Proceedings Index

EM
2002

15th ASCE Engineering Mechanics Division Conference
Columbia University in the City of New York
June 2-5th , 2002

Author Index

Program at a Glance

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Program at a Glance
(All conference sessions take place in Lerner Hall)

Monday, June 3rd, 2002

7:30-8:30 am	Breakfast & Registration
8:30-9:00am	Welcome & Opening Remarks
9:00-10:00	Keynote Lecture - Earl Dowell (Duke University)
10:00-10:15am	Break
10:15-11:45am	Technical Sessions
11:45am-1pm	Lunch (not provided)
1:00-2:30pm	Technical Sessions
2:30-2:45pm	Refreshment Break
2:45-4:15pm	Technical Sessions
4:15-4:30	Refreshment Break
4:30-6pm	Technical Sessions
6:15pm	Meet for Icebreaker Reception Cruise (in front of Lerner Hall) Commentary: Bojidar Yanev - NYCDOT

Tuesday, June 4th, 2002

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8:30-9:30am	Keynote Lecture - Charles Peskin, Courant Institute (New York Univ.)
9:30-9:45	Break
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11:15-11:30am	Refreshment Break
11:30-1:00pm	Technical Sessions
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2:30-4pm	Technical Sessions
4:00-4:15pm	Refreshment Break
4:15-5:45pm	Technical Sessions
6:30pm	Cocktail Hour followed by Conference Banquet (Lerner Hall)

Wednesday, June 5th, 2002

7:30-8:30 am	Breakfast & Registration
8:30-9:30am	Keynote Lecture - Ephrahim Garcia, Vanderbilt University
9:30-9:45	Break
9:45-11:15am	Technical Sessions
11:15-11:30am	Refreshment Break
11:30-1:00pm	Technical Sessions

Monday - June 3rd, 2002
Session Abstracts

Structural Control - I
June 3, 2002
10:15
Chair: Anil Agrawal City College of New York
Co-Chair: Genda Chen University of Missouri-Rolla

ROBUSTNESS DESIGN OF FUZZY CONTROLLERS FOR NONLINEAR INTERCONNECTED TMD SYSTEMS WITH EXTERNAL FORCES

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This paper investigates the effectiveness of a passive Tuned Mass Damper (TMD) and active fuzzy controllers in reducing the structural responses under the external force. In general, TMD is good for linear system. We proposed here a fuzzy controller to deal with the nonlinear system. A robustness design of fuzzy control via model-based approach is proposed in this paper to overcome the effect of modeling error between nonlinear systems and Takagi-Sugeno (T-S) fuzzy models. A stability criterion in terms of Lyapunov's direct method is derived to guarantee the stability of nonlinear interconnected TMD systems. The common P matrix of the criterion is obtained by using linear matrix inequality (LMI) optimization algorithms to solve the robust fuzzy control problem. Based on the decentralized control scheme and this criterion, a set of model-based fuzzy controllers is then synthesized via the technique of parallel distributed compensation (PDC) to stabilize the nonlinear interconnected TMD system. Finally, an example is given to illustrate the concepts discussed throughout this paper.

APPLICATION OF MAGNETO-RHEOLOGICAL DAMPERS FOR MULTI-LEVEL SEISMIC HAZARD MITIGATION OF HYSTERETIC STRUCTURES

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A main goal of supplemental control devices is to manage the energy dissipation in the system. Magneto-rheological (MR) dampers have emerged as a promising control device for application to civil structures as they are effective energy dissipators. This paper presents a bang-bang-like control and investigates its ability to mitigate structural response in the presence of hysteretic, geometric and yielding non-linearities under various intensity level seismic hazard suites so as to examine control efficacy and seismic hazard statistics. Results show that MR Dampers limited to realistic peak force/dissipation levels of ~12% building weight are effective at limiting permanent deflections and indicate the importance of zero tracking for non-linear systems. However, floor accelerations rise significantly as displacement is limited and the performance improvement is not the same for all ground motions.

HYBRID CONTROL REALIZATION IN BUILDING STRUCTURES AND EFFECTIVENESS COMPARISON WITH MR CONTROL

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Hybrid control and semi-active control systems have been studied to take advantages and yet avoid some shortcomings of active and passive controllers. In this paper, the hybrid damper-actuator bracing control system is based on a tube fluid damper (passive device) with an active controlled piston mounted on structural brace. The magnetorheological (MR) damper is one of semi-active control systems, which uses controllable MR fluids as damping device.

An intelligent control strategy is developed for the hybrid system in which active control begins to operate once structural response exceeds a threshold value. Active control feedback gain will then be adjusted for achieving desired response level. Thus control system is passive for small or moderate earthquakes and the hybrid system will be utilized for stronger ground motion. At different threshold stages, the active system is activated with consideration of control effectiveness and energy consumption. When comparing hybrid system with MR systems, both are mounted on the same structure with the same required response subjected to several given earthquake excitations. Thus the simulation results can show the maximum control force, acceleration, and number of control devices for the individual systems of which the strength and weakness are qualitatively observed. Among the advantages of the intelligent hybrid control strategy, the system can effectively use external energy for various earthquake magnitudes.

Benchmark Problem for Control of Base Isolated Buildings

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This paper presents the benchmark problem definition for seismically excited base-isolated buildings. The objective of this benchmark study is to provide a well defined base isolated building with a broad set of carefully chosen parameter sets, performance measures and guidelines to the participants, so that they can evaluate their control algorithms. The control algorithms may be passive, active or semiactive. The benchmark structure considered is an eight story base isolated building similar to existing buildings in Los Angeles, California. The base isolation system includes either linear or non-linear bearings. The superstructure is considered to be a linear elastic system with lateral-torsional behavior. The base isolation system includes linear and non-linear bearings and devices. A new nonlinear dynamic analysis program has been developed and made available to facilitate direct comparison of results of different control algorithms.

Close Form Approximations of Near-Field Ground Motions for Design of Protective Systems

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Wanlong He *City College of New York*

Near-fault ground motions are characterized by long-period pulses with high peak ground velocity. In this paper, a simplified closed-form approximation using decaying sinusoids is proposed to model long-period velocity pulses in near-fault ground motions. The objective of such formulation is to represent dominant kinematic characteristics of ground motions instead of modeling ground motions accurately since only the most prominent frequency component of such ground motions can be represented by the closed-form approximation. The validity and usefulness of the proposed approximation is demonstrated using near-fault earthquakes measured during Northridge (1994) and Landers (1992) earthquakes.

Biologically Inspired Materials - I
June 3, 2002
10:15
Chair: Dinesh Katti North Dakota State University
Co-Chair: Franz-Josef Ulm Massachusetts Institute of Technology

Functionally Graded Cellular Metal Alloys for Human-Joint Implants

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The purpose of this research is to investigate the fundamental science and engineering of a porous or functionally graded metal alloy to be used to improve the material casting of artificial hip or knee joint prostheses, or as a replacement of segments of human bone. Currently technology uses Hip and Knee replacement prostheses that are generally made of Titanium alloys or from Cobalt Chromium alloys. This has the advantage of having biocompatibility with the human body, but problems arise from the dissimilarity of stiffness between bone and implant due to the high stiffness of the implant material compared to bone causing unnatural levels of stresses in the adjacent bone leading to bone remodeling and resorption (bone loss) and eventually cause loosening of the implant and failure of the join function. The reduction of stiffness of the prosthesis has been documented to reduce the stress levels in the adjacent bone and produce favorable stress levels.

Morphology-Based Models for Wood and Wood-Based Composites

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William Davids *University of Maine*
Svetlana Vasic *University of Maine*

In this study we are exploring ways to couple experimental measurements with numerical simulations of the mechanical properties of wood. For our numerical simulations we have adopted a discrete element approach, where wood fibers are modeled as discrete elements that interact with other similar elements. Wood fiber bundles are modeled as tubular beams having unique strength and stiffness properties. Bundles are connected by spring elements with independent strength and stiffness. Effectively the solid piece of wood becomes a structural system that can be analyzed for deformations and damage by conventional methods. The advantage of this approach over a traditional continuum approach is that the different physical phenomena that contribute to material behavior can be isolated and measured. In this preliminary work we seek to numerically simulate both the microstructural changes and the gross load deformation response in small wood specimens subjected to longitudinal and transverse uniaxial tension, and shear. The results show the model to be effective at capturing both microstructural damage and load-deformation response.

A Unified Approach to the Ultrastructural Elasticity of Mineralized Tissues

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Franz-Josef Ulm ***Massachusetts Institute of Technology***

We recently found that mineralized tissues (mineralized tendons and bones), at an observation scale of some microns,are dense isotropic hydroxyapatite crystalfoams which are reinforced unidirectionally by (organic) collagen molecules. The collagen reinforcement is mechanically activated by crosslinks betweencollagen assemblies and hydroxyapatite. With this morphology in mind, we develop a micromechanics model for the ultrastructural stiffness of mineralized tissues. The homogenization is achieved in two steps: At a scale of some hundred nanometers, the isotropic crystal foam is represented as a two-phase polycrystal composed of a hydroxyapatite crystal phase and a non-mineralic phase filling the inter-crystalline space. At a scale above of some five to ten micrometers, the polycrystal plays the role of aconnected matrix, in which a collagen inclusion phase is embedded. The input for the model are the mineral volume fraction and the collagen volume fraction, which are species and tissue-type specific.Then, on the basis of four intrinsic micromechanical stiffness constants, the model is able to predict the full ultrastructural stiffness tensor of mineralized tissues, from low-mineralized turkey leg tendon to highly anisotropic human bones, and high-mineralized isotropic ear bones of whales.

Bio-Chemo-Mechanics of Bone Remodeling and Fracture

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In this paper, we develop a biochemomechanics theory, which allows the integration of a biological process orchestrated by cells into a chemomechanics framework. The derivation is based on first principles of thermodynamics and is developed around the modeling of bone resorption. We show that the driving force of the process involves three quantities: a biologically generated chemical potential, developed by the cell on the solid surface; the chemical potential of the solid mineral; and, finally, the strain energy stored in the solid phase. Orders of magnitude of these three quantities are evaluated using existing data. It is shown that the average strain energy is some orders of magnitude smaller than the BGP. However, in the immediate surrounding of cracks, the strain energy increases due to stress concentrations to 10-50% of the BGP. In the course of remodeling events, we propose that this chemomechanical coupling is a nonrandom remodeling stimulus, helping repair damage in bone, which at the same time reduces the risk of crack propagation.

