fire conditions. A good agreement between the experimental and numerical results in terms of the failure mode and moment-rotation-temperature characteristics of the connection was achieved.

KEYWORDS: Connections, elevated-temperature, moment rotation, strength, stiffness, steel flush end-plate, modelling.

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Fatigue failure of knife-plate bracing connections

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ABSTRACT: Cross bracing is frequently added to structures to carry lateral loads and to reduce the lateral displacements, thereby increasing the overall structural stability. In the construction of steel frames, it is not uncommon to use square steel tubing as bracing members. One of the most efficient and economical means of connecting tubular bracing in frames is by the use of knife plate connections. Although widely used in tubular bracing systems, uncertainties still exist with respect to this type of connection. Due to construction and fabrication tolerances, it may be occasionally necessary to leave an unfilled gap between the edge of the inserted gusset plate and the end of the slot. In the research described herein, the effect of this gap as well as of the influence of various parameters on the behaviour of knife plate connections are investigated using an experimental program consisting of nine full-scale specimens subjected to cyclic axial loading. In all cases, fatigue stress concentration cracks developed in the HSS walls at the leading edge of the inserted knife plate leading to relatively low fatigue life.

KEYWORDS: Connections, knife-plate, bracing, fatigue, experimental, tubular, welded.

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29.
Aluminium and stainless steel applications

Cross-section strength of stainless steel members

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AB STRACT: A conceptually new approach has recently been developed by the authors for the prediction of the strength of compressed plate elements in stainless steel members. This recognises the continuous nature of the stress-strain characteristic of stainless steel and does not, therefore, use the classification system found in modern codes dealing with the structural design of carbon steel members. The original development was confined to plate elements supported on both longitudinal edges; the basic concept is expanded herein to consider a wider range of cases. The resulting design procedure forms part of a general treatment of stainless steel structural members that predicts resistances significantly in excess of those obtained from currently available design methods. These resistances are found to accord well with the observed strength of sections obtained in laboratory tests.

Aluminium elements subject bending and compression

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ABSTRACT: The Ramberg-Osgood law provides the most accurate description of the stress/strain relationship of aluminium alloys (and many other materials). Repeated numerical integration of this function will result in a database for the acting bending moment and the relative rotation in a rectangular cross-section. Using this base an approximating moment-curvature function can be established in a modified form of the Ramberg-Osgood law. Approximating values of the moment, which causes conventional yield stress or ultimate stress in the extreme fibre, can be stated also. Changing the strain in the extreme fibres and numerically integrated the stress function one can get relating data for the actual normal force, bending moment, strain and relative rotation. Analysing these data we have found relations for the normal force—bending moment pairs, which results yield or ultimate stress in the most loaded extreme fibre. Function for the moment-relative rotation curvature in case of simultaneous normal force also sated. Published values and relations will be applicable in further research.

KEYWORDS: Aluminium, bending and compression, stress-strain relation, Ramberg-Osgood law, momentrelative rotation relation, interaction curves.

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Application of stainless steel in seismic design

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ABSTRACT: The appropriate use of stainless steels (SSs) for structural applications in building systems provides possibilities for a more efficient balance between whole life costs and in service performance. The present paper assesses the feasibility of the application of SSs in the seismic design of framed structures, either braced (CBFs) or moment resisting (MRFs). In so doing, inelastic analyses have been carried out on a set of 22 multi-storey frames. The results of both static (pushovers) and dynamic (response history) analyses demonstrate that SSs exhibit enhanced plastic deformations and excellent energy absorbing capacity. The augmented strain hardening of SS, which is nearly twice that of carbon steels (2.30 vs. 1.20) is beneficial to prevent local buckling in steel members in both MRFs and CBFs. The analyses also demonstrate that, when SS is spread within columns in MRFs, the system over-strength increases by 30% with respect to the carbon-steel benchmark structure. The design over-strength, plastic redistribution and energy dissipation capacity increase by the same amount. The study also reveals that there is no significant benefit in spreading SS within beams (dissipative members). The onset of yielding in dissipative members is delayed when SS is employed. On the other hand, in CBFs with SS braces and columns the increase in overstrength is about 33% with respect to the configuration in mild steel. Values of lateral drifts (d_{top}/H_{top}) for CBFs with SS are 10–15% higher than those for frames in mild steel. There are no benefits in using SS in beams of CBFs.

KEYWORDS: Stainless steel, carbon steel, seismic performance, seismic design, overstrength, plastic redistribution, energy dissipation capacity, moment resisting frames, concentrically-braced frames.

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30.
Behavior of steel structures in fire

Load-carrying behaviour of thin-walled steel sections subjected to fire

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ABSTRACT: Local buckling and additional capacity resulting from plastic cross sectional behaviour have a strong influence on the resistance of steel sections subjected to fire. Local buckling of steel members in fire occurs at lower geometrical slenderness ratios than for room temperature. The following study indicates that the design methods for room temperature cannot be adapted by changing the material properties only. Local buckling effects occur below the Winter limit of $\bar{\lambda}_p \leq 0.673$ due to large strains required because of the distinct nonlinear material behaviour of steel at high temperatures. However, considering large strains and plastification lead to a distinct increase of cross sectional capacity of thin-walled sections subjected to fire. A proposal for a structural model for steel plates in bending and compression at elevated temperatures is presented. The model uses a strain-based formulation for effective widths considering plastic stress distribution and strain-dependent nonlinear material behaviour to analyze the load-carrying capacity at elevated temperatures of steel plates supported on three or four sides. It is in good agreement with the results found using the finite-element method. The investigation on steel plates is part of a research project to develop new design methods for thin-walled steel members under fire conditions, considering local buckling and nonlinear material properties at elevated temperatures, as well as the effect of transient heating, thermal expansion and internal stresses.

KEYWORDS: Steel, steel constructions, fire, fire engineering, fire resistance, local buckling, local buckling in fire, effective widths, plastic resistance.

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VIRTUALFIRES: A virtual reality simulator for tunnel fires

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ABSTRACT: The *VIRTUALFIRES* (Virtual fire emergency) simulator will be presented, that allows to train fire fighters in the efficient mitigation of fires in a tunnel and in rescue operations, using a computer generated virtual environment. This is a cheap and environmentally friendly alternative to real fire fighting exercises that are currently carried out and that involve burning fuel in a disused tunnel. The simulator can also be used to test the fire safety of a tunnel and the influence of mitigating measures (ventilation, fire suppression etc.) on it's fire safety level. The simulator is developed with financial support from the European community under the IST (Information society technology) programme and combines the simulation of fires using advanced CFD software and the visualisation of smoke, toxicity levels and temperature. Two versions are being developed: One using a head mounted display and a laptop computer, the other using a CAVE virtual environment together with a supercomputer.

KEYWORDS: Visualisation, virtual reality, tunnels, CFD.

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Steel structure and fire: Analysis of a steel portal frame

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ABSTRACT: A numerical experiment on a steel frame subjected to fire is performed. The behaviour of a loaded plane steel portal frame is studied considered with a standard ISO fire and two natural fires. An empirical stress-strain law is assumed for steel taking into account the creep due to high temperature. A step-by-step time integration algorithm is used to study the behaviour of the frame.

The main effects of the fire are:

1. A restrained thermal elongation of columns and beams
2. A gradual formation of plastic hinges because of the steel strength degradation due to elevated temperature.
3. A buckling of columns of elasticity modulus degradation due to elevated temperature.

A plane steel frame is simulated by a truss model. A computer program is used for the step-by-step nonlinear structural analysis of plane truss models of steel frames subjected to fire. This program is applied to a typical steel portal frame. The main effects of the fire are: a restrained thermal elongation of columns and beams, a gradual formation of plastic hinges because of the strength degradation of steel due to elevated temperature, and a buckling of columns because of elasticity modulus degradation due to elevated temperature. From the output of the application, it is observed that, for temperatures lower than 300°C, the effect of the fire is demonstrated by thermal expansion and additional stresses, as well as by thermal bowing of the beams due to the temperature gradient over the cross-sections. Whereas, for temperatures higher than 300°C, plastic hinges are gradually formed due to yield stress reduction with temperature, and columns may buckle due to the elasticity modulus reduction with temperature. Each of the above two phenomena may lead to a collapse of the portal frame. The critical temperature of the frame is estimated.

KEYWORDS: Fire, heat diffusion, steel portal frame, truss model, beam column connection, step-by-step algorithm, thermal expansion and bowing, steel creep, plastic hinges, buckling.

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Linear static analysis of a steel space truss subjected to temperature elevations

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ABSTRACT: Because of their high strength characteristics, coupled with ease of construction, steel structures are greatly favoured by architects and engineers for industrial and high-rise buildings. Although industrial fire outbreaks appear to be directly related to the degree of industrialisation, not much research data is available on building performance under temperature elevations resulting from fire conditions. Fires in buildings usually result in high financial and human losses. A case still fresh in many people's minds is the destruction in 2001 of the World Trade Center twin towers in New York City. For this and other reasons, fire resistance requirements in buildings will continue to get more stringent in the coming years and the field of "fire engineering" is likely to show a significant growth in the coming years. In order for a structural member to be able to carry its load during and after a fire, its size may need to be greater than that which is dictated by purely structural considerations. Using a space truss as an example, this paper attempts to model the performance of a steel structure subjected to moderate temperature elevations. The analysis has been limited to linear static mechanics, although the procedure can be extended to non-linear analysis to cater for large deformations that would result from high temperature elevations. The results show that even moderate temperature elevations are highly destructive to, especially, rigidly constructed structural arrangements.

KEYWORDS: Compartmentalisation; determinate; fire resistance; indeterminate; linear; modulus of elasticity; non-linear; pin-jointed; space truss; steel; temperature; thermal expansion.

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31.
Concrete and construction materials

Structural performance, reliability and service life prediction of concrete beams subject to pitting corrosion

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ABSTRACT: Pitting corrosion of reinforcing steel due to chloride attack is one of the major causes of deterioration of concrete structures. Pitting corrosion clearly is a spatial and temporal variable. However, most studies to date have only modelled the strength and reliability of flexural members subject to deterioration by focusing on mid-span capacities, regions of peak actions or other “critical” sections. Hence, ignoring the spatial variability of pitting corrosion will lead to an over-estimation of structural capacities and structural reliabilities, at least for members in flexure.