Dynamics of Structures I

June 3, 2002
10:15
Chair: Lawrence Bergman **University of Illinois**

Free Vibration of non-prismatic Beams

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The analysis of non-prismatic beams by the displacement based formulations includes some inherent approximations. One of the most convenient methods for overcoming this problem is to use a flexibility based formulation . This is an inherently exact formulation due to the lack of any assumptions on the displacement field. The main problem in using such methods is the complicated computations involved, while due to the simplicity of the geometry of one dimensional elements they have been widely used. A number of methods for the calculation of the stiffness and mass matrix have been presented , but since they have not utilized an exact shape function for the non-prismatic beams, they all have to make certain approximations in their methods. Here, a new formulation for the non-prismatic EulerñBernoulli Beams based on the implicit derivation of exact shape functions is presented. The stiffness and consistent mass matrices of these beams have been obtained in an exact fashion, and the vibration properties of the beam have been studied. The results obtained show the precision of the proposed formulation.

Experimental Dynamic Characterisation of two incinerator chimneys near Verona (Italy).

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Daniele Facchin ***University of Padova***
Claudio Modena ***University of Padova***

The dynamic measurement system installed to study the dynamic behaviour under wind action and dead loads of two chimneys (60m high) of the incinerator in the Disposal Plant of solid urban refuse near the city of Verona (Italy), is described. The results of the experimental campaign are presented: the analysis of the dynamic response of the structure under wind action and the experimental identification of mode frequencies, shapes and damping. The work is completed with comparisons with numerical results obtained from a FE model.

Bridge Weigh-in-Motion System Development Using Static Truck/Dynamic Bridge Models

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Harold Stalford ***Sandia National Laboratories/University of Oklahoma***

In this paper, we expand upon previous work on the development of a weigh-in-motion (WIM) system for use on in-service highway bridges. Using a bridge's elastic response due to truck traffic, the inverse problem of covertly estimating the weight of a truck and its individual axle weights is examined. The extension is focused on including a bridge's dynamics into a previously examined static model. The model used in this paper is based on data from an actual interstate bridge. It is constructed using finite element modeling of an Euler beam and its first and second modes. As in the previous work of the authors, the truck model is constrained to be a static model in which two moving point masses are used to describe it. From the bridge's elastic response to truck traffic, the deflection of the beam at the midpoint is measured over time. An optimization routine is employed to estimate the values of unknown axle weights of the truck. Two sensor scenarios are considered. First, we consider the scenario in which the weight as well as the speed and axle spacing are unknown parameters. In the second scenario, the speed is assumed known, being measured by an independent sensor. The axle spacing is then determined from the known speed. The only unknowns in the second scenario are the truck axle weights. Various truck cases were treated in which truck weights varied between 4.4x104 and 5x105 N with ten ratios of front to rear axle weights for each gross weight. Without knowledge of truck speed, the estimated values of the unknown axle weights were accurate to within 35% of their true values. Knowing the truck speed improved the accuracy of the estimates of the axle weights and total weight of the truck to within 0.1% of their true values. The second scenario produces one order of magnitude improvement in accuracy over other methods contained in the literature. The results are obtained using a single sensor measurement of beam displacement. The performance and speed of the algorithm is also compared to the authors' earlier, less complicated model in which the dynamics of the beam were neglected.

The Rocking Spectrum and the Shortcomings of Design Procedures

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This paper is concerned with the superficial similarities and fundamental differences between the oscillatory response of a single-degree-of-freedom (SDOF) oscillator (regular pendulum) and the rocking response of a slender rigid block (inverted pendulum). The study examines the validity of a simple, approximate design methodology, initially proposed in the late 70's and now recommended in design guidelines to compute rotations of slender structures by performing iteration either on the true displacement response spectrum or design spectrum. This paper shows that the simple design approach is inherently flawed and should be abandoned, in particular for smaller, less-slender blocks.

Men-induced dynamic excitations of stand structures

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Stand structures may be subject to larger excitations induced by an active audience for any kind of mass event, i.e. for open-air concerts and sport events. After the British Code BS 6399, the new German Code DIN 1055 will be the second national code in Europe which is addressing this design problem. Both codes, however, fail in specifying design targets for serviceability criteria in terms of the comfort and the safety of the audience. Respective limits are discussed, emphasizing that a 'natural' scatter of the individual sensitivity in regard to vibrations should be considered as well. For existing stand structures, a method of evaluating the serviceability is presented which is based on observed acceleration amplitudes. For the design of new stand structures, applying the idealized load-model of a half-sine-wave in combination with a general coordination factor seems to lead to over-conservative solutions. Therefore, a better approach is based on a Monte-Carlo simulation of the random load process. Some basic demands for a consistent load model will be discussed and some first results are presented.

Symposium on Micromechanics of Heterogeneous Materials - Session I
June 3, 2002
10:15
Chair: Jiann-Wen Ju UCLA
Co-Chair: Lizhi Sun The University of Iowa

OPTIMAL LOW-WEIGHT MICROSTRUCTURES

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We introduce a new class of high-porosity microstructures, called ''single-scale laminates,'' made from arrays of parallel walls. They are extremal, in the sense that no stiffer structure exists with the same total mass. They are simple, in the sense of being easy to describe, and perhaps to manufacture. And they are universal: for any high-porosity microstructure there is a single-scale laminate using at most as much material which is at least as stiff. Moreover, any nondegenerate high-porosity Hooke's law can be bounded both above and below by a single-scale laminate of the same weight.

We give a simple formula for the effective Hooke's law of such a structure. It reduces the task of minimum-weight design in the high-porosity regime to a problem of linear programming.

MULTI-SCALE UNIT CELL ANALYSES OF TEXTILE REINFORCED COMPOSITES

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HyungJoo Kim *The University of Iowa*

Unit cell homogenization techniques are applied on multiple length scales to compute the macroscopic hyperelastic stiffness characteristics of textile-reinforced polymer matrix composites. On the smallest scale (~50μm) the effective transversely isotropic properties of tows (or yarns) are computed based on both fiber and matrix properties. These position-dependent transversely isotropic effective yarn properties are then incorporated into a full textile unit cell model and the nonlinear effective stiffness properties of the textile composite are computed and discussed.

HIERARCHICAL RELATIONS FOR THE APPARENT YIELD STRENGTH DOMAINS OF HETEROGENEOUS MATERIALS

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The purpose of the present work is to propose a novel micromechanical approach to material yield strength problems by applying the kinematic and static variational principles of limit analysis. We preliminarily present the notion of gauge functions together with theirs main properties and relationships with closed convex sets. In light of these results and by recognizing the important (but hidden) role played by gauge functions in the theory of limit analysis, the fundamental variational principles of the latter are reformulated in a novel manner such that they are suited to our purpose. In particular, the polar duality between them is brought out. Considering uniform velocity and traction boundary conditions, kinematic and static apparent yield strength domains are defined. Appropriate application of the aforementioned variational principles allows us to show: (i) the static apparent yield strength domain of any specimen is included in its kinematic one; (ii) the static apparent yield strength domain of any specimen includes the intersection of the static apparent yield strength domains of the smaller specimens resulting from the partition of the initial one; (iii) the kinematic apparent yield strength domain of any specimen is included in the volume fraction weighted convex combination of the kinematic apparent yield strength domains of the smaller specimens partitioning the initial one. A synthetic characterization of these effects gives rise to either a hierarchical chain of yield strength domain inclusions or a hierarchical chain of inequalities for the relevant dissipation functions or a chain hierarchical of inverse inequalities for the corresponding gauge yield functions.

INVERSE PROBLEM IN RECONSTRUCTING MICROSTRUCTURE OF UNIDIRECTIONAL COMPOSITE MATERIALS

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Bogdan Bochenek *Cracow University of Technology*

The physical properties of a material are strongly influenced by the microstructure which is designed during processing. Amount of constituents elements forming the material is in many cases known beforehand as for example the volume fraction of reinforcing phase in composite materials. However, the final architecture of a microstructure is controlled only to a limited extent, and on a microscale the geometrical arrangement of second-phase inclusions is a result of complex and interacting processing micromechanisms rather than a design variable. This seems to create an obstacle in modelling the relation between the microstructure and overall material properties since variability of an arrangement of microstructural features and their mutual interaction determines physical characteristics of materials. This is particularly true for the description of strongly nonlinear phenomena such as fracture, where short range interactions between microstructural entities play a dominant role in non-homogeneous local variations of field quantities. For not dilute concentrations the interaction effects between neighbouring inclusions are highly influential on the overall behaviour of the material. These interaction effects produced by inclusions are sensitive to their exact positions and sizes. A certain degree of regularity of the microstructural pattern is usually assumed a priori in modelling the microstructure-property relations. However, the distribution of second-phase inclusions rarely appears to be homogeneous and/or regular. Furthermore, only a tiny fraction of the original material specimen can actually be analysed and therefore, it is mandatory to reconstruct the dispersion pattern that would have similar geometrical charcteristics as the dispersion of inclusions acquired from the limited experimental observations.

In the present paper the simulated annealing procedure is used to reconstruct the positions of continuous fibres as observed using X-ray microtomography on transverse cross sections of a composite. The modified concept of a pair correlation function is used to define the objective function which is identified as a sum of squared differences of nodal points of correlation functions for a reference and optimized pattern. The optimization process is subject to two constraints. The geometrical constraint of topological entropy introduces a measure of arbitrariness of the polygonal tessellation associated with the point pattern of fibre centres. The second constraint is related to maximal radial stresses calculated at the fibres interfaces. This constraint is expressed in terms of angular positions and distances from the reference fibre to its nearest neighbours. Thus the screening effect and local interactions are taken into account. The results show that reconstructed families of the fibres dispersion resemble the reference pattern to the degree that is bound by the selected pattern descriptors and therefore can be used for a further analysis to describe overall properties of the underlying composite material.

Effective Elastoplastic Damage Model for Fiber Reinforced Metal Matrix Composites With Evolutionary Complete Fiber Debonding

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A micromechanical damage model is proposed to predict the overall elastoplastic behavior and interfacial damage evolution of fiber-reinforced metal matrix composites. Progressive, completely debonded fibers are replaced by voids. The effective elastic moduli of three-phase composites, composed of a ductile matrix, randomly located and unidirectionally aligned circular fibers, and voids, are derived by using a micromechanical formulation. In order to characterize the overall elastoplastic behavior, an effective yield criterion is derived based on the ensemble-area averaging process and the first-order effects of eigenstrains. The proposed effective yield criterion, together with the overall associative plastic flow rule and the hardening law, constitutes the analytical framework for the estimation of effective elastoplastic responses of metal matrix composites containing both perfectly bonded and completely debonded fibers. An evolutionary interfacial fiber debonding process, governed by the internal stresses of fibers and the interfacial strength, is incorporated. Further, the Weibull's statistical function is employed to describe the varying probability of complete fiber debonding. Finally, comparison between the present predictions and available experimental data and various numerical simulations are performed to illustrate the potential of the proposed framework.

Inelastic Behavior - Nonlinear Behavior of Structures

June 3, 2002
10:15
Chair: A. (Rajah) Anandarajah **Johns Hopkins University**

Nonlinear Behaviour of Yielding Damped Bracing Frames

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Since the nature of earthquakes is the energy which released due to tectonic events, investigations and improvements of behavior of structures based on energy concepts have been concerned. Input energy must be dissipated in order to decrease the damage effects of earthquake, which is received by structures. For this purpose YDBF system is presented which acts as a fuse -when earthquake acts-, and because of high ductility which it has, the damage of fundamental elements in structures is prevented. Because of nonlinear behavior of such a system, which is based on yielding of ductile style, YDBF increases dissipated and hysteresis energy. This class of dampers often yields in high or intermediate earthquake shakes and their hysteresis loop is relatively thick and stable. In this research seven YDBF are modeled by EMRC NISA II F.E.Software and controlled by Ansys program. These models with various percentages of openings are tested and the results of structural behavior due to variation of opening percentages are income.

Seismic Response of Reinforced Concrete Bearing walls, 2D and 3D F.E. Simplified Analysis

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Geraldine Casaux ***LMT-Cachan***
Jacky Mazars ***LSSS, INPG***

This paper deals with the behavior of reinforced concrete bearing walls subjected to seismic loading. The presentation focuses on the numerical tools dedicated to nonlinear transient simplified analysis allowing parametrical studies. In a first step, the multifibers beam approach is presented as well as the local nonlinear constitutive equations. Comparisons between experimental results and numerical computations for 2-D and 3-D case-study are presented.

Modeling the Non-linear Behavior of Wood Frame Shear Walls

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Wood frame shear walls are an integral component of the lateral load resisting system of any low-rise structure constructed today. While seemingly ordinary, a wood frame shear wall is a complex physical structure that includes various types of structural members and connections. A study has recently been undertaken to investigate the effect of vertical load on the static and cyclic lateral load response of wood frame shear walls. A coordinated theoretical and experimental program is underway; the theoretical program is to involve the development of simple mechanics based models and detailed finite element models of the wall. Presented in the paper are preliminary results of the detailed finite element modeling effort, and a comparison to experimental results. The shear wall is modeled using the ANSYS finite element program. The static, non-linear behavior of the wall is investigated, including the effect of vertical load. Results are verified against available test data. Preliminary results show good correlation between the finite element model and the experimental data.

A MODEL FOR ANALYZING INELASTIC SEISMIC RESPONSE OF PLAN-IRREGULAR BUILDING STRUCTURES

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Most papers in the field of inelastic seismic response of plan-irregular building structures have been conducted by using simple single storey asymmetric models. Such models have been considered very suitable because they allow to clarify the influence of the governing parameters and to derive effective design criteria; furthermore, they are capable to provide results applicable to those multistorey plan-irregular buildings which are regular in height. However, simplified models neglect important effects that may influence inelastic behaviour of resisting elements and, in turn, of the entire structure. Namely, resisting elements are assumed to resist uni-directional horizontal forces only; therefore, no allowance for interaction among bi-directional horizontal and vertical forces in resisting elements is usually made. Moreover, vertical earthquake component cannot be introduced in those analyses. In this paper, a refined numerical model of one storey asymmetric building structure is presented, which is able to overcome the above-mentioned limitations and to fulfill the need for taking into account interaction phenomena and vertical earthquake component.

Frank L. DiMaggio Symposium on Constitutive Modeling of Geomaterials I

June 3, 2002
10:15
Chair: A. (Rajah) Anandarajah **Johns Hopkins University**
Co-Chair: Hoe Ling **Columbia University**

REVIEW OF THE DEVELOPMENT OF CAP MODELS FOR GEOMATERIALS

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The history of the development of CAP constitutive models is reviewed. These models, which are used to represent the dynamic behavior of geomaterials, provide a powerful, yet adaptable way of representing many aspects of the stress-strain behavior of geological materials, and they have been extensively used for more than three decades to characterize soils and rocks as well as concrete.

The modern series of CAP models, introduced in the early 1970ís as a result of government-sponsored university and corporate R&D technology, is based on the adaptation of several earlier models. The basic behavior of these models is briefly discussed and compared here, and the reasons for the introduction of CAP models and guidelines for their use are outlined.

Many adaptations of the CAP model have been developed and utilized. Several examples of these model extensions and their salient features are discussed, and some opportunities for future extension of the models are examined.

Finally, the possibility of transferring the results of CAP model research to application in commercial engineering practice is discussed.

CONSTITUTIVE MODELING OF POST-LIQUEFACTION CYCLIC DEFORMATION OF SANDS

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Yannis Dafalias

Large post-liquefaction deformations, which can be induced in sandy soils during earthquake shaking, often are responsible for heavy damage to built structures. Recent laboratory tests demonstrated that shear deformation develops continuously, following initial liquefaction, in sands that are subjected to cyclic loading. The effective stress paths after liquefaction repeat similar dilative and contractive behaviors in each cycle, but the corresponding shear strain amplitude increases continuously.

We have limited understanding of why large post-liquefaction deformations can occur. Empirical relationships were proposed to correlate the development of shear deformation to the °ßpreceding maximum shear strain°® during cyclic loading (Shamoto et al., 1997). Constitutive modeling also was proposed to capture the development of deformation by assigning zero shear modulus where the effective stress path crosses the phase transformation line (Para, 1996;Young, 2000).

The present study proposes a strain history dependence of soil

modulus and uses an intrinsic variable to capture the reduction in the modulus. Thus, the development of post-liquefaction deformation can be simulated within the framework of a bounding surface plasticity model (Wang, et al., 1990). The basic differential equations of the model are integrated to obtain the stress-strain relationships for post-liquefaction response in two phases. The first is the dilative phase, which is a loading phase along a critical stress path. The second is the contractive phase, which is an unloading accompanied by a rapid drop in effective mean stress. In each phase, the soil modulus is affected by a softening (or hardening) factor, C(ÉË), in which the intrinsic variable ÉË is taken as a function of the accumulated plastic strain. The integrated relationships demonstrate the development of shear strain with the declining modulus, although the effective stress paths in each cycle essentially repeat.

With the selected simple functional form of C(ÉË), three types of post-liquefaction deformation behavior can be simulated using the above constitutive equations: (1) rapid increase of shear strain amplitude; (2) linear increase of shear strain amplitude; and (3) limited shear strain amplitude. All of these behaviors can be related to the initial void ratio of given sand.

Model simulations are compared with recent laboratory test results, showing reasonable agreement in the deformation developed throughout the sequence of loading cycles.

The procedure for calibrating model parameters also is reviewed. The model parameters can still be calibrated as with the original model using results from pre-liquefaction loading tests assuming C(ÉË) = 1. The post-liquefaction responses are captured using two additional model parameters in the functional form of C(ÉË). It is shown that the predicted pre-liquefaction responses are not affected significantly by the softening factor (i.e., if C(ÉË) <1). With this validation, the model°¶s enhanced applicability to a fully coupled dynamic analysis is demonstrated for simulating both pre- and post-liquefaction behavior of sands.

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On the Structure of Constitutive Laws for Sands

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While a macroscopic approach yields practical models for simulating constitutive behavior of sands, there is a critical need for physically meaningful models. Such models can not only shed some light on the structure of macroscopic laws, but also provide some physical meaning for constitutive functions and parameters. In this paper, a microscopic model is developed and some aspects of the essential structure of the constitutive behavior of sands are examined. In particular, the flow rule and yielding are examined. The model is developed by first considering the load-deformation behavior of a microelement, and then synthesizing to simulate the behavior of a volume of a sand. The model is based on the assumption that an externally applied load is carried by columns of particles, or more precisely, columns of microelements. The derived equations show that the constitutive equations are incrementally nonlinear. Also, in some domains, it is seen that plastic behavior is associated with not only loading, but also stress reversal ñ an attribute needed for modeling liquefaction behavior of sands realistically.

Elasto-Plastic Strain Hardening-Softening Soil Model with Shear Banding

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The solutions of boundary value problems involving strain-softening material property are full of serious difficulties from both modeling of strain-localization and a viewpoint of numerical and mathematical procedures. The straightforward use of a strain-softening model in the framework of classical continuum generally does not result in a well-posed problem. It is well known in a finite element procedure that a strain softening material yields mesh-sensitive solutions. However the physical experimental data show that a shear-band localization exhibits a strain localized zone with a finite width and a finite value for the consumption of energy. There are several techniques, employed to obtain mesh size independent shear banding. In this Paper they are discussed in the first. A material model for a real soil is described with the features of (1) non-associated flow characteristics, (2) post-peak strain softening, (3) strain-localization into a shear band with a specific width, (4) anisotropic deformation and strength characteristics, (5) pressure-sensitivity of the deformation and strength characteristics of sand. Stress-dilatancy relation is considered through non-associated plastic flow. Mesh size-dependent hardening modulus is considered to alleviate the mesh size-dependency of the solution. The elasto-plastic soil model is applied to capture the formation of shear band in a plane strain compression test on dense sand. Also the direct shear test, the bearing capacity of strip footing and retaining structure are analyzed. The soil model is based on experimental findings about inherent and induced anisotropies involved in sand. The results of simulation are compared with those from the physical experiments.