This paper describes the development of probabilistic models to predict the spatial distribution of maximum depths of pitting corrosion for reinforcing bars and prestressing strands. The pitting corrosion model was developed using accelerated corrosion tests in a chloride-concrete environment. The model is then combined with appropriate failure criteria to calculate the reduced strength of prestressing strands under pitting corrosion attack.

The probabilistic pitting models are applied to reinforced and prestressed concrete beams in flexure. The influence of pitting corrosion on structural strength, mean time to failure and structural reliability can then be estimated. The reliability analyses included the random, temporal and spatial variability of loads, material properties, dimensions and deterioration processes. It was found, for instance, from a distribution of time to failure of an AASHTO Type IV prestressed concrete bridge girder exposed to a coastal environment that the mean time to failure is 60 years. It was also found that significant increases in probabilities of failure were observed if spatial variability of pitting corrosion are included in the analysis.

Improved estimates of structural performance and reliability allow for more realistic predictions of remaining service life, particularly if service life prediction is based on reliability-based safety or life-cycle cost criteria.

KEYWORDS: Structural reliability, pitting corrosion, prestressed concrete, failure.

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Implications of chloride ion binding for rapid chloride ion resistance tests for concrete

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ABSTRACT: The durability of reinforced concrete structures exposed to chloride-laden environments is determined, at least in part, by the chloride penetration resistance of the concrete. Many tests have been proposed to rapidly evaluate concrete chloride penetrability. One aspect of chloride resistance of concrete that is not normally considered in evaluating the results of these accelerated tests, however, is the chloride ion binding ability of the concrete. As chloride ions penetrate the concrete matrix, they interact with the pore surfaces and a portion of the ions will be bound, either physically or chemically. This binding serves to immobilize some ions and to reduce the free chloride ion concentration of the pore solution. These interactions can occur within a short time frame. The specific amount of chloride ion binding depends not only upon the chloride ion concentration, but also upon the properties of the concrete matrix. The impact that chloride ion binding has on the test procedures and on interpreting the rapid test results are discussed for three separate accelerated test methods that have been proposed in the literature: (1) the Non-Steady State Migration Test by Tang and Nilsson (1991), (2) the Steady-State Migration Test by Dhir et al. (1990), and (3) the Chloride Conduction Test by Streicher and Alexander (1995).

KEYWORDS: Concrete, testing, durability, chloride ion binding.

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Fire damage of natural stones and their laboratory analysis

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ABSTRACT: Fire and high temperature cause changes in the petrological and petrophysical properties of the building materials that often lead to stability problems. Numerous historical monuments contain stone parts or often the whole structure is built of stone. Fire damaged stone buildings show further stages of deterioration since the fire is followed by natural weathering (moisture, frost action), which further aggravates the state of the monument. The knowledge of mechanical properties of natural stones is fundamental for conservation and restoration of the building stones. In addition, it serves as a basis for the development of conserving materials and for structural calculations. Changes in the colour of stones, rounding off corners, spalling and scaling of surfaces and cracking refer to earlier fires. These signs of former fires play a significant role in dating of the stone elements or even the entire building. The injured stone material is exposed more intensively to the natural effects. The effect of fire has been studied on seven German and three Hungarian sandstone types. The specimens were burnt in an oven at 6 different temperatures and investigated by different test conditions (air dry, water saturated and after 25 freezing cycle). The petrological (polarizing microscope, X-ray, SEM) and petrophysical (density, porosity, water adsorption, ultrasonic sound velocity, duroskop rebound, uniaxial compressive and indirect tensile strength, colour measurement) investigations have shown that the texture and mineral composition of sandstones are changed by heating. These changes influence the strength and durability of stone material. It was observed that sandstones of different cement types show various features to fire. The heat resistance of different quartz sandstone depends on the type of the cementing mineral, the amount of cement (grain/cement ratio), the grain size (fine, medium, coarse) and the grain to grain or matrix to grain contacts.

KEYWORDS: Sandstone, heat effect, petrology, petrophysics, historic, monuments.

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Comparison between different lightweight concrete blocks for thermal insulation

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ABSTRACT: This paper presents the results from an experimental investigation to study the possibility of developing lightweight concrete blocks which can be used for cladding and serve the purpose of thermal insulation. These blocks were produced from two indigenous materials: vermiculite and polystyrene beads which are used as lightweight aggregates with different proportions in the mix. The mechanical and thermal properties of two types of block developed in the laboratory were compared with blocks manufactured commercially as thermal insulation blocks and ordinary concrete blocks. The strength of masonry columns constructed from the produced blocks was also compared. The results indicated that blocks manufactured from polystyrene possessed lower thermal conductivity than vermiculite and ordinary concrete blocks despite the variation in the density and compressive strength.

KEYWORDS: Lightweight concrete, masonry blocks, polystyrene, vermiculite, thermal conductivity.

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The effect of cement extenders on temperature development in concrete

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ABSTRACT: Thermally induced cracking of concrete as a result of the heat evolved during cementing reactions, presents a significant problem in the design and construction of mass concrete structures such as dam walls and large foundations. One of the strategies used by designers and contractors to minimise the absolute temperature differences in the structure is to maximise the use of cement extenders such as fly ash (FA) and ground, granulated blastfurnace slag (GGBS). The work presented in this paper was aimed at experimentally quantifying the rate of heat evolution of Portland cement containing varying proportions of FA and GGBS under adiabatic conditions. Concretes were prepared and subjected to adiabatic testing. The resulting heat rates were expressed in maturity form to account for the varying temperature regimens which concrete is exposed to in situ. The paper also reports on the use of a finite difference heat model, which takes these measured heat rates as input, to predict the time-temperature profiles in a mass concrete structure. The results show that the effect of cement extenders is to significantly reduce the peak heat rate, maximum temperature and maximum temperature gradient achieved in a mass concrete structure.

Compatibility of destructive and non-destructive tests of concrete strength

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ABSTRACT: The result of a research project aimed at the examination of the compatibility between the conventional destructive and non-destructive tests of concrete strength is reported. Statistical analysis of 206 non-destructive and 46 destructive test results of concrete columns and slabs are performed. A correlation analysis is also undertaken to examine the degree of linear association between the two test results. Linear and quadratic forms of regression models are calibrated with the test data. Findings of the study indicated that a strong correlation exists between the two test results, and the linear or the quadratic forms of regression models may be employed to predict the structural strength of concrete components accurately.

KEYWORDS: Destructive and non-destructive tests, compatibility of concrete tests, concrete strength, regression statistics, Kuwait.

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Influencing factors on the yield point determination of bentonite suspensions for the stability prediction of diaphragm walls and slurry shield tunneling

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ABSTRACT: For the construction of diaphragm walls and for slurry shield tunneling, bentonite suspensions are used. Here, the suspensions have a stabilizing function. For stability analysis, the knowledge of the rheological behavior of the bentonite suspensions is necessary. Properties such as viscosity and thixotropy are important. A main parameter for stability calculations is the yield point.

Various devices for measuring rheological parameters exist for the suitability test and the quality control of bentonite suspensions. However, not all of them are applicable on construction sites. Several devices are available for the determination of the yield point, but they do not give the same results.

In this paper, different measuring systems are compared. Conventional, simple devices such as the Marsh funnel, a special flow cup, are considered as well as a modern, precise rheometer. A comparison of the results is performed, with focus on the yield point. Influencing parameters are studied, such as the type and concentration of the bentonite in the suspension, the type of mixing water (tap water or desalted water), temperature and additives (sand). These parameters affect the rheological properties of the bentonite suspensions and thus the supporting effect. It was found that the main factor is the bentonite type.

KEYWORDS: Bentonite suspension, rheology, yield point, diaphragm wall, slurry shield tunneling.

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32.
Housing, low-cost construction & construction technology

The impact of structural engineering on the sustainability of human settlements in developing countries

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ABSTRACT: Just under half of the world's population live on less than 2US$ per day. Agenda 21 (1992) recognized that access to safe and healthy shelter should be a fundamental part of national and international action. The Habitat Agenda (1996) linked locally available, appropriate, affordable, safe, efficient and environmentally sound construction methods and technologies that emphasize optimal use of local human resources to the concept of "sustainable construction". The Johannesburg World Summit (2002) includes an action relating to the use of low-cost and sustainable materials and appropriate technologies for the construction of adequate and secure housing for the poor.

Sustainable housing can be considered to be housing that provides adequate shelter whilst satisfying fundamental human needs relating to health, safety and well being of residents; is affordable to access, maintain and live in; minimizes the harmful effects of housing developments on the environment; conserves natural resources in its construction, maintenance and functioning; and provides significant employment opportunities in its construction.

Structural engineering has a major impact on the choices made in the technologies that are employed and the construction materials that are used. These choices impact directly on the nature of the employment generated during construction, the performance of the house in use, the vulnerability of the house to natural disasters, the affordability of a house and the accessibility of housing to the poor.

This case study documents the South African experience including the innovative work done by the Joint Structural Division of IStructE and SAICE in the design of low cost housing in a sustainable manner which has resulted in Standards South Africa in reinterpreting building regulations. It furthermore demonstrates how structural engineers can use performance based standards to promote sustainable housing and how performance standards can be linked to procurement arrangements to realise employment objectives in mass housing schemes.

KEYWORDS: Housing; sustainability; performance-based standards; structural engineering; human settlements; sustainable housing; housing units; employment.

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Risk management of structural performance of housing in South Africa

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ABSTRACT: Despite the fact that a large pool of technical and legislative information on the structural aspects of house construction in South Africa is available, unacceptable construction quality, affecting the integrity of buildings, is apparent throughout the entire spectrum of housing (i.e. low- to high income). This issue forms one of the main concerns and mandates of the National Home Builders Registration Council (NHBRC). The paper highlights the role of NHBRC, the relevance of risk management and performance based codification and summarises typical structural problems which take place in South African housing. It also presents selected statistics of damage and their socio-economical implications. This risk of structural failures has to be managed proactively and specific measures in this regard are considered in the paper. At the initial stage an introduction of a comprehensive and consistent quality assessment system of houses is postulated. The information which will be obtained, will then enable the implementation of relevant strategies for training and grading of home builders.