Anisotropy of Clays Based on Bounding Surface Model

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This paper presents an improved soil model based on anisotropic critical state theory and bounding surface plasticity. The anisotropic critical state theory of Dafalias was extended into three-dimensional stress space. In additional to the isotropic hardening rule, an anisotropic (rotational.) and a distortional hardening rule were incorporated into the bounding surface formulation. An anisotropic tensor and its development with the stress system and volumetric strain rate were introduced to function as the anisotropic rule. The projection center that is used to map the actual stress point to the imaginary stress point was specified along an axis that represents the initial anisotropic state in the stress space. The model requires 11 material parameters and was validated against the isotropic and anisotropic undrained triaxial test results of Kaolin clay. The effects of anisotropy in compression and extension modes were well described by proposed model.

Discrete and Continuum Modeling of Granular Materials I
June 3, 2002
10:15
Chair: Ching Chang University of Massachusetts
Co-Chair: Jin Ooi University of Edinburgh

PARTICLE ROTATIONS IN GRANULAR MATERIALS

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Katalin Bagi *Technical University of Budapest*
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Particle rotations can have a dominant influence on the behavior of granular materials, particularly in materials with circular or spherical particles. The paper reviews experimental evidence of the magnitude and variability of particle rotations and their effect on a granular material's stiffness and strength. Evidence of rotational patterning is reported from DEM simulations of a large square assembly of multi-sized circular particles. The translational velocities of the particles were used to compute the rotation and deformation rates within small polygonal regions of material. The material rotation could then be compared with the rotations of the particles themselves. Two meso-scale phenomena are described in the paper: rotating clusters and rotation chains. During biaxial tests, the local deformation rates are highly variable, with banded regions having deformation rates much greater than the mean rate, and with clustered regions in which very little deformation occurs. Material within a nearly-rigid region usually rotates in either an entirely clockwise or entirely counter-clockwise manner. The direction of this material rotation matches the direction of particle rotations in these regions. In a second rotational pattern, the most rapidly rotating particles are aligned in chain-like patterns oblique to the principal stress directions. These rotation chains are usually located within intensely deforming band-like regions.

MICRO-MECHANICAL DEFINITION OF STRAIN TENSOR FOR GRANULAR ASSEMBLIES

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In a micro-mechanical study on the behavior of granular materials, the stress and strain defined from the micro-mechanical viewpoint may play essentially important roles. However, although some micro-mechanical definitions for stress and strain have been proposed, the definition of strain tensor seems to be still open to discussion. This paper proposes a new micro-mechanical definition by using the Dirichlet tessellation (modified Voronoi tessellation) for granular assemblies. The notable and advantageous points of the proposed definition are as follows: 1. The definition of stress and strain starts from those considered at contact points, 2. Introducing the so-called dual branch vector and defining the region of contact (region accompanied by contact), the proposed definition shows some important properties such as similarity to Cauchy?s theorem in continuum mechanics, 3. The region of contact defined by the proposed definition makes a natural and continuous change for a sudden change of virtual branches during deformation, 4. The overall stress and strain discussed here satisfy the Hill?s condition in a modified form.

The incremental nonlinearity observed in numerical tests of granular media

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Recently, incrementally nonlinear constitutive models have been proposed for granular media by several researchers. It seems that such generalization of constitutive relationship is the key to grasping true behaviors of granular media. However, it is very difficult to do rigorous evaluation of the validity of these models, because of the limitations inherent in available experimental measures. On the other hand, numerical simulations in terms of suitable discrete element methods have a capability to solve this problem. This paper demonstrates the incremental nonlinearity observed in numerical tests conducted by a discrete element method proposed by the author. Through a series of true tri-axial stress-probe tests, it is found that the direction of plastic strain increment changes with the component of stress increment that is orthogonal to the current stress and the yield surface normal. The result suggests that the plastic deformation is accompanied by multiple shear mechanisms. The stability in the incremental relationship between stress and strain is also discussed based on the calculated results of second-order work.

Computational Mechanics - Advances in Finite Element Methods

June 3, 2002
10:15
Chair: Apostolos Fafitis **Arizona State University**

Nonlinear Truss Analysis by One Matrix Inversion

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A new method for nonlinear structural analysis has been developed. The novelty of the method is that only one Stiffness Matrix inversion is required without the need for updating and re-inverting the Matrix at every Load Increment. This Stiffness Matrix is not necessarily the real Stiffness Matrix of the Structure. Instead any Matrix that would guaranty joint equilibrium can be used. The advantage of this option is that if the design of some members of the Structure is revised, the already inverted and stored Matrix is used for the new analysis. Nonlinearities due to plasticity, strain-hardening, strain-softening, buckling, breaking, and stifiness-degradation are handled by iterations involving only multiplications of the banded matrix with a Transformed Force Vector. The Inversion of the half-banded original Stiffness Matrix is done using Gauss Elimination performed on the half-banded matrix without destroying the bandedness, and the inverted matrix replaces the original without need of additional storage. The coefficients for the transformation of the force vector are stored permanently in a new matrix of size equal to the size of the half-banded original. Thus the total storage needed is equal to the storage for the banded original Stiffness. Because, after the Gauss Elimination, only multiplications of a matrix with a vector are involved the method is computationally efficient. The method is not a step-by-step procedure. Any load increment can be applied, therefore, proportional, non-proportional, and cyclic loads are treated in a unified fashion. The energy-dissipation and the residual stresses and strains after one or more cycles are readily available and thus the method can be used in quasi-dynamic analysis (e.g. push-over) for an evaluation of the dynamic parameters of the structure.

Refined Beam Finite Element with a Non Nodal Degree of Freedom

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The beam element used in frame analysis has 4 degrees of freedom corresponding to the transverse displacement and the rotation at each end node. This condition allows a cubic variation of the transverse displacement along the length of the element, which is the correct one if the bending moment has linear variation, that is, no transverse load acts between the end nodes. However, this is not the usual case of beam behavior because distributed loads are commonly acting. To solve this contradiction the frame analysis is performed substituting the distributed load by fictitious equivalent nodal concentrations corresponding to the so-called fixed coordinate state.

We can not get rid of these artificial fixed end moments and shear unless we establish an appropriate distributed degree of freedom, that is, the smeared coordinate of displacement along which the

distributed load is acting. The purpose of this paper is to identify such non-nodal degree of freedom related to a uniform distributed load.

Accordingly, a refined beam element with five degrees of freedom (four nodal and one non-nodal) is presented. Corresponding shape functions are developed and explicit expression of the 5x5 stiffness matrix is presented. The consistent load vector associated with a uniform load is discussed to show that no components exist at the end nodes. Moreover the 5 x 5 geometric stiffness matrix is developed and successfully applied to solve second order analysis. Finally, use of non-nodal degrees of freedom in plane elasticity problems leading to a 34 DOF plane stress element is briefly discussed.

A Numerical Method Of Mixed Modeling On Shear Design Of Reinforced Concrete Members Strengthened With CFRP Laminates

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This paper presents a general system aimed at dealing with the failure analysis of reinforced concrete members strengthened with carbon-fiber-reinforced plastic (CFRP) sheets. It is based on the yield design theory with a mixed modeling of the structure, according to which the concrete material is treated as a classical two-dimensional continuum, whereas the longitudinal reinforcing bars are regarded as one -dimensional rods and in shear reinforced zones both the shear CFRP sheets and transverse reinforcing bars are incorporated in the analysis through a homogenization procedure and they are only in tension. The static method is then implemented numerically by means of the finite-element formulation, thus produces accurate estimates for the loading-carrying capacity of the shear members taken ad an illustrative application. Numerical predictions are in good agreement with the experimental results.

Mixed Finite Elements with Voids and Inclusions

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For stress concentrations around voids and inclusions, one can derive appropriate stress and strain functions, which characterize the local fields very well, and use them for special problem adapted finite elements. For linear problems, such stress and strain functions can be obtained from complex solution representations. The functions can be derived in such a way that the equilibrium equations and the boundary conditions on the void surface or the continuity conditions along the matrix/inclusion boundary are satisfied a priori. For special finite elements with voids and inclusions, piecewise linear or quadratic boundary displacements have to be assumed for an appropriate coupling with other finite elements. There has to be a balance between the number of stress/strain parameters and the nodal displacements of the special elements with built-in voids or inclusions. The outer boundary of a special finite element can be a polygon or a polyhedron. Some early versions of special purpose finite elements with holes and internal cracks are described in reference [1]. Special purpose finite elements with voids and inclusions have applications in the analysis of heterogeneous materials. For an accurate approximation of the stress concentration around a hole or an inclusion a fine mesh of displacement finite elements is needed. When considering a domain with a large number of holes or inclusions, the discretization effort can be substantial. In order to reduce the number of elements needed in a computational model, special finite elements with holes or inclusions can be utilized. Although the focus will be on some experiences with two-dimensional special finite elements, some aspects of the derivation of three-dimensional special finite elements will be covered.

[1] R. Piltner, "Special finite elements with holes and internal cracks", Int. J. Num. Methods Eng., 21, 1471 -1485, (1985).

Nonlinear Finite Element Simulation of Suction Caisson Behavior

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Suction caissons are hollow cylinders capped at top and used as foundations and anchors for offshore structures and mooring lines. An earlier study, conducted at the Offshore Technology Research Center of The University of Texas at Austin, was focused on prediction of axial capacity of such caissons considering the effects of installation. Computational tools were developed assuming axial symmetry. To capture the installation effects on the axial capacity, caisson penetration by self-weight was simulated. A frictional contact algorithm based on slide-line formulation was used to analyze the interaction between the caisson and the surrounding soil during installation along a preset straight penetration path. In the present study, computational tools are developed to predict the path of penetration as caisson installation progresses, thereby avoiding the need for a priori specification of the path. Verification of the numerical results has been accomplished using data from recent experiments conducted at The University of Texas at Austin.

Acoustical Methods for Civil Structures

June 3, 2002
10:15
Chair: Laurence Jacobs Georgia Institute of Technology
Co-Chair: Jason Weiss Purdue University

HIGH RESOLUTION SEISMIC TOMOGRAPHY BASED ON COHERENT WAVE TECHNOLOGIES

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A brand-new active high resolution seismic tomography method is presented. Recent seismological research on heterogeneity of seismic sources has revealed the concept of asperities, while many reports exist about significant drop of P wave velocity or other inelastic deformation in the seismogenic zone; i.e., if one can detect the asperities and monitor their properties, short term prediction of earthquakes is possible. But conventional seismic tomography has not sufficient resolution. Therefore we have initiated a new approach. In EM2000, we discussed the possibility of the phased array. Unfortunately, this approach could not be compatible with the conventional tomography method and the question was left open. Since then, we have constructed a direct tomography strategy on the general theory of inversion. Another important result discussed in EM2000 was a remarkable effect of embedment. Accordingly, we deployed the instruments in a deep enormous tunnel network that had been located in a high seismicity region. We will show the geophysical environment and will report how the equipments were installed and the system established.

NON-CONTACT LASER VIBROMETER WAVE SENSING ON CONCRETE

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Non-destructive evaluation techniques are needed to assess the in-place condition of concrete structures. However the time and effort required to perform NDE tests using conventional surface-mounted contact sensors hinder rapid evaluation of structures. The authors are cooperating in research to develop rapid and robust methods that collect mechanical wave signals from concrete structures and to characterize defects using that signal data. The suitability of surface waves and laser-based, non-contact wave detection techniques for this purpose are examined here. After an introduction to non-contact sensing, an experimental set-up is described and results from experimental tests are presented. Surface waves in a concrete slab specimen are generated with several different conventional sources. The ability of a laser vibrometer to detect wave propagation from concrete that does not have any reflective treatment is demonstrated, allowing the generation of ultrasonic images. Results from a concrete specimen containing a subsurface defect are then presented. The obtained ultrasonic images illustrate some limitations of using surface waves to detect subsurface defects in concrete, although approaches to improve the results are proposed.

MICROWAVE SUB-SURFACE IMAGING TECHNOLOGY FOR DAMAGE DETECTION OF CONCRETE STRUCTURES

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Invisible damage such as voids and cracks inside concrete and debonding between rebars and concrete caused by corrosions and earthquakes are of significant concerns. In this study, a microwave sub-surface imaging technology using a bi-focusing operator has been developed in order to detect such internal voids/objects and to quantitatively assess their dimensions. The proposed imaging system consists of several cylindrical- or planar-arrayed antennas for transmitting and receiving signals, and a numerical focusing operator is applied to the external signals both in the transmitting and receiving fields. An imaging algorithm using a numerical focusing operator was developed, which allows the recovery of a 2-dimensional object from its scattered field. For the experimental verification, a prototype planar antenna array consisting of 64 transmitting and 64 receiving antennas was fabricated and tested on a concrete block. Internal and invisible voids in the block were successfully detected. The sub-surface imaging technology developed in this research for quantitative condition assessment of concrete structures will lead to improvement of the effectiveness and efficiency of the current visual-inspection-based maintenance.

USE OF PASSIVE ACOUSTIC ENERGY MEASUREMENTS TO QUANTIFY MICRO-CRACK AND CRACK DEVELOPMENT IN VOLUMETRICALLY RESTRAINED CEMENTITOUS SYSTEMS

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Experiments were conducted using restrained and unrestrained linear 'bar-type' specimens. Acoustic sensors placed on the restrained specimens show a high degree of activity during the first several days due to the development of distributed damage. This can be attributed to surface cracking that occurs as a result of moisture gradients that cause the surface concrete to shrink much more rapidly than the core concrete. After the first few days however a discrete increase in acoustic activity is typically observed in the restrained specimens that was followed by the development of a visible crack. As the concrete nears the age of visible cracking the acoustic waves generated in the restrained specimen increase in duration and amplitude. The rate of energy dissipated in the unrestrained and restrained specimens is typically observed to deviate prior to the development of visible surface cracking signifying the onset of crack initiation and growth. Current research is aimed at relating the acoustic energies of different specimens with mechan-

ical properties such as fracture energy or stiffness reduction.

Characterization of Bond Properties in Repaired Concrete using Guided Lamb Waves

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Laurence Jacobs *Georgia Institute of Technology*

A popular repair method for reinforced concrete involves externally bonding fiber reinforced plastic (FRP) patches on to the tension face of a beam, thus increasing the beam's flexural stiffness and loading capacity. The usage of FRP patches in these applications has created the requirement for reliable nondestructive evaluation (NDE) techniques capable of characterizing these bonded patches; this research proposes using guided Lamb waves for this purpose. The primary advantage of using guided Lamb waves in this application is that they are capable of interrogating large, inaccessible components in a time-efficient manner. This research combines laser ultrasonic techniques with time-frequency representations (TFRs) to characterize the material properties of this adhesive layer. The current study examines the viscoelastic effect of the adhesive bond, specifically measuring attenuation. This experimentally measured attenuation is then related to changes in the bond's material properties. The experimental results are interpreted in terms of an analytical guided wave model that considers a two-layered system (the FRP patch and the bond) attached to a half-space (the repaired concrete).

Structural Control - II

June 3, 2002
13:00
Chair: Genda Chen University of Missouri-Rolla
Co-Chair: Anil Agrawal City College of New York

TLCD Semi-Active Seismic Control of Irregular Structures Using Artificial Neural Network

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In this paper, the control approach to irregular strucyures excited by multi-dimensional ground motions is presented by using semi-active tuned liquid column damper (TLCD). A back propagation Artificial Neural Network (ANN) is used to predict the responses of structure due to two-dimensional seismic inputs. The semi-active control strategy is established and implemented based on ANN. The numerical examples have shown that it is an effective method presented for controlling the translational and rotational responses of irregular structures.

Vibration Control of Stiffened Composite Panels with Smart Materials

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Piezoelectric devices (PZT) and electrorheological (ER) fluids, integrated as active components in stiffened composite panel systems, could be used effectively to control vibration response to random excitation. These panel systems are essential for structures such as aircraft, spacecraft, submarines, and high-speed trains, which are prone to random vibration from boundary-layer turbulence or power plant noise. Intelligent materials could be utilized to control these vibrations, reduce transmitted or radiated noise, and increase the fatigue life of the structure.

The adaptive panel structure is comprised of self-sensing piezoelectric actuators and active sandwich-beam stiffeners that contain a core filled with ER fluid. The piezoelectric sensor/actuators are bonded to the panel as discrete segments. An analytical model is developed in which the PZT devices sense the strain rate at the extreme fiber of the panel and then actuate to produce a localized moment. An active damping mechanism based on collocated velocity feedback control is thus obtained. The ER fluid changes its stiffness and damping properties with applied voltage. These active fluid properties are incorporated in the derivation of the governing equations of motion for the sandwich beams, which are attached to the panel at discrete intervals. It is demonstrated that applying voltage to the ER fluid alters the mode shapes and frequencies of the discretely stiffened panel system. Thus, positive gains might be

achieved for vibration reduction and control of noise transmission/ radiation.

The mode shapes, modal frequencies and deflection response are determined by transfer matrix methods. The root-mean-square (RMS) and spectral density of the response to a truncated Gaussian white noise excitation are calculated for a fiber reinforced laminated composite panel stiffened with two active stiffeners. The effect of the intelligent materials on vibration response is determined by varying the controller voltage gains of PZT actuators and ER fluid.

A direct application of the transfer matrix procedure for optimal active control of discretely stiffened panels, which incorporates intelligent materials, presents significant numerical difficulties. Thus, an alternative simplified solution based on a modal, Galerkin-like approach, in which the required modes and modal frequencies of the stiffened panels are first calculated by transfer matrix methods, has been developed. The resulting modal differential equations are transferred into the state-space domain to utilize the advantages of linear stochastic control theory. To be compatible with digital processing, the system is converted from a continuous to a discrete-time system using a ''zero-order hold'' controller and a sampling observer. A performance index is established consistent with the stochastic linear quadratic regulator problem and the state is reconstructed using a Kalman-Bucy filter. The algebraic Riccati equations are solved for the optimal observer and controller gains. Numerical results are presented to demonstrate the effectiveness of optimal control of stiffened-panel vibrations.

Optimal Control of Framed Structures Including Seismic Soil-Structure Interaction Effects

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In this work, a linear quadratic Gaussian (LQG) controller is constructed to optimally control seismic response of framed structures founded on soils. An approximate frequency-independent lumped-parameter model is used to represent the response of the foundation. This allows a full representation of the system equations, including the interaction between soil and the structure (SSI effects), in the time domain. The optimal control gain is interrelated to the SSI factors. To demonstrate the significance of the detailed modeling of the framed structure, a simplified one-column model including SSI effects is set up for comparison with the response of the full planar frame founded on soil. Simulation results show that, at least in some circumstances, simplification of the structure into a 1D model by neglecting its 2D nature may lead to missing important characteristics of the structure. While the soil foundation is very soft, the controller incorporated the SSI effects shows a better performance. For much stiffer soil conditions, the LQG controller works very effectively, designed either with the fixed-base model or the SSI model.

Semi-Active Vibration Control for the 3rd Generation Benchmark Problem Including Modal Spillover Suppression

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New control algorithms that combine spillover suppression with semi-active modal vibration control via the use of magnetorheological (MR) dampers are studied. The advantages of this approach include the traditional positive attributes of MR dampers as well as more efficient use of the dampers obtained by targeting control effort at high energy modes and preventing spillover. Strategies for this combined approach are compared to existing algorithms that concentrate solely upon vibration control. Performance measure improvements have been found and are discussed. In the context of the benchmark problem, one structure is shown to possess vibration modes that involve primarily vertical motion with virtually no horizontal displacements. Some of these vertical vibration modes occur at relatively low frequencies, and their presence can produce unexpected behaviors. The impact of including these modes in the new control/spillover algorithms has been quantified and found to be significant. The modeling of this structure has been investigated to determine the relevance of these modes to the actual behavior of the structure. The consequences of this for all structural control algorithms are discussed.