KEYWORDS: Risk management, housing, structural failures, NHBRC.

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The analysis of buildings from the aspects of resources consumption, cost and construction period

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ABSTRACT: The goal of the analysis was comparation of the costs, building period and consumption of the resources for the structures with the different architectural and constructural systems, but with the same heights. The research was based on technical documentation and prepared conceptual design on organization and building technology. Tree apartment houses of the same heights (four floors), but with different constructive systems were analised. The procedure of comparation of the costs, building periods and resource consumption followed the location analysis, climatic conditions, local conditions and architectonic and construction solutions. Basic task was to create parallel view of resources consumption by the type and the quality, depending on useful area and volume of the structure. Further on, the unit prices of construction were checked upon single types of works and total prices, but the most important price of building for useful area and the volume of the structure. At the end, by the comparation and the analysis of obtained results for the resources, prices and deadline, the conclusion and recomandation for economical building, which means lover resources consumption, shorter building periods and lower prices.

KEYWORDS: Analysis, building, cost, resource consumption, building period.

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Effect of partial replacement of cement with microsilica in compressed soil blocks

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ABSTRACT: Cement stabilized blocks (CSBs) are a major resource for affordable shelter in developing countries. It is generally understood that the compressive strength of a block represents one of its most important properties. Unfortunately, current production processes have failed to deliver high-strength, low-volume blocks. Research into alternative ways to increase block strength without incurring additional production costs have proved futile over the years. Methods used in the past included investigations into: water-cement ratio, cement-content, degree of hydration, compaction pressure, curing conditions, and soil type. All these methods have met with limited success. A new approach, involving the use of microsilica as a partial cement replacement material (CRM) has now been investigated for the first time. The objective of this paper is to report on the findings from this new procedure that was successfully used. Microsilica (condensed silica-fume) was mixed with ordinary Portland cement to produce blocks of extraordinarily high strength. It was found that partial replacement of cement by as little as 10% of its weight by microsilica generally resulted into doubling of the strength of CSBs. Other surface and bulk properties were also found to be significantly enhanced. From a general survey of CSB literature, it can be safely stated that no previous method has so far been reported to be as successful as this one. It can be concluded that use of micosilica as a CRM significantly increases the strength of blocks. The increase in strength is thought to be due to improved inter-granular bonding, material reduction of both voids and porosity, and considerable lowering of the water-cement ratio. To the knowledge of the authors, no previous publication has ever been made on this particular subject.

KEYWORDS: Compressive strength, cement stabilized soil blocks, microsilica, cement replacement material.

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Wave attack in Haor areas of Bangladesh and cement concrete blocks as structural revetment materials

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ABSTRACT: Haor is the local name of the saucer shaped naturally depressed areas of the north eastern part of Bangladesh. The areas are at very remote locations and underdeveloped. During July to November due to flood these areas go under deep water and look like seas with erosive waves on water surface. During wind storm these wave reach up to 1.5 m in height. All settlements in the haor areas are on earthen mounds. People are mostly poor and day labourers. They fight against natural calamity by applying traditional indigenous methods which are not at all effective. Many villages have already been washed away. The existing ones are on threat of extinction. By this time many people have become homeless and migrated to the slum areas of the nearby urban and cities. This has become a grave national problem for Bangladesh. Recently NGOs and Government agencies are trying to mitigate the sufferings by constructing protection works which are based purely on empirical data and information. The present paper evaluates some of the already completed projects and explores the cost effectiveness and sustainability of the C.C. blocks as structural revetment materials against wave attack. Laboratory experiments have also been conducted to answer the validity of the popular design formulae.

KEYWORDS: Wave, haor, CC blocks, revetment, rural, protection, gazaria, mithemain.

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Prop-less beam and block slabs for Africa

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ABSTRACT: The construction of suspended slabs is the biggest challenge to small emerging contractors who have neither skill or equipment to erect cast "in-situ" solid concrete floors or a variety of beam and hollow block floors. Various bad practices of slab construction are shown and proposed new prop-less pre-cast beams and hollow block slabs are described. The new slab is based on using lattice beams and hollow filler blocks in between them to form permanent shutter. The difference between known lattices and the proposed lattice beams is that new lattice is much stronger by adding top flat bar to form together with bottom concrete I-section of significant structural performance.

Two methods of construction are shown. Both methods have been investigated for ease of construction and structural merits.

The design calculations were based on the combined results of a finite element analysis and by hand calculations. Results of the cracked and un-cracked sections were taken into account to define the permissible loading conditions for the different spans of the beams.

The following effects have been considered in the investigation:

- Stresses in the lattice beam during each stage of the construction
- Deflections of the beams during each stage of the construction
- Buckling of the lattices and the top flat bars
- The ultimate strength of the beams loaded with wet and hardened concrete
- Shear at the interface of the concrete lintel and concrete and at the interface of the rib and the top flange of the composite.

The new slabs were successfully erected on variety of projects with slabs varying in size from 15 to 150 m^2. After first applications it appeared that new emerging contractors enthusiastically accepted the proposed propless slabs and erected them with speed and ease. Further investigations will be carried out to increase prop-less spans by using lighter blocks.

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Diagnosis of a failed water reservoir at River Sezibwa

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ABSTRACT: To address the need for clean water for the Sezibwa rural community in Mukono District, Uganda, a low-cost water supply system was constructed in 1998 near the Sezibwa waterfalls on River Sezibwa. The system consisted of a three-stage cascading water tank arrangement to provide the required water treatment by way of filtration. The uppermost tank was an unroofed rapid sand filter, followed by a slow sand filter water tank in the middle and then a clear water storage tank at the lower end. All the tanks were constructed out of concrete blocks and cement-sand mortar in stretcher bond. The water flowed into all the tanks by the force of gravity. The clear water from the storage tank was then pumped for use to the surrounding villages through HDPE pipe network. However, not long after commissioning of the system, cracks began to appear on the tanks, and one of them (the rapid sand filter water tank) had to be reconstructed altogether. The cracks recently appeared again to such an extent that the water supply system had to be shut down both as a safety precaution and also to allow an investigation into the causes of the failure so that proper remedial engineering interventions could be administered. This paper presents the findings of a research effort that carried out a structural assessment of the water supply system so as to identify the causes of failure of the water tanks. Remedies are also suggested for stopping any further deterioration and putting the system back into safe use.

KEYWORDS: Cement content; compressive strength; concrete; cracks; destructive test; deterioration; diagnosis; inspection; masonry; mortar; reservoir; sand filter.

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33.
High-strength and fibre-reinforced concrete

Structural behavior of high strength reinforced concrete with steel fibers

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ABSTRACT: The test series reported here is part of a research program aimed at defining tools for static design of structural elements made of High Strength steel-Fiber Reinforced Concrete (HSFRC). Four-point bending tests have been carried out on 120-MPa (cube strength) beam specimens with a 3.5-m span and a 200×300-mm cross section in flexure, and 2.0-m span and 200×325-mm cross section in shear. The tests included examination of the minimal shear and longitudinal reinforcement with and without fibers and evaluation of the influence of "short" (35-mm) versus "long" (60-mm) hooked-end steel fibers. The experimental results are compared with various theoretical models with an aim to study and improve the ability to predict the structural behavior of HSFRC members.

KEYWORDS: Cracking, Ductility, Fiber-Reinforced-Concrete, High Strength Concrete, Steel Fibers, Toughness.

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The flexural toughness of high strength fiber reinforced concrete with styrene-butadiene latex

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ABSTRACT: Styrene-butadiene latex was used to produce a concrete matrix with a compressive strength ranging from 65 to 85 MPa; 28 groups of high strength concrete beam specimens were cast with different combinations of this latex and three fiber types: a deformed steel fiber, a high density polypropylene fiber (HPP) and an un-fibrillated fiber with blended polypropylene and polyethylene components. These specimens were tested in four-point bending, and results were analyzed following the JSCE-SF-4 procedure.

Fiber type, fiber volume fraction and latex content all had a strong influence on toughness characteristics. The mix with 10% latex and 1.0% of steel fibers showed optimum toughness, and its load-deflection curve exhibited strain hardening after the first cracking of the beam. An attempt was made to characterize the synergy between the fibers and the latex over a wider range of deflections. Synergistic effects were observed in almost all composites when the latex content was at the optimized dosage (10%), but steel fibers appeared to be more compatible than the synthetic fibers in the latex modified concrete in terms of both load-carrying capacity and toughness. Considering its other properties, such as excellent bonding properties and durability, it is concluded that this high performance composite could be a promising material for both structural and repair purposes.

KEYWORDS: Flexural toughness, polymer (latex), fiber-reinforced concrete (FRC), polymer-modified concrete/mortar (PMC/M), steel fibers, synthetic fibers.

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Behavior of normal and high strength concrete columns: Experiments and simulation

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ABSTRACT: This paper deals with an experimental investigation and numerical simulation of reinforced concrete columns. Normal and high strength columns were studied together with confinement effects of transversal reinforcement. Behavior of six series was investigated. Two different grades of concrete and three different stirrups' density were chosen. Columns were loaded in eccentric compression with small eccentricity. Special attention was paid to the character of a failure, ductility and post-peak behavior of columns. It was found the stirrups' density does not have a significant influence on strength parameters. It influences the post-peak behavior of columns. Ductility of columns increases as the distance between stirrups is smaller. Three-dimensional computational model based on the microplane model for concrete was constructed and compared with experimental data. Results of numerical model showed good agreement in the shape and size of the damage process zone, buckling of steel reinforcement, load capacity of the structure (peak values) and character of the post-peak behavior and proved capabilities of the used material model. The model gives less ductile response in the post-peak region and should be improved in the steel-concrete interaction.

KEYWORDS: Reinforced concrete, normal and high strength concrete, columns, experiments, finite element analysis, microplane model.