Efficiency of Piezoelectric Wedge Actuators for the Fine Tuning of Mass Dampers in Structural Applications

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A piezoelectric wedge actuator (PWA) is proposed in this paper to improve the seismic effectiveness of a passive tuned mass damper (TMD). A PWA is composed of a thin aluminum plate and two piezoelectric sheets bonded on the aluminum plate. The actuator is connected in series with a TMD and will be used either as a variable stiffness device or a damping unit regulated with applied voltage. Several control algorithms including displacement proportional, velocity proportional, and Bang-Bang strategies are considered. Numerical results indicate that a PWA is effective for a light mass damper and rapidly become ineffective as the weight of the damper increases. A change of 1% in natural frequency of a TMD experiencing a peak displacement of 0.25 in. can be achieved with the displacement proportional control when 750 Volts are applied on the piezoelectric actuator. Similarly, an increase of 33% in damping ratio can be achieved with the velocity proportional control and an equivalent damping ratio of 0.054 is obtained with the Bang-Bang control for a TMD of 0.024 original damping ratio.

Biologically Inspired Materials - II

June 3, 2002
13:00
Chair: Dinesh Katti North Dakota State University
Co-Chair: Eric Landis University of Maine

An orthotropic hyperelastic model of cylindrical thick shells under pressure : application to the modeling of aneurysm

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The mechanical behavior of blood vessels has been analyzed considering a thick-walled multilayer cylindrical orthotropic model material undergoing large deformation. We analyze herewith the behavior of thick non-linear shells submitted to a pressure on both their internal and external faces, up to the bifurcation regime. We aim thereby at modeling some pathologies encountered in vessels, like aneurysm development, when an instability inherent to the vessel is triggered by external factors, leading to a bifurcated shape. In order to model in a as realistic manner as possible the vessel, the material of the shell is assumed to obey an orthotropic hyperelastic behavior, and a single layer model is envisaged first. The response is assumed to be instantaneous, so that time-dependent effects shall not be considered in the present contribution. The cases of Saint-Venant Kirchhoff, Mooney-Rivlin materials, and a classical four parameters form of the constitutive law are considered with special emphasis. The stability conditions of the shell are being studied, and bifurcation conditions are formulated, in terms of the applied pressure, and the geometrical and mechanical parameters that characterize the shell. Bifurcation points are evidenced and calculated. In a second step, the multilayer structure of the blood vessel is considered : an approach using a gradient of mechanical properties is employed, as well as a model considering several concentric layers endowed with homogeneous specific properties. The numerical study of some bifurcation's from one branch of solutions to another branch is envisaged as a perspective of development.

Nanostructure-Nanomechanical Property Correlations in Biological Hard Tissues: Towards Biomimetic Materials Design

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Biological hard tissues (bones, teeth, spicules, particles, thin film, spines, and shells) are composites of biological minerals and macromolecules (proteins and polysaccharides) that form complex hierarchical structures. These biocomposites have unprecedented mechanical and other physical properties that are not seen in human-made materials. Both the ordered structures and, therefore, the multifunctional properties of biological materials are a result of control imposed by proteins over the collection of ionic precursors and their mineralization, development of mineral type, morphology and crystallography resulting in an overall structural hierarchy through self-assembly processes. Unlike common engineering materials, biological hard tissues are synthesized under ambient conditions in water, the inorganic components are common materials, and the biocomposites are formed via self-assembly. It is desirable to use the principles of biomaterials and mimic them in real (bio, physical, chemical, and civil) engineering applications. Such a task requires a thorough understanding of the bases for fabrication, structural formation, and mechanics of these biological systems.

Although structure-function relationships of some hard tissues have been studied at the macro and bulk scales, this has not been so common at the nano- and sub-micrometer scales. The individual components of the biological hard tissues, i.e., the mineral and the organic phases, often found at dimensions of smaller than a micrometer. This is the scale, therefore, at which organic and inorganic components form ordered aggregates and constitute the lowest scale of the structural hierarchy, dictating overall property of the biocomposite. Here we present three examples of biological hard tissues and illustrate detailed correlations of structure-function relations at the nano- and submicro-meter scales. These are: 1. Tooth enamel in mice and humans; a hard, wear resistant nanocomposite (Fig. A) on the outer section of tooth covering softer and tougher dentine that form functionally-gradient composite; 2. Sponge spicule, a concentrically layered composite of silica and proteins that form a tough optical fiber (Fig. B); 3. Nacre, mother-of-pearl, of mollusk shells, a segmented, laminated, tough and strong composite (Fig. B) with impact-resistant properties. We used transmission and scanning electron microscopy and scanning probe microscopy techniques to analyze nano- and micro-scale substructures of the inorganic components (hydroxyapatite, silica, and calcium carbonate, respectively) and correlated these with nano- and micro-mechanical properties, performed via atomic force microscopy to establish structure-property correlations at the lowest dimensional (nm/sub-m) and loading (nN and mN) scales.

Control of Mechanical Responses in Insitu Polymer-Hydroxyapatite Composites for Bone Replacement

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Polymer-hydroxyapatite (HAP) composites are extensively studied for their potential use as bone replacement materials. In situ mineralization of HAP and the role of organics in initial nucleation and growth of HAP is critical for the resulting nano and microstructure of HAP. It is becoming increasing known that materials based on or mimicking biological structures exhibit far superior properties. In order to mimic biological processes, HAP is synthesized in the presence of polymeric additives. A molecular control of the crystallization of HAP to obtain desirable response of composite to loading is attempted. This work presents fundamental studies on the role of initial mineralization of HAP on bulk mechanical responses of composite. Fourier transform infrared attenuated total reflectance (FTIR ATR) spectroscopic experiments are undertaken to evaluate the association of polymeric chains with HAP during mineralization processes. Small changes are seen in the absorbance spectra of in situ HAP that relate to large differences in mechanical response of the composite to loading. Changes in mechanical response in the in situ composites include improved strain to failure and improved compressive strength under aqueous environment. In addition, smaller plastic strains are observed for in situ samples when subjected to cyclic loading. Our results may have significant implications in the design of biomaterials for biomedical applications.

Effect of Nanostructure in Nacre: A Multiscale Modeling Approach

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A shift from a test-based to simulation-based methodology is desired for new naonostructured engineered systems. Also, for complex bio-nanocomposite systems, the modeling methodology must cover length scale from molecular (nanometer) to meso and macroscale. In this work, we model and simulate mechanical responses of nacre, a biomimetic layered nanocomposite of an organic (polymer - protein) and an inorganic (ceramic - calcium carbonate) components. Nacre (mother-of-pearl) is a common mollusk shell hard tissue with a successful ìstructural engineering designî that has survived five hundred million years of evolution. As a nanotechnological model system, nacre represents several unique opportunities; it has a relatively simple layered architecture. It is a self-assembled system with hybrid components (organic/inorganic) that are highly organized hierarchically at the molecular, nanometer, micrometer and macro scales. Numerical models using three-dimensional finite element analysis are developed for predicting nonlinear response of the nanocomposite. These three dimensional models represent the true pseudo-hexagonal symmetry of the nacre and also include such details of the nanostructure as mineral contacts through the organic phases. Material properties obtained at nanometer scale using nanoindentation experiments are incorporated into the 3D FE models. Our linear and nonlinear response simulations indicate that the organic phase is a material of exceptional yield strength and elastic modulus. Our simulations indicate mineral contacts through the organic phase are not significant for mechanical response in the elastic region. Identical elastic modulus of nacre is obtained for models with and without contacts. In addition, effective normal stress in the contact regions is much higher than that applied. Thus, contacts break long before (~10 MPa) yield begins in nacre (~30 MPa) implying that they are not of much consequence for yield behavior of nacre. Our results identify the quantitative influence of details of the nanoarchitecture on bulk linear and non-linear response. These results have important ramifications on the design of novel nanocomposite systems mimicking those found in nature.

Analysis of Materials with Random Microstructures

June 3, 2002
13:00
Chair: Lori Graham Johns Hopkins University

A path-following constraint with application to Monte Carlo simulations of failure in softening solids

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A fundamental issue in computational solid mechanics is the development of robust algorithms to trace the equilibrium path. The essence of these algorithms consists of coupling the load increment to the increment of selected degrees-of-freedom through a constraint function.

When solids are studied that exhibit material instabilities it is often necessary to select the path-following constraint such that only the degrees-of freedom involved in the failure process are coupled to the load increment. While this kind of constraint is robust, its applicability is limited when the location of the failure process zone is not known a priori. In this contribution a path-following constraint is developed which is based on the energy release rate. The constraint is derived from the first principle of thermodynamics for a finite element discretisation of a solid with a continuum damage model.

The constraint is especially applicable to Monte Carlo analyses of random quasi-brittle solids. Indeed, the position of the failure process zone is then often determined by the weak spots in the material and cannot be predicted beforehand.

Modeling the Impact of Localized Deformation on the Bulk Response of Heterogeneous Energetic Materials

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A multiscale homogenization approach, based on the generalized method of cells (GMC) is proposed for examining the influence of local variations in microstructure on the bulk response of heterogeneous high explosive (HE) composite materials. On average, the material consists of 93% brittle crystal particles ranging from 1 mm to 450 mm in size, bound by a plastic polymer material. Using GMC, we analyze the HE elastic response considering several representative volume elements with the same crystal volume fraction but with different particle/binder arrangements. Based on strain rate sensitivity of the composite elastic moduli, we find that these microstructures can be classified as either binder bridging or particle bridging. The microstructures with particle bridging exhibit significantly higher moduli (by an order of magnitude) and lower strain rate sensitivity than do microstructures with binder bridging. Such a classification can be used to reduce the number of configurations that need to be considered in mechanical simulations of HE.

Effective Conductivity for Random Heterogeneous Materials

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A method is developed for estimating the effective conductivity of random heterogeneous materials. The methods can be applied to both multi-phase materials with inclusions of arbitrary geometry and spatial distribution as well as materials with smoothly varying properties. Since conductivity is assumed to vary randomly in space and its range is bounded, it is represented by a non-Gaussian random field. The analysis is based on Ito calculus and Monte Carlo simulation. The Ito calculus is used to find the local solution of heat equations corresponding to samples of the conductivity field generated by Monte Carlo simulation. The proposed method is applied to find the effective conductivity of a two-phase materials and materials with smoothly varying conductivity.