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Strength and ductility of wrapped HSC columns under eccentric loads

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ABSTRACT: With the technology development on the compressive strength of concrete over the years, the use of high strength concrete has proved most popular in terms of economy, superior strength, stiffness and durability due to many advantages it could offer. However, strength and ductility are inversely proportional. High strength concrete is a brittle material causing failure to be quite sudden and 'explosive' under loads. It is also known that true axial compression of structural concrete columns (axially compressed) rarely occurs in practice. The stress concentrations caused by the eccentric loading further reduce the strength and ductility of high strength concrete. This paper presents results of testing eccentrically loaded columns externally wrapped with different types of materials. The experimental results show that external reinforcement can enhance the properties of high strength concrete columns.

KEYWORDS: High strength concrete, FRP, reinforced concrete columns, eccentric loading.

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An adhesive cross-linkage model for textile glass fibre reinforcement in concrete

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ABSTRACT: For the crack bridging behaviour of textile glass fibre reinforcement an adhesive cross-linkage model is created which allows a very well description of the complex bond behaviour of textile glass fibre reinforcement and concrete. In this model all filaments are bond to each other by a pattern of adhesive crosslinkages consisting of binder particles, e.g. hydration products of cement. The adhesive cross-linkage model allows generally a numerical prediction of either the stress distribution in all filaments of a roving cross section as well as the typical successive cracking of single filaments due to increasing crack width.

For concrete reinforcement purposes only such glass types can be used which are alkali-resistant (AR) due to the high pH-value of solutions in the pores of cement stone. Very thin AR-glass fibres with diameters of about 10 to 15 µm, the filaments, are bundled to rovings consisting hundreds of filaments laying parallel to each other. In machines made for textile manufacturing the rovings are processed to meshes which can be embedded in concrete as reinforcement. This technology is not to mistake for the well known use of the short glass fibres for strengthening precast concrete units.

All textile glass fibre reinforcements contain rovings, which consist each of a large number of single filaments. That is the reason for a totally different bond- and fracture behaviour compared to monolithic cross sections of reinforcement as steel, especially in cases of crack bridging action of reinforcement. After cracking of concrete under tensile or bending load the reinforcement transfers load over the concrete crack. But over the cross section of a single crack bridging roving not all filaments can have identical stresses, because contrary to polymer-glass fibre technology the bond between filaments and cement stone is not homogeneous. It is determined by a large number of adhesive cross links, which can be shown using an Environmental Scanning Electron Microscope (ESEM).

An adhesive cross-linkage model is created which allows a very well description of the complex bond behaviour of textile glass fibre reinforcement and concrete. In this model all filaments are bond to each other by a pattern of adhesive cross-links consisting of binder particles, e.g. hydration products of cement. The adhesive cross-linkage model allows generally a numerical prediction of either the stress distribution in

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KEYWORDS: Textile AR-glass fibres, glass fibre reinforcement, bond of reinforcement, adhesive cross linkage model, crack bridging behaviour.

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Load bearing behaviour of fastenings in steel fibre reinforced concrete (SFRC)

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AB STRACT: Modern fastening systems are used in a wide range of construction industry. It is well known, that the load bearing capacity of the various fastening systems is essentially influenced by the mechanical properties of the anchorage ground. Because of the increasing quantum of the application of steel fibre reinforced concrete (SFRC) for structural purposes it is urgent necessary to have safe and durable fasteners which are suitable for usage in this building material.

The paper presents the investigations of the structural behaviour of various post-installed fastening systems in steel fibre reinforced concrete (SFRC) which were performed in Leipzig/Germany. Tests of expansion and undercut anchors, as well as bonded anchors in combination with 3 different anchorage grounds have been carried out. The used anchorage grounds were a normal concrete without fibres and two steel fibre reinforced concretes of similar strength in which different kinds of steel fibres were added.

The results for all tested anchors show that the structural behaviour of fastenings in non of the investigated concretes is better. However, the scattering of the load bearing capacity of the anchors installed in SFRC is even higher. This fact leads to a decrease of the design values of the resistance in the ultimate limit state.

KEYWORDS: Fastenings, steel fibre reinforced concrete.

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Pull-out problem of special fibers in concrete

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ABSTRACT: The pull-out problem has frequently been solved in a problem of cracking of composite structures of several sorts. Previously, several numerical studies were carried out by the first author using the FEM, and the BEM, and the results were compared with experimental results from available literature with a good agreement. In the papers from the available literature the topics have mainly been focused on experiments starting with low volume ratio of fibers, i.e., the results from the theoretical considerations were very appropriate in studies of fiber reinforced concrete (volume ratios of 1–2% at most). A remarkable feature in the works of Procházka & Šejnoha in 1995 and 1996 of the mathematical solution occurred: a cracking was initiated not only at the face of the fiber-matrix system, but also inside the trial body. As the previous problems were concentrated only on straight fibers and the nature of the material used was based on classical composites with epoxy matrices and a high bearing capacity and durability, a natural question arises: what happens when the matrix is created from concrete with nonlinear material behavior and the aggregate behave realistic, i.e., the shape of the fibers is no more straight. The answer to this question is the objective of this paper. Plenty of numerical experiments have been carried out, compared with own experiments and the accessible literature, but because of restricted extend only some show on how the theoretical considerations can be applied in reality. The examples differ by positioning the fibers and by volume fractions and again only short amount of samples will prevailingly show the contact behavior between fibers and matrix. Dramix-type fibers are used.

KEYWORDS: Pull-out problem, fiber reinforced concrete, finite element method, Uzawa’s algorithm, curvilinear fibers.

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Strength and deformation properties of high-strength concrete containing fly ash

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ABSTRACT: The influence of fly ash on the compressive strength and deformation properties of high-strength concrete with 28-day cube compressive strength in excess of 80 MPa has been investigated. Four concrete mixes were prepared with fly ash replacement levels of 0, 10, 20 and 30%. The same water/binder ratio and the same amount of superplasticiser were used for all concrete mixes.

The results showed that the inclusion of fly ash reduced the early age strength of HSC, but enhanced the later age strength. Early age autogenous shrinkage measured from the time of initial set was significantly reduced, while long-term autogenous shrinkage measured from the age of 24 hours was marginally increased. Thus, total autogenous shrinkage was reduced for the fly ash concretes. Total creep and basic creep loaded at constant stress/strength ratio from the age of 28 days were reduced. However, total shrinkage after 28 days of moist curing was very marginally increased for the fly ash concrete.

KEYWORDS: Fly ash, strength, deformation, high-strength concrete, autogenous shrinkage, total shrinkage, drying shrinkage, total creep, basic creep.

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Mutual effects of stress and corrosion mechanisms in glass fibre reinforcement

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ABSTRACT: From previous work we know the evidence of the influence of load and corrosion induced damage mechanisms. In concrete these effects depend of the existence of microcracks in material structure. Investigating glass fibre reinforcement we have to distinguish between corrosion of the size (surface coating), the glass body and the effects of new formed crystals of binder materials on the surface of the filaments which affect the stiffness. These effects are shown in an experimental work separately. Microcracks are of lower interest.

In modern textile machineries yarns consisting of fine glass fibres can be manufactured into reinforcement meshes for concrete. Mostly concretes as usual in steel bar reinforced concrete technology are needed. The pH-value in the pores of the cementitious binder than is unavoidably high. E-glass types as usable for reactive resin binders will be destroyed totally by alkali reaction under long term wet conditions in concrete. The glass fibre industry has developed alkali resistant (AR)-glass fibres by changing the glass composition.

Corrosion problems may be existent on long term alkali attack as well as bond problems concerning crack bridging behaviour of reinforcement which depend on the crack width and on the transferred load over the crack. Mutual effects of stress and corrosion mechanisms will occur. Test were carried out as flexural tests on tensile cracked reinforced concrete specimens where the reinforcement was crack bridging.

– The observed reduction of capability of crack bridging load transfer was not the result of AR-glass corrosion. The original diameter of filaments has not reduced during alkaline attack. The typical appearance of glass corrosion has not been found on AR-glass samples.
– The elevated constant alkalinity and temperature in interaction with permanent humidity lead to a relatively rapid decomposition of polymeric filament sizing. Consequently primary glass defects at the filament surface are re-uncovered. The load bearing capacity of the reinforcement decreases.

This process is superposed by growing shells of hydration products of portland cement on the surface of the filaments according to the duration of exposition. With an increase in thickness of shells the stiffness of filaments will be increased. This effect has no influence on the load bearing capacity as long as the load remains constant. In the case of a load increase the crack bridging load capacity or a yarn will be diminished.

KEYWORDS: Glass fibre reinforcement, textile AR-glass fibres, corrosion of glass fibres, crack bridging behaviour.

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34.
Analysis of concrete structures

Development of micro-meso-macro scale models for seismic analysis

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ABSTRACT: This paper describes part of the research work performed by the authors for the Co-ordinate Research Project promoted by the International Agency for the Atomic Energy (IAEA) and entitled “Safety Significance of Near Field Earthquakes”. The work focused on the structural modelling of one of the two reinforced concrete (R/C) shear walls tested for the CAMUS Benchmark (Combescure, 2002), with the aim of studying the wall at different levels of refinement: the micro-scale of finite element method (FE), the meso-scale of the fibre model and the macro-scale of the beam phenomenological model. In the following the procedures adopted and the results obtained with the micro- and meso-scale, FE and fibre model, will be described.

KEYWORDS: Numerical modelling, finite elements, fibre models, seismic design, structural safety.

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Effects of coupled shear walls openings on nonlinear behavior of RC building structures

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ABSTRACT: Despite the common acceptance of high stress concentration around the wall openings and their significant effects on the general system behavior, current building codes and design provisions comprise no specific or broadly described information concerning the detailing of coupled shear-walls openings and shear core systems. To address this deficiency, the load capacity and stress distribution around the wall openings were studied in representative 2D and 3D finite element models. Diaphragm flexibility, behavior of transverse walls and slab-wall interaction during 3D action were investigated. An effort was spent to illuminate the impacts and significance of different size and location of openings within the coupled shear-walls having variable reinforcement ratios. The analyses results showed that stress flow and crack patterns around the openings of 3D cases were drastically different than those computed for 2D cases. The tension-compression (T/C) coupling effects caused by the wall-to-wall and wall-to-slab interactions provided a significant contribution for increasing the global lateral resistance. Based on the obtained results, the amount and location of the main reinforcement needed around the openings of pierced shear walls were recommended.

Analysis of nonlinear response of RC subassemblages to static cyclic loads

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ABSTRACT: The objective of this study is to evaluate the effect of modeling of inelastic regions on the nonlinear cyclic response of reinforced concrete (RC) frames. The predictions of a previously developed spread plasticity (SP) model are compared with those of the widely used concentrated plasticity (CP) model. The two models are compared by investigating the local and global response of simple structural subassemblages under cyclic load reversals. It is concluded that the parameters of the CP model can be adjusted to match reasonably well a given response. These parameters vary, however, with the type and history of loading as well as with the type of subassemblage. By contrast, the SP model, while maintaining computational efficiency, is based on parameters which are directly connected with the physical properties of the structural elements and can be derived by well established rational methods. Moreover, it overcomes many of the limitations shown by the CP model.

KEYWORDS: RC frame, hysteretic behavior, nonlinear beam models, parametric studies.

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Analysis and assessment of seismic drift of concrete framed structures

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ABSTRACT: An analytical method is proposed to determine the sway of a totally framed building subject to seismic forces. The validity of the analytical method is tested on 3-D frame buildings of different heights. The sway results obtained by the analytical method and computer agree well. The implementation of the proposed analytical method to framed buildings in regions of high seismic risk is emphasized. The determination of which building is earthquake prone and should be strengthened can easily be done by the analytical method proposed.

KEYWORDS: Seismic drift, earthquake resistant, concrete framed structure.

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Experimental analysis of the biaxially bent slender RC columns subjected to long-term load

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ABSTRACT: This paper presents experimental results of ultimate capacity testing of slender RC columns, which were exposed to eccentric pressure using long-term load. The experiments were conducted at Civil Engineering laboratory of Civil Engineering faculty—Podgorica. They present a part of comprehensive research on slender RC columns. Two series of slender columns, in total 8 columns, using twin specimens were tested. After initial application of constant axial force, the columns were tested step by step using incremental load up to failure. At the same time at the Laboratory of Civil Engineering Faculty of Belgrade University, applying the sane thermal and dampness conditions, tests were conducted on long-term behavior of identical prism specimens. Based on the measured results it is possible to conclude reduction of ultimate capacity on long term-loaded columns, what is caused by the effects of II order theory initiated by the creep in concrete. These results can be useful for comparison with the results of other authors investigating or evaluating current regulation in this field, or for new design methods.

KEYWORDS: Slendernes ratio, columns, experiment, long-term load, creep of concrete, relative eccentricity, biaxial bending, ultimate capacity, pressure force.

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Nonlinear analysis of slender concrete frames

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ABSTRACT: The design of structures is increasingly determined by architectural, aesthetic and economic criteria leading to slender cross-sections of structural elements. This trend to more slender structures requires the development of adequate analysis software. Concerning concrete structures, an analysis software which can model the non-linear and time-dependent material behaviour of reinforced concrete and large deformations up to the ultimate limit state is desirable. Commercial standard software, however, is generally not yet able to comprehensively take into consideration all relevant effects. In particular, the phenomena of concrete cracking and long-term deformations due to creep and shrinkage cannot be properly modelled. To overcome these problems the authors have developed a new analysis method combining the transfer-matrix procedure and the finite-element method. This method does not require a choice of shape functions since the actual deformation functions of the beam element can be accurately approximated by using the transfer-matrix procedure. Numerical problems in search for the transition zone from the state of uncracked to cracked concrete, which arise in other procedures, do not occur here. Element sectional forces, element stiffnesses and nodal displacements are determined in an iterative process until equilibrium is obtained. Analysis of cross-sectional distortions and cross-sectional stiffnesses due to acting sectional forces is effected through an iterative cross-sectional integration at preselected intermediate locations, which are determined by the stiffness gradient along the element axis. The element tangent stiffness matrices are determined by variation of sectional forces and are subsequently assembled into the system stiffness matrix. The method presented here allows the use of arbitrary material laws including concrete cracking and time-dependent material behaviour as well as the considereation of large deformations and thus a close-to-realitiy analysis of slender reinforced concrete frames.

KEYWORDS: Transfer-matrix procedure, finite-element method, slender structures, frames, large deformations, concrete cracking, creep, shrinkage, cross-sectional integration.

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Peculiarities of relaxation processes in statically indeterminate structures

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ABSTRACT: The paper deals with experimental results carried out on statically indeterminate prestressed reinforced concrete members. The results of 4 series tests comprising 4 specimens in each series are analyzed. The relative initial stresses of concrete prestressing (by 0,25 to 0,64) and eccentricities of prestressing forces were different. Duration of specimens tests were in the limits from 141 to 248 days. Increase of initial prestressing and of prestressing force eccentricity, the processes of creep and relaxation become more intensive, though final relaxation of internal stresses is about negligible and is in limits from 0,4 to 0,5. Changes of internal forces are smaller in comparison with statically determinate systems. For evaluation of this difference is offered the formula.

KEYWORDS: Prestressed, reinforced, concrete, relaxation, indeterminate structure.

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Durability evaluation of concrete structures based on multi-neural networks

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ABSTRACT: Concrete structures durability evaluation based on multi-neural networks is introduced in this paper. According to various influencing degrees, the influencing factors are divided into several hierarchies and each hierarchy includes several sub neural networks. Through decomposition of the multi-neural network, each sub neural network contains input variables as few as possible. The scale of networks decreases greatly through the stepwise decomposition and the problem of training neural networks with the increase of input variables is solved. In the meantime, the application of neural networks scale is expanded to solve the large complicated problems with multi-input variables.

KEYWORDS: Concrete structures, multi-neural networks, durability evaluation

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Shear response of panels subjected to in-plane stresses

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ABSTRACT: This research work is directed to study the shear response of panels reinforced in one direction (unidirectional steel RC membranes) subjected to in plane stresses and to predict their shear strengths. The study represents a basis for a new layer approach to estimate the behavior of panels reinforced in two directions by treating each panel as two bonded layers of panels reinforced in one direction. The paper derives new relations using the equilibrium equations and the compatibility conditions. The principles of smeared stresses, smeared strains and the tension stiffening as well as the softening of concrete strength are introduced to the derived equations. A flow chart that summarizes the steps needed to estimate the shear response is appended in the study. The approach is verified by predicting the shear strength of twenty one unidirectional RC panels of different concrete grades and containing different percentages of steel reinforcement. The ratios of the predicted shear to the experimental values of the current study are compared with the more complicated methods such as the modified compression field theory (MCFT) and the disturbed stress field model (DSFM). The comparisons showed comparable results with the more complicated methods. Also, the responses of panels subjected to pure shear and shear combined with tensile stresses were predicted and compared with the experimental values. The predicted responses and the estimated panel strengths showed good agreement with the corresponding experimental values.

KEYWORDS: Shear strength, membrane structures, shear response, in-plane stresses, softening of concrete, tension stiffening parameter.

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35.
Design of concrete structures

On the ductility of reinforced concrete slabs containing low ductility reinforcing steels

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ABSTRACT: Welded wire fabric (WWF) is commonly used in reinforced concrete slabs. In Australia, such steel is classified as Class L—low ductility (AS/NZS4671–2001). Typically, the strain at peak stress (termed the uniform elongation) is less than 0.03 and the ratio of tensile strength to yield stress (0.2% proof stress) is in the range 1.03 to 1.10. The relatively low deformation capacity of WWF has very significant implications in the analysis and design of slabs, particularly with regard to ductility. A reinforced concrete slab containing low ductility steel usually fails by fracture of the tensile reinforcement at the critical section, well before the concrete in the compression zone becomes overstressed, and the conventional understanding of ductile under-reinforced flexural failure is not valid. The failure is brittle and quite catastrophic, often with little or no warning.

For lightly reinforced indeterminate slabs containing WWF, the amount of moment redistribution that can take place at the ultimate limit state may be very small and plastic design techniques may no longer apply. Indeed, even elastic analysis techniques may not be applicable at the ultimate limit states. Concrete structures are non-linear and in-elastic, and must possess some ductility if the actual distribution of internal actions is to redistribute towards the elastic distribution. This minimum ductility may not be available for members reinforced with low-ductility WWF. These problem are not unique to Australia, with low ductility reinforcements now being promoted in Europe and elsewhere.

This paper presents experimental results of tests on several simply-supported and continuous one-way slabs, reinforced with WWF. In all cases, flexural failure was initiated by fracture of the tensile reinforcement, resulting in sudden collapse. The great significance of strain localization in lightly reinforced slabs and its adverse impact on the ductility of slabs containing WWF is also explored.

KEYWORDS: Ductility, ductility class, fracture, reinforced concrete, reinforcement, rotation, slabs, strain localization, strength, ultimate limit state, under-reinforced, welded wire fabric.

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The effect of transverse reinforcement of RC T-shaped structural walls

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ABSTRACT: The performance of RC structural walls with symmetrical cross sections like rectangular or barbell type of walls has been studied extensively and well established. In general, these kinds of symmetrical walls with ordinary reinforcement ratios, low axial loads, and low shear stresses, can withstand a moderate level of inelastic flexural deformation without special details for concrete confinement. However, Structural behaviors of irregular typed shear walls with unsymmetrical cross sections (T, L and C-shaped) are considerably different from those of symmetrical walls. In an irregular wall, because of unsymmetrical cross sections, range of confinement must be determined according to the distribution of strain in the section. When compression loads are imposed to web of T-shaped wall, stresses are concentrated on the bottom of the web. So constraint regions of transverse reinforcement of web are larger than those of rectangular wall. When the flanges are compressed, effects of lateral reinforcements of flange are relatively low. Therefore, in this study, experimental researches were performed to evaluate the effect of transverse reinforcement of RC T-shaped structural walls. For this purpose, four RC T-shaped wall specimens with different confining area and reinforcement spacing were tested. Based on the test results, sectional analysis and FEM analysis were performed according to the types of transverse reinforcements.