Micromechanical Analysis of Concrete with Random Microstructure

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A model based on the moving window generalized method of cells is presented for the mechanical analysis of concrete microstructure. This model includes debonding between unlike phases to capture aggregate-cement paste interfacial cracking, a phenomenon that is accepted as a major source of nonlinearity in the stress-strain behavior of concrete. The model results in stress-strain responses that are highly dependent on the orientation of aggregate particles within the cement paste matrix. The model is calibrated to a typical concrete stress-strain curve, and used to generate equivalent material property fields for an actual concrete microstructure. Statistical analysis of the resulting data underscores a number of features of the model. The initial elastic modulus is highly dependent on the volume fraction of aggregate in concrete. The post-debonding elastic modulus is dependent on the presence of aggregate-cement paste interfaces in the direction of the applied strain. The model shows significant promise for evaluating the material properties of concrete specimens based on their individual microstructural characteristics.

Symposium on Micromechanics of Heterogeneous Materials - Session II

June 3, 2002
13:00
Chair: Colby Swan Center for Computer-Aided Design
Co-Chair: Lizhi Sun The University of Iowa

A Differential Scheme for Elastic Properties of Rocks with Dry or Saturated Cracks

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Differential effective medium (DEM) theory is applied to the problem of estimating physical properties of elastic media with penny-shaped cracks, filled either with gas or liquid. These cracks are assumed to be randomly oriented. It is known that such a model captures many of the essential physical features of fluid-saturated or partially saturated rocks. By making an assumption that the changes in certain factors depending only on Poisson's ratio do not strongly affect the results, it is possible to decouple the equations for bulk (K) and shear (G) moduli, and then integrate them analytically. The validity of this assumption is then tested by integrating the full DEM equations numerically. The analytical and numerical curves for both K and G are in very good agreement over the whole porosity range. Justification of the Poisson's ratio approximation is also provided directly by the theory, which shows that, as porosity tends to unity, Poisson's ratio tends towards small positive values saturated samples. A rigorous stable fixed-point is obtained for Poisson's ratio of dry porous media, where the location of this fixed-point depends only on the shape of the voids being added. These theoretical results for the elastic constants are then compared and contrasted with results predicted by Gassmann's equations and with results of Mavko and Jizba, for both granite-like and sandstone-like examples. Gassmann's equations do not predict the observed liquid dependence of the shear modulus at all. Mavko and Jizba predict the observed dependence of shear modulus on liquid bulk modulus for small crack porosity, but fail to predict the observed behavior at higher porosities. In contrast, the analytical approximations derived here give very satisfactory agreement in all cases for both K and G.

Influence of Geometrical Features of Unidirectional Fibrous Lamina on Its Transverse Response

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Dimensional analysis is used in this study to establish general relations between geometric features of unidirectional fibrous lamina and the corresponding transverse responses, including transverse modulus and stress distribution in matrix. Prediction of transverse response of unidirectional fibrous lamina was made long ago, e.g.

Halpin-Tsai equations. However, specific geometrical features of such composites are typically lumped into the volume fraction of fibers. Using micromechanics via explicit representation of fibers, it is demonstrated explicitly in this paper that the transverse response is dependent on two geometrical parameters, one is the usual fiber volume fraction, and the other is the ratio of fiber diameter to fiber spacing. A new formula for prediction of transverse response of the composite is established based on linear elastic finite element analysis. The new formula is validated via lab test data. The formula is extended to nonlinear analysis by integrating nonlinear matrix behavior in a separable way under certain restrictions. It is also demonstrated that stress distribution in the matrix and location of peak stress changes with the aforementioned ratio when fiber diameter and thickness are fixed. The effect of random fiber spacing is also investigated.

Micromechanics of anisotropic damage in rocks and concrete : unilateral effects modeling and coupling with friction

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Anisotropic damage of quasi brittle geomaterials such us concrete or certain rocks is investigated within a general three-dimensional micromechanical approach. Firstly, we establish general expressions of the macroscopic potentials (free energy and free enthalpy) which incorporates microstructural quantities of this class of materials (mesocracks density parameter and orientation, crack opening displacements). Assuming that damage by mesocracks growth is the main dissipative mechanism of the considered materials, we derive then expressions of the damage-dependent potentials which takes into account the opening/closure status of mesocracks. The mesocracks closure criterion as well as the elastic moduli recovery conditions are carefully addressed and discussed. A suitable damage potential based on the use of the damage-energy release rate is also proposed and illustrated in various stress subspaces. The local integration of the rate formulation of the model (derived with normality assumption) is done using a classical strain discretization of the considered loading paths and a particularly simple elastic predictor - damage corrector scheme. Numerical simulations performed on the basis of the developed model are consistent with experimental data on a French (Vosges) sandstone. In order to show the main capabilities and some advantages of the micromechanical approach, we detail various numerical results where material evolving microstructure and damage-induced overall anisotropy are clearly correlated.

The last part of the study is devoted to the coupling between damage and sliding by friction phenomena. Such coupling, which occurs on closed mesocracks, provides an unified treatment of damage, permanent strains and hysteretic effects generally observed at macroscopic scale for most cohesive and frictional geomaterials. A classical Coulomb law is adopted. Then the general computational issues associated to the stress-based and strain-based formulations of the coupled model are presented and discussed. Finally, the two formulations are compared in details through the responses predicted under particular stress paths.

Microstructural Simulation of Asphalt Materials: Modeling and Experimental Verification

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Results will be presented of a research project dealing with simulation of the mechanical behavior of asphalt concrete using a microstructural finite element approach. Asphalt is a heterogeneous material composed of aggregates, binder cement and air voids, and may be thought of as a cemented particulate system. Load carrying behaviors are strongly related to the local load transfer between aggregate particles, and this is taken as the microstructural response. Numerical simulation was developed using the finite element method, whereby the microstructural asphalt/binder system is replaced by an equivalent finite element network. Based on a mechanics solution for the load transfer between cemented particles, special elements in the network have been developed to predict the load carrying behavior between neighboring aggregates. Simulations of standard laboratory compression and indirect tension tests have been conducted, and the results have compared favorably with experimental data. Modeling simulations have been developed for a variety of material microstructures including aggregate gradation and distribution, binder volume and distribution and porosity. Further experimental verification has included tests on specially prepared cemented particulate systems, which have allowed detailed measurement of aggregate displacements and rotations using video imaging and computer analysis. Model predictions have compared well with this verification data.

The effect of damage on diffusivity of composite materials

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This paper describes a new method using composite theories to evaluate the effect of damage on diffusivity of distressed materials. Distressed materials can be considered as a two-phase composite material with the distressed elements as one phase and the original material as the other phase. Then, composite models developed for effective properties of two-phase composites can be used to evaluate the effect of damage on distressed material. The progressive damage can be characterized by the change in volume fraction of the distressed phase. As an example, the diffusivity of distressed materials is evaluated by a two-phase composite model based on generalized self-consistent theory. The methods for determining the model parameters are introduced, and the prediction of the two-phase composite model is compared with the test data. The concept of the two-phase composite theory can be further extended into a general multiphase composite theory to evaluate the effect of multilevel damage on effective stiffness and transport properties of materials.

Inelastic Behavior of Materials
June 3, 2002
13:00
Chair: A. (Rajah) Anandarajah Johns Hopkins University

An Analytical Investigation of Necking in the Tensile Test

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A very small inhomogeneity in macroscopic material properties is considered for the investigation of necking of a (polycrystalline) bar in the tensile test. A simple, one-dimensional model is adopted (i.e. spatial variation only along the barís length), corresponding to which the evolving nonuniformity of cross-sectional area with increasing load, up to the maximum, also is small. The inhomogeneity is represented by a single modulus varying slightly with position, but with the same dimensionless form of the stress-strain curve throughout. A transcendental equation is derived that relates the strains at the weakest and strongest sections to their respective material strengths. It is shown that, at the well known ConsidËre strain (corresponding to the maximum load), the decrease in area at the minimum section is only a little greater than at the strongest, but its rate of change with the latter strain is infinite. The analysis thus gives an idealized representation of the rapid increase in necking that typically ensues from the maximum load in experiments.

Nonlinear Analysis Using Regular Yield Surface

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In this paper, a new methodology is presented to non-linear analysis of masonry shear wall under biaxial stress state using the finite element method. The methodology focuses on the definition / specification of the yield surface for the case of anisotropic masonry under biaxial stress state, as well as on the numerical solution of this non-linear finite elements problem. Specifically, in order to define the yield surface we use a cubic tensor polynomial, whereas we use the initial stress method in order to solve the elasto-plastic problem. In addition, novel computer code of finite elements has been developed in order to apply the method of elasto-plastic analysis of plane masonry wall. The main advantages of the method can be summarized as follows: a) The plasticity equations through a regular surface leads to the elimination of the problem that occurs by the use of singular surface, and b) It is clearly shown that the non-linear behavior of masonry is strongly affected by the yield criterion.

A Non-Local Approach with Evolutionary Internal Length for the Analysis of Mode I Fracture Processes in Concrete

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A non-local approach with an “evolutionary internal length” is here proposed and implemented in the formulation of the “Crush-Crack” non-local damage model. The internal length is actually made evolving with the damage from its initial value, which is correlated to the material characteristic length. The evolution laws of the internal length with damage have been calibrated, mainly with reference to the value that such a length has to assume at complete breakage of the material (damage equal to one), in order to not retrieve the drawbacks of a local analysis. The calibration of such a law and of the whole set of model parameters is performed on both 1D and 2D benchmarks in uniaxial tension, taking a Normal Strength Concrete as a reference. The reliability of the proposed approach is finally checked with reference to experimental results from direct tension tests.

A Continuous Dislocation Model of Mode I Crack

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A dislocation-free zone model for centrally symmetrical mode I crack of finite length is presented on the basis of continuous dislocation distribution model. The crack and the plastic zones at the crack tip are simulated by continuous distribution of dislocations. A simultaneous set of singular integral equations has been derived for the configuration of a crack and two pairs of symmetrical slip bands. This equation set reduces to the case of Chang & Ohr (1981) when the sliding plane is in the prolongation of the crack plane. Numerical results demonstrate that an increase in stress can give rise to dislocation density increment, and thus excite dislocation activities. When the ratio between the lengths of the crack and the dislocation-free zone is 100, the distribution of dislocations is in proximity to that of the case for the infinite-length crack. The derived dislocation-free zone condition simplifies the measurement of experimental parameters.