KEYWORDS: Performance, unsymmetrical cross sections, transverse reinforcement, confinement, RC T-shaped structural walls, ductility.

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Crack width predictions of high strength reinforced concrete beams

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ABSTRACT: High strength concrete (HSC) has revolutionised the construction industry in the 1980's and Australian researchers, consultants and contractors have been very active in this area. However, most major codes for design and construction with concrete are applicable only to normal strength concrete $(f'_c < 50\,\mathrm{MPa})$ and are based on research on normal strength concrete (NSC).

It is generally observed that under service load, a reinforced concrete flexural member cracks in the tensile zone of the concrete. While hairline cracks are considered inevitable, cracks of appreciable width are undesirable because of the long-term detrimental effects. Furthermore, cracks, which are visible, may affect the aesthetics and be a cause for concern to the lay person. Researchers have concluded that the problem of cracking is more pronounced for high strength concrete (HSC) structures because of their relative brittleness compared to normal strength concrete (NSC). Four full-size high strength reinforced concrete simply supported beams were tested to failure to investigate the cracking characteristics of HSC beams. This paper presents the cracking test results of these HSC beams. A comparison has also been made with the authors' earlier developed formulas for predicting crack widths of NSC beams. It is found that the formulas for NSC beams are reasonably applicable to HSC ones. The initial findings are very encouraging.

KEYWORDS: High strength concrete, normal strength concrete, crack width, crack spacing, simply supported beam, cracking characteristic.

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A systematic approach to the evaluation of errors in predicted deflections of reinforced concrete structures

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ABSTRACT: A systematic approach was developed to tackle evaluate systematic errors in serviceability calculations. The proposed approach is based on determining a band of errors in deflection calculations based on a priori known levels of variation of all the parameters affecting deflection calculation. The approach utilizes principles of the theory of error propagation.

Joint contribution to the deformation of RC beam-column sub-assemblies

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ABSTRACT: Most finite element (FE) analysis tools used for seismic analysis represent reinforced concrete (RC) building frames with beam and column elements that are interconnected to a common node at joint locations. This idealization is based on the assumption that the joint is perfectly rigid, and hence does not account for the distortion of the joint panel. As is well known, the overall deformation of a beam-column sub-assembly comes from the deformations of beam and column and the shear deformation of the joint panel. Provisions in current seismic design codes aim to ensure that joint cores in RC building frames have sufficient amount of properly detailed shear reinforcement. Quasi-static tests on such ductile beam-column joints have shown that the contribution of joint panel deformation to overall response is usually less than 20%. Although neglecting shear deformation of the joint panels in frames that are properly designed to meet seismic demands may be acceptable for engineering purpose, there are cases where the joint deformation cannot be overlooked. For example, buildings designed according to seismic design codes that prevailed a few years ago may not satisfy the stricter requirements of the current seismic design codes. Due to sub-standard reinforcement detailing, joints in such building frames are not as rigid as they were designed to be. In moderate to low-seismicity regions, the design of RC frames does not follow seismic code recommendations, and joints in such building frames may also undergo excessive shear deformation when subjected to lateral loading. In this paper, rigidity of joint panels is investigated through cyclic tests of lightly reinforced beam-column sub-assemblies. The tests showed that excessive damage in the joint panel leads to the ultimate failure of such lightly reinforced beam-column sub-assemblies, and joint shear deformation accounts for more than 40% of the overall storey-drift.

KEYWORDS: Lightly reinforced, beam-column sub-assembly, cyclic test, storey-drift, joint panel, shear deformation.

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Durability of reinforced concrete structures

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ABSTRACT: In the last century the durability of concrete structures was guaranteed by the concrete itself. Later this situation progressively changed. Using the new design theories, the new construction methods, the new prestressing technologies, the concrete structures become more and more slender. The influence of the corrosive environmental effects became more and more intensive.

The resistance of concrete structures against corrosion can be significantly increased by using high strength-high performance (HSC/HPC) concrete. The composition of mixtures for strength classes between C40/50 and C80/90, the technology of the manufacturing process as well as the condition of the application of HSC/HPC concrete have been determined and tested on prestressed concrete beams in laboratory conditions at the Budapest University of Technology and Economics, Dept. of Structural Engineering. The conclusions of the work carried out can be summarized as follows:

- The main reason for the durability problems of concrete structures is the insufficient density and impermeability of the concrete mix.
- The increase of the density has to be solved by concrete technological means. It results
  - in one hand in higher concrete strength and as a consequence, in static advantages,
  - on the other hand in lower amount of source material. Therefore the HSC/HPC can also be taken as environmentally compatible building material.
- Based on the results of research works carried out in this field, there is a good chance that the structures made from HSC/HPC can satisfy the durability requirements necessary even for bridges as well as the load bearing capacity and the serviceability requirements according to the EC-2.
- The application of HSC/HPC on industrial scales in Hungary absolutely needs the modernisation of all the participants taking part in this field of civil engineering. However, using the HSC/HPC, the competitiveness of concrete structures can be increased against the structures made from other materials.

KEYWORDS: Durability, high strength concrete, high performance concrete, corrosion, concrete mixture, strength, frost-resistance, watertightness, design.

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Effect of confined concrete stress-strain model on the moment-curvature relationships of reinforced concrete members

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ABSTRACT: Cross-sectional moment-curvature analysis is one of the essential steps for inelastic analysis of reinforced concrete (rc) structures. Consequently, the precise prediction of the moment-curvature behavior of the critical cross-sections of reinforced concrete members is necessary for a reliable inelastic analysis. The precision of the cross-sectional moment-curvature analysis depends on the accuracy of the stress-strain models adopted for confined concrete and steel reinforcing bars. In this study, analytical moment-curvature relationships are obtained for reinforced concrete members that were tested under the combined effects of constant axial load and reversed cyclic lateral loads. During determination of the moment-curvature relationships by using fiber element approach, two different axial stress-axial strain relationships were taken into account for confined concrete. The comparisons of the analytical results with the moment-curvature data obtained from different experimental studies showed that the moment-curvature relationships of the reinforced concrete members can be predicted with a satisfactory accuracy by using a relatively simpler trilinear model than the existing complicated stress-strain models proposed for confined concrete. The considered experimental programs for comparison include varying concrete compressive strengths, cross-sectional dimensions, longitudinal and transverse reinforcing bars and axial load levels.

KEYWORDS: Confined concrete, stress-strain curves, curvature, concrete, ductility.

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Experimental air and aerosol permeability of undamaged reinforced concrete shear walls

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ABSTRACT: A major concern associated with the location of radioactive materials usage sites and storage facilities in seismically-active regions is the maintenance of effective containment of radioactive materials during and following seismic events. The most likely means of egress for these contaminants is via cracks in containment walls resulting from seismic deformations. This report describes the results of a preliminary study conducted jointly between the University of California, Irvine and the Los Alamos National Laboratory in which the air and aerosol permeability of an undamaged reinforced-concrete shear wall were evaluated.

A flanged shear wall test specimen was fabricated with vertical and horizontal reinforcing patterns modeled after a radioactive materials research and storage facility in the United States. Air permeability measurements were conducted by pressurization of one side of the shear wall structure above atmospheric pressure and permitting transient decay of pressure across the shear wall to atmospheric pressure. Further, these results were confirmed using steady-state flow from the pressurized upstream side to the atmospheric downstream side. Aerosol permeability was measured using steady-state flow from a pressurized aerosol challenge volume on the upstream side of the shear wall to a near-atmospheric aerosol penetration volume on the downstream side.

Results from this test program agreed well with the results of a similar program for air permeability conducted at LANL for undamaged state, and also with findings in the extant literature. Intrinsic permeability values of between 3.4×10^{-11} mm^2 and 5.2×10^{-11} mm^2 were obtained through both pressure decay and steady-state flow methods. Aerosol filtration efficiency of the undamaged sample was observed to be in the range of between 99.9 percent and 100 percent over the size range of the aerosol (0.065 micron to 1.0 micron). Details of the testing program, a discussion of results, and plans for future work are presented.

KEYWORDS: Reinforced concrete shear wall, gas permeability, aerosol filtration, seismic resistance.

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Reinforced concrete beam capacity for biaxial bending

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ABSTRACT: This paper describes the application of the true parabolic stress method of analysis for predicting the ultimate strength capacity of reinforced concrete beam for biaxial bending. It is different from the current so-called parabolic-rectangular stress block method of analysis in that it utilizes the true parabola, which approximates the stress/strain diagram of the compressive properties of the concrete material. It also utilizes the concept of beam capacity axis (line perpendicular to the moment axis at center of beam) where the concrete and bar forces are referred to in the analysis. The axis to use for predicting the ultimate strength capacity is the line coincident with the diagonal of the rectangular section. The methodology of the true parabolic stress method is a rational method for determining the concrete forces developed in a section. It utilizes the strength of material approach and basic calculus in solving for the stress volumes, which represent the ultimate concrete capacity of the rectangular beam section. The bar forces are determined with respect to the beam capacity axis and added to the concrete forces to obtain the ultimate strength capacity of the reinforced concrete beam. The ultimate strength capacity of a rectangular beam for uniaxial bending has already been presented in ISEC-01 and SEMC 2001 international conferences. Derived formulas for biaxial bending are shown with numerical examples, which can be compared with results using derived formulas for uniaxial bending published in the ISEC-01 and SEMC 2001 proceedings. The results from these examples indicate that the capacity of a reinforced concrete rectangular beam is reduced when subjected to biaxial bending.

KEYWORDS: Analytical method in beams, beam capacity axis for biaxial bending, concrete force, parabolic stress method, reinforced concrete beams, steel bar force, steel yield strength, ultimate concrete strength, ultimate strength of beams.

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ACI minimum thickness provisions and estimated deflections for two-way edge-supported reinforced concrete slabs

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ABSTRACT: In limit states design, members are so proportioned that will have adequate strength against failure and at the same time must posses sufficient stiffness to ensure serviceability. ACI Code provides minimum thickness for two-way edge-supported slabs so that the deflections are not excessive. It also allows thinner slabs if calculated deflections are found tolerable. The method given in ACI Code for deflection estimation is relatively straightforward in compare to other codes. It uses Branson's equation to take into account cracking for shortterm deflection calculation. As for long-term deflection, a simplified multiplier approach is proposed in the Code. These calculation approaches, suitably incorporated in a finite element package, were used in this study to estimate incremental and total long-term deflections of two-way edge-supported slabs having ACI thicknesses. The prospects of using thinner slabs were also studied. Geometric, material and loading parameters were varied in the usual range to identify their effects on deflection and to study the adequacy of ACI Code thickness under different situations.

KEYWORDS: Concrete slab, deflection, serviceability.

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Durability and reliability of prestressed concrete structures, under long-term loads

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ABSTRACT: Many previous theoretical and experimental studies have shown that the use of Prestressed concrete for the precast pre-tensioned beams, slabs and columns is effective to improve the stiffness of the structural material, predicting the eventual progressive cracking characteristics of the structural members. Design formulas for stress-strain limit states of the structures have been previously proposed based on these said experiments. However, little evaluations of time effects provided by the stretching of high strength steel tendons, and by the long-term static, quasi-static and quasi-dynamic loading of the structural members have been conducted. But few original research works concerning the long-term deflections due to creep, shrinkage and fatigue in the above said structural elements, predicting the above said negative factors have been really conducted in these last years of theoretical and experimental conditions of modern technology and equipment. The main research objective in this present paper relates to reinforced, precast and prestressed concrete beams, slabs and columns of I and II categories of resistance to cracking. These structural elements should be investigated not only as the most often used prefabricated structural elements, but also like the most convenient models for theoretical and experimental studies, which can permit to widely and reliably reveal the positive effects and generalize them to more complicated type of structural elements. This analytical procedure should be aimed to predict the quality, stiffness, strength, reliability, durability, fatigue, life safety and stability of the structural concrete members at the planning phase. The extended interests include the study of the influence of the material non-linearity, fatigue, creep, integrity and the progressive cracking characteristics under long-term static, quasi-static and quasi-dynamic loads. The need to validate the theoretical results has required detailed planned of series of full-scale controlled experiments.

KEYWORDS: Reinforced, precast, prestressed, quality, stiffness, strength, reliability, durability, fatigue, stability.

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Experimental study of splices in reinforced concrete slab joists with lattice truss reinforcement

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ABSTRACT: Precast reinforced concrete slabs have greatly being used in civil engineering construction in Brazil mainly due to economic reasons, slab weight reduction, lighter construction processes, less use of props and formwork and construction speed. In a local survey conducted with engineers and construction personnel, it was verified that a procedure to facilitate vertical precast joist transport during the erection stage was needed. This could be obtained by verifying the possibility of executing splices in precast joists with lattice truss reinforcement, since the use of smaller pieces could facilitate transport, minimizing the use of heavy construction equipment and increasing construction safety. Erection procedures have become increasingly more difficult when executing slabs with longer spans.

An experimental program was set up to study the behavior of precast slabs strips with “T” shaped section, constituted of lattice truss joist lapped splices, and to evaluate the use of the spliced joist device. Ten 10 specimens were tested: 05 specimens were 3,15 m long and the other 5 specimens were 6,30 m long. Some of the splices tested did not work and rupture occurred very early.

If we don’t consider the limitation caused by a fragile failure, splices in joist with lattice reinforcement are possible to accomplished as shown in one of the specimens studied. With the conducted experimental study it was verified that the proposed spliced lattice truss device was effective and can be accomplish during the production stage.

KEYWORDS: Slab joists, splices, reinforced concrete, experimental analysis.

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The theory of the symmetrical-reinforced and the over (under)-reinforced concrete section

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ABSTRACT: Despite the common development of the RC section theory, some of its parts need additional and more fundamental investigation. This regards, first of all, to some peculiarities of the section reinforcement (symmetrical reinforcing, over (under)-reinforcing, etc.). The common problem in calculation of these sections is additional unknown stress in the forces' equation (the tensile reinforcement stress in the over-reinforced section, the compressive concrete stress in the under-reinforced and symmetrical-reinforced sections). Another problem, which should be taken into consideration, is determining the tension reinforcement plastic strains for the symmetrical-reinforced and under-reinforced concrete section. This paper deals with a technique for application of the strain energy equation in order to calculate the unknown plastic strains in the tensile reinforcement. To the best of our knowledge this technique was not introduced before. The major symbols used in this paper correspond to the RC structural codes. The results of this study lead to farther development of the RC elements' theory and can be used for RC structures design code.

KEYWORDS: Concrete section, symmetrical reinforcing, over (under)-reinforced section, bending element, large-essentric compression element, ductility.

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Rectangular footing with bi-axial bending and tension on part of its area

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ABSTRACT: This paper illustrates the analytical method of determining the area of tension on a part of a rectangular footing subjected to bi-axial bending. This type of problem occurs when an existing rectangular footing is subjected to bi-axial bending resulting in a negative value of pressure in one or more corners of the footing foundation. The analysis uses the concept of planar distribution of pressures under the footing due to vertical loads and utilizes the concept of bearing capacity axis (line perpendicular to moment axis at center of footing). This concept of capacity axis was first employed in the analysis for ultimate strength of reinforced concrete rectangular column presented in ISEC-01 international conference in structural engineering and construction held in Honolulu, Hawaii January 24–26, 2001. The axis to use in the analysis is coincident with the diagonal of the rectangular footing since the development of maximum allowable bearing pressure due to bi-axial bending occurs at a corner as a result of the application of these vertical loads. The dimensions of the footing and the maximum allowable bearing pressure under it are given conditions in a particular rectangular footing such as for instance under a bridge pier foundation. Applying basic mathematics and equilibrium conditions of vertical loads and resisting forces under the rectangular footing will result in bi-quadratic equation of the compressive depth, "c", of footing. This quadratic equation with "c" as a variable is solvable by standard mathematical formulas or by Newton's method of approximation. The analytical method is presented in its entirety and derived equations can easily be programmed in a computer for faster calculations. A numerical example is shown to illustrate the application of the method and maybe used by the reader to compare with results obtained using current finite-element and approximate methods.

KEYWORDS: Analytical method in footing analysis for bearing capacity, area of tension in footing foundation with bi-axial bending, calculation of bearing capacity in rectangular footing foundation, minimum area of a rectangular footing to resist bi-axial bending when one corner has zero stress, rectangular footing with tension on part of its area.

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36.
Repair & strengthening of concrete structures & FRP applications

Design of FRP confinement for square concrete columns

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ABSTRACT: Many of the existing structures built according to obsolete codes may not have sufficient ability to resist major earthquakes expected in their areas. A major deficiency of these structures has been the inadequate amount of confinement reinforcement in the plastic hinge regions of the columns. To provide additional confinement to these deficient columns, fiber-reinforced polymers (FRP) jacketing provides an attractive solution. In this paper, a procedure for the design of confining FRP in square concrete columns is presented. The procedure is patterned on the philosophy of an available design approach for steel-confined columns and is based on the experimental results of FRP-confined columns. In this procedure, the required amount of confining FRP is a function of the column ductility performance and the level of axial load. The required FRP content increases with an increase in ductility increment demand and an increase in the level of axial load applied.

KEYWORDS: Columns, concrete, confinement, design, ductility, earthquake, energy dissipation, fiberreinforced polymers (FRP), retrofitting.

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Reliability of strain compatibility-based model for estimating flexure strength of CFRP-retrofitted girders

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ABSTRACT: The use of Advanced Composite Materials in strengthening reinforced concrete bridge girders has gained a lot of ground in the past few years. In this paper, flexure strengthening of precast bridge girders using Carbon Fibre Reinforced Polymers (CFRP) strips/sheets has been presented. The experimental investigation was performed on full-scale girders from a dismantled bridge in Alberta (Canada). The mathematical models currently used to predict the flexural strength of FRP retrofitted girders are adopted for the retrofitted girders. Results of the experimental investigation were found to be in contradiction with the currently used mathematical model results. This discrepancy is outlined and explained using a simple strut and tie model. Further investigation on the failure modes of CFRP retrofitted girders is presented by testing smaller size beams with sofit-bonded CFRP strips. Outcomes of the present study lead to the conclusion that the reliability of the currently available mathematical models used to estimate the flexural capacity of reinforced concrete girders retrofitted with bonded CFRP strips is seriously open to question.

KEYWORDS: Bridges, Carbon Fibre Reinforced Polymers, flexure strengthening, precast girders, rehabilitation.

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FRP reinforcement in bridge deck slabs for transverse negative moments

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ABSTRACT: In concrete deck slabs of girder bridges, transverse negative moments induced by loads on the cantilever overhangs of the slab are not catered for by the arching action. Accordingly, these moments should be provided for by tensile reinforcement. In corrosive environments, the deck slab can be made virtually maintenance-free by using reinforcement made of fibre reinforced polymer (FRP). Since FRP bars are considerably more expensive than the conventional steel bars, there is a need to optimize the use of the former. The authors, and their research colleagues, have developed two computer programs: (a) to analyze transverse negative moments in bridge deck slabs due to various design vehicles, and (b) to design FRP reinforcements for these moments. The former program was used to determine the governing transverse negative moment intensities due to the loads specified in the Canadian Highway Bridge Design Code in many slabs, covering nearly the entire practical range. The second program was used to design the corresponding optimum FRP reinforcement. The purpose of this paper is to present the results of the study with the hope that bridge designers will find them useful in making decisions about the use of FRP in bridge deck slabs for transverse negative moments. This paper is a compendium to another paper, which deals with the use of FRP to harness the arching action in the deck slab.

KEYWORDS: Arching, bridge, cantilever slab, CFRP, crack control, deck slab, FRP, GFR, transverse negative moment.

Comparison of the flexural perfomance between two different strategies for strengthening a RC beams by means of CFRP: The experimental investigation

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ABSTRACT: For many years the reinforced concrete structures had been considered as untoucheable structures. On the contrary, many r.c. buildings have shown signs of degradation that required their retrofitting or strenghetening. The strengthening done by composite materials represents the most innovative aspect among this type of operations and it seems to be very suitable also in the case of structures undergoing flexural actions thanks to its ability of giving the investigated structural members an increment of resistance and ductility as well as a better fatigue response and durability. In this study we treat a new methodology for reinforcing a damaged beam by increasing enormously its bearing capacity. The proposed technology differs from the previous since it aims to greatly increase the internal couple of the transversal section by inserting a new composite joist of polyurethane joined at the intrados of the original beam and connected at the extremities to two blocks made by reoplastic mortar. The block of reoplastic mortar are performed in order to improve the characteristics of stiffness of the node of the beam-columns of framework. This solution seems to be very useful in the case of a change of the use destination of a civil structure and also any time an increase of the resistant section is required.

That was already the object of a previous study where its performance was compared only to a control group of beams characterized by the absence of any strengthening. Here the proposed method of reinforcement is, instead, compared to a series of RC members with externally bonded CFRP applied directly at the intrados of the beam.

The paper reports the results obtained from an experimental investigation carried out on both structural beam members scaled 1:2 in size. Nine identical specimens of beams prepared for this study were divided into three different series consisting in three beams (one group) each. The first series was employed as control group without CFRP reinforcement, a second and third series were strengthened either with CFRP directly applied at the tension side of the concrete and applied to a new polyuretan mass inserted always at the tension side of the beam.

The tests show that by applying the proposed technique the variation of the height of the transversal section produces an increment of the collapse stress either three times greater in respect to the beam group of control or twice in respect to the traditional CFRP reinforced beams. This is due to the variation of the internal couple which produces a lowering of the neutral axis because a great region undergoes to compressive strength.

Besides, both the collapse deformation and the energy strain is higher in the case of the proposed technique of reinforcement.

KEYWORDS: Structural damage, CFRP, retrofitting, innovative repairing.

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Displacement determination of composite plate reinforced concrete blocks using electronic speckle pattern interferometry

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ABSTRACT: In this investigation a whole field method known as electronic speckle pattern interferometry (ESPI) is used to study the displacement distribution of strengthened concrete blocks. Concrete blocks of various lengths are strengthened with carbon fiber reinforced polymers (CFRP) composite plates which is loaded in axial tension. In-plane displacement for different anchor lengths of CFRP is studied in real-time and experimental results for a range of strengthened concrete blocks are presented.

KEYWORDS: Composite plate, concrete, laser interferometry, in-plane displacement.

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Additional strengthening of concrete structures with contemporary nano-materials

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ABSTRACT: Methods of external strengthening of concrete make use of elements of very high tensional strength glued on tensioned surface of it. These elements may be of metal, carbon fibers (CFRP), glass fibers (GFRP) or others, being ordinarily of very good mechanical properties. Presentation of several short-term experiments as so as long-term experiments executed either in past or just now being in motion are briefly descript. Short of history is also included. Some elementary knowledge about this know-how is described here with brief categorization of used materials. But these high strength elements are attached to concrete most frequently by epoxy resins. However, epoxy resins are of low Young's modulus and therefore a higher rate of creep may have influence on long-term behavior of such external strengthening. In order to verify this idea experimentally a special space saving arrangement of tests is put on in part of this paper. General reference to existing practical realizations is added, too.

KEYWORDS: Carbon fiber (CFRP) and glass fiber (GFRP) reinforced materials, external concrete strengthening, epoxy-resins creep, long-term test arrangement.

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Stresses and strains due to differential shrinkage in repaired concrete elements

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ABSTRACT: The generation of stresses associated with differential shrinkage between concrete overlay and existing base concrete has long been recognized as the main problem for the durability of repaired concrete structures. The free shrinkage strain of most concrete repair materials is far higher than the tensile strain capacity. The interface between substrate and repair material acts as an external restraint to differential shrinkage, which causes the development of stresses in the repaired member. Extensive tests on composite concrete-to-concrete specimens were carried out and the development of actual shrinkage strains was examined. The test results indicate that shrinkage strain develops along the whole interface in similar magnitude with a high peak value at the end of the beam. The paper reports on measurements of differential shrinkage between substrate and overlay on composite beams and gives a critical review of existing analytical models.

KEYWORDS: Concrete repair, differential shrinkage, composite concrete beams, restrained shrinkage stress, interface stress, concrete overlay cracking, shrinkage strain.

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Numerical modelling of mechanical interaction of lugged FRP rods with concrete

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ABSTRACT: The need for infrastructure renewal and the potential advantage of composite material has led to increased interest in applying these materials in civil engineering structures. Among them, the FRP lugged rods are of great importance from the point of view of structural application. It is mainly due to considerable bond resistance it has in comparison with similar smooth rods, especially because they are famous for their capability to eliminate corrosion and increase the durability of in-cast concrete structures. The article includes a brief introduction of FRP material and its mechanical properties applied in the FE research in discussion. An overall overview of previous researches on bond behaviour is presented. Note that the authors research basis is in fact a numerical simulation of a tentative test carried out by other researchers. A lugged rod with surface deformation is modelled in concrete of 40 MPa compressive strength. Details of finite element modelling is explained. Mechanical behaviour of lug in pull-out is investigated by means of finite element. Evaluation of the shear strength of lugs and the lug mechanical behaviour in pull-out is investigated by means of finite element method in comparison with experiment. Further suppliers of bond resistance after occurence of different types of local failure such as: “concrete splitting” and “rib shear-cut off” are introduced and the latter is verified numerically. Typical graphs indicating a comparison between numerical and experimental investigation are shown and verified.

KEYWORDS: FRP, bond, mechanical interaction, lug, concrete, pull-out, finite element, numerical.

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Inelastic behavior of RC jacketed damaged concrete sections under reversed cyclic flexure

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ABSTRACT: It is well known that many existing structures in seismic areas of the world were not constructed considering the recent codes and the up-to-date construction methodologies. The seismic resistance of such structures may be further reduced due to aging, lack of durability of materials and environmental effects. The structural members of this type of structures may experience damages in different extents during earthquakes. Consequently, research on repair and retrofit of these type of structural members is vitally important to be able to choose the most appropriate and economical repair and retrofit technique and to develop and/or improve the design methods. In this study, the behavior of the priorly damaged reinforced concrete members after retrofitting with different types of reinforced concrete (rc) jackets is investigated. For this purpose, nine original reinforced concrete specimens were tested under the combined effect of constant axial load and reversed cyclic flexure until around the displacement ductility ratios of 4~5. During this first stage of the test, the specimens experienced large inelastic deformations and were significantly damaged. Then these specimens were retrofitted by rc jacketing following a repair process. After repairing, the specimens were retrofitted with rc jackets either on one, two or four sides of the specimens. Although generally in practice, columns are jacketed on four sides, sometimes due to boundary conditions all sides cannot be jacketed. After the retrofit work, the specimens were once more subjected to the same loading pattern as the original specimens. It was observed that the specimens, which were jacketed either on two or four sides performed very well. However, one specimen, which was retrofitted on one side, could not exhibit a satisfactory performance. The moment-curvature relationships of the critical sections of the original and retrofitted specimens were predicted by an analytical procedure. It was seen that the predicted moment-curvature relationships were in satisfactory agreement with the experimental moment-curvature relationships.

KEYWORDS: Retrofit, reinforced concrete, jacketing, ductility, strength.

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Optimizing FRP reinforcement in bridge deck slabs

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ABSTRACT: The Canadian and American empirical methods of design for deck slabs of girder bridges take account of the arching action in the slab, and require that the slab be provided with two orthogonal meshes of steel bars. Recent experimental investigation has shown that only the transverse bars in the bottom mesh confine the slab in the transverse direction. The rest of the reinforcement in the two meshes only controls widths of fatigue-induced cracks. The bottom transverse bars in the slab serve the same function as the steel straps in steel-free deck slabs. An analytical method is presented in the paper for designing the transverse confinement of the deck slab; this method, proposing to replace the existing empirical method, can be used for designing both the external straps and the embedded bottom transverse bars, made of steel or FRP. An experimental fatigue study on full-scale models of deck slab showed that slabs with steel bars have the poorest fatigue resistance, and slabs with GFRP bars the best. The paper provides guidance for designing GFRP crack control grids. It is argued that external steel straps provide the transverse confinement most economically.

KEYWORDS: Arching, bridge, confinement, CFRP, crack control, deck slab, fatigue, FRP, GFRP, steel strap.

Repair of buckled steel pipes using FRP sleeves

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ABSTRACT: When a pipe is buried in permafrost terrain in Canada north, it interacts with the surrounding soil through frost heave, slope movement, and thaw settlement. These can cause the pipe to deform plastically and a wrinkle can appear in the pipe wall. This paper presents an innovative method of repair for a locally buckled pipe using fibre reinforced polymer (FRP) composite sleeves. Full-scale tests with different repair techniques were conducted on the FRP repaired specimens under combined axial loads, internal pressure, and bending moment. The test results, both qualitative and quantitative, are presented in this paper. The finite element method was used to model the test specimens. The analytical results were then used to compare to the test results to determine the validity of the model. The test results show that well-designed FRP sleeve repair system can significantly improve the moment-curvature behaviour of the wrinkled pipes.

A study of FC girder bridges using non-destructive methods

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ABSTRACT: Almost two hundred precast prestressed FC girder bridges were built in the province of Alberta over a twenty year period from 1960 to 1980. Many of these bridges have required rehabilitation due to the deterioration and failure of the field grouted longitudinal shear keys between the girders. This research program was designed to investigate and better understand the behaviour of FC girder bridges. An extensive field survey was conducted to review the current condition of these bridges which was followed by the field testing and assessment of five FC girder bridges to observe load sharing concerns. A three dimensional finite element model was then developed and calibrated with results from the field tests. With the help of the model, this paper will present the effects of using different rehabilitation schemes on FC girder bridges and indicate the best solution for the shear key cracking problem.

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