Scaling Of Failure Of Floating Sea Ice Plates

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Because laboratory tests showed sea ice to be notch-insensitive, the failure of floating sea ice in the Arctic has until recently been analyzed according to either elasticity with a strength limit or plasticity, which both exhibit no size effect. Fracture mechanics was considered to be inapplicable to sea ice, and if a size effect was suspected, it was regarded as strictly statistical. This state of affairs was radically changed by the epoch-making size effect tests of Dempsey's team in the Arctic, in which fracture specimens up to 80 m in size were broken. The tests confirmed a strong deterministic size effect and applicability of fracture mechanics on the large scale. Building on this fact, now almost generally accepted, the present paper presents fracture mechanics solutions for several important problems: Fracture caused by a vertical concentrated load or by a vertical line load, and fracture in moving ice pressing against a stationary object such as an oil platform. Various approximations are introduced and the cohesive nature of fracture is taken into account. The buoyancy of water, which acts as an elastic foundation, is found to have a major effect on the response. The solutions exhibit a strong deterministic size effect, but different size effect laws are found for the aforementioned different modes of loading. Comparisons with previous numerical simulations and some limited test results indicate good agreement.

Frank L. DiMaggio Symposium on Constitutive Modeling of Geomaterials II

June 3, 2002
13:00
Chair: Hoe Ling Columbia University
Co-Chair: A. (Rajah) Anandarajah Johns Hopkins University

Fatigue Tests On Bituminous Composites: Balance Between Damage And Recovering

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Estimating the lifetime of a bituminous mix under traffic loading is a hard step in the pavement design process, since the model loading used in laboratory tests can only be regarded as highly simplified when compared to real loadings. On site, the losses of stiffness can be more or less deleted when rest periods are managed between two following loading cycles. Therefore the on-site relation between stiffness and number of cycles cannot be directly derived from that obtained in the laboratory. Predicting this evolution is even more difficult when sampling processes on an existing road can induce some biases in the evaluation of material properties.

Generally speaking, when one performs tests with mixed loading sequences and rest sequences, it is shown that the stiffness (or loss of stiffness) is only a poor indicator of the remaining lifetime.

A specific experimental process has been developed such as to distinguish the effects of various factors influencing the loss of stiffness during fatigue bending tests: magnitude of imposed displacements, number of cycles, number of sequencesÖ The main results are the following ones: - The recovering kinetics follows an hyperbolic law, the asymptotic recover (limit when rest time tends to infinity) is roughly complete, in a wide range of loadings. When considering initial stiffness (just after loading sequences), the viscoelasticity makes the material can 'forget' a significant part of the effects of past loadings. - The loss of stiffness rate (decrease with number of cycles of the stiffness during any loading sequence) progressively and softly increases when the number of repetitions (loading sequence + rest sequence) increases. The kinetics of the loss of stiffness seems to be a relevant indicator of the damage level the material has yet reached: even if it has apparently totally recovered, a highly damaged material will loss its stiffness more quickly when it will be re-loaded. Therefore, it seems reasonable to develop a model in which the damage level is linked, for a given magnitude of loading, with the loss of stiffness rate. Additionnal tests are being performed such as to validate this concept and identify the relations between : - past loadings (number and magnitude) and the loss of stiffness rate, - loss of stiffness rate and remaining lifetime, for a given magnitude of incoming cycles, - remaining lifetime and magnitude of cycles, for a given initial damage level. This last point should allow to generalize the concept of e6 strain to any pre-damaged composite mix and to better predict the residual lifetime of existing pavements.

Modelling The Unbound Granular Material Long Term Behavior

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The paper deals with the long term behavior of unbound granular materials (UGM) used in lower layers of flexible pavements since the permanent deformation of the unbound layers is the first cause of rutting, the visible deterioration mechanism of such structures.

Predicting long term deformations of these materials under repeated traffic loads and with real environmental conditions requires one is able to : - identify the main factors which contribute to the material evolution, - reproduce such evolution of deformations under a large number of loading cycles, - quantify and model the final properties (stiffness, non reversible strains) of the material as a function of the initial values of the relevant properties of the material, - evaluate the real values of these properties in the 'initial state' in the real structure.

Each of these steps introduces some approximations and uncertainties, whose the quality of the final predictions depends on.

The study has been focussed on the response of limestone UGM and it has followed three directions : - laboratory tests, including a large number of repeated triaxial tests on 16x32 cm cylinders. The number and analysis of test results has been optimized referring to the experimental design theory which allowed us to reduce the duration of the program. Two series of tests have been performed, the first one being focussed on the material fabric (initial state as a function of the works process and of the material physical parameters : kind of limestone, smaller particles content, water content and intensity of compaction), the second one being devoted to the long term response (relations between initial state and final state, for various magnitudes of stresses) ; - on-site measurements, allowing to obtain informations at the different steps : material fabric and initial state (including its -very important- spatial variability), environmental conditions and physical evolution during the life of the road, final state (strains, stiffnessÖ including an 'autopsy' of the road which has been demolished) ; - the two studies have been coupled through numerical simulations and a model has been established to predict the long term evolution of strains in the road. The limits of the model have been highlighted. They are linked with: (a) the range of variation of the influent factors during the program, (b) the high level of uncertainties in some field measurements, (c) the statistical quality of the models, itself being linked with the repetability of laboratory tests.

Interpretation of combined axial-torsional test For 3D constitutive behavior of geo-materials

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Laboratory experiments on long and thin hollow cylinder soil specimens subjected to a combination of normal and shear stresses under confined conditions is valuable for evaluating their three dimensional constitutive behavior. The present paper discusses a new approach for interpreting the complete state of stress and strain during isotropic consolidation and subsequent phase of applying shear stress. A clear rationale for assumptions involved in updating the specimen geometry, correcting for latex membrane effects while undergoing axial and/or torsional deformations, appropriate expressions for evaluating the current state of stress and strain are presented. The interpretation of measured data (initial specimen geometry, axial load, axial deformation, torque, rotation, pore pressure, volume change, and cell pressure) as proposed is based on minimum number of assumptions, and are justified by the theory of elasticity. The proposed method was applied to interpret the results of a combined axial-torsional test data on Kaolin clay performed at a constant inclination of major principal stress of 60 degrees with the axis of rotational symmetry.

AN ENERGY-BASED MODELING OF SAND AND ITS FEM APPLICATION

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The paper describes a non-linear three-component model (an elasto-viscoplastic model) consisting of a hypo-elastic component connected in series to a combination of non-linear inviscid and viscous components connected in parallel. The hardening function for the inviscid component is an anisotropic relationship between a stress parameter and the modified irreversible strain energy, which is independent of stress path. The viscous component exhibits a non-linear viscous property. Inherent and stress system-induced cross-anisotropic elasticity and strain localization into a shear band(s) having a thickness that is a function of particle size are considered. The FEM code incorporating the above-proposed model is validated by a direct comparison between the results from the FEM analysis and corresponding plane strain compression tests and model footing bearing capacity tests of unreinforced and reinforced Toyoura sand.

Optimization and Sensitivity Analysis in Calibration of Liquefaction Constitutive Model

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Large sets of soil experimental data (field and laboratory) are becoming increasingly available for calibration of soil constitutive models. A challenging task is to calibrate a potentially large number of model parameters to satisfactorily match many data sets simultaneously. This calibration effort can be facilitated by optimization techniques. In this paper, an existing numerical optimization computer code is employed in calibrating a plasticity model developed for liquefaction simulation. Calibration is based on experimental data from a dynamic mild-slope liquefaction centrifuge experiment. The objective function is chosen to minimize the difference between computed and observed liquefaction-induced lateral spreading. The optimized computational results show a reasonable agreement with the experimental counterparts. In addition, a parametric study is conducted to demonstrate the effectiveness of, and certain subtleties associated with numerical optimization techniques.

A Sand Model Based on Generalized Plasticity

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The behavior of sand and performance of earth structures are strongly affected by the confining stress. Many existing models for sand are not capable of describing the behavior ranging from very low to very high confining stresses. In this study, a generalized plasticity model is extended to capture the dilatancy and strength properties of sand under a wide range of stress levels. The model is validated with the experimental results of several different types of sand under drained conditions.

Discrete and Continuum Modeling of Granular Materials II

June 3, 2002
13:00
Chair: Ching Chang University of Massachusetts
Co-Chair: Jin Ooi University of Edinburgh

On the Error Control by Damping in Cluster Impact Problems in Granular Mechanics

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The two properties of the colliding balls: their stiffness and damping are important in predicting the outcome of dynamic simulations in granular mechanics, especially when in dense systems clusters of balls are formed. A ball is usually modeled as a soft sphere with its stiffness properties described either by a linear or a nonlinear (Hertz model) spring. As it was shown previously by the author the above two models lead to qualitatively different patterns of break up of a linear chain of balls struck by a cue ball. The less clear question is the modeling of damping (or loss of energy) during the collision since there are different physical mechanisms responsible for such losses. For the case of binary collisions a conventional approach is to assume some coefficient of restitution, which is based on a linear damping model. However, even in this case the linear damping model may lead in a long run to distortion of the simulation outcome. Such a model may produce even more erroneous results in the case of multi ball collisions. The present paper is focused on analyzing the effect of damping models on the behavior of a chain of balls struck by a cue ball. The collisions are central in this case and the nonlinear Hertz stiffness and a nonlinear damping model for a ball are considered. The numerical investigation is focused on establishing the relationships between the size of the system, the accumulated error for a given coefficient of damping, and the time step of simulation. A concept of error-controlled damping is introduced which allows a time-step increase without loss of accuracy of results.

Modelling Of Injection Of Fine Cement Grout : Discrete Approach

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Injection aims to improve the soil characteristics through consolidation and/or sealing. This paper presents a new groutability criterion dedicated to select the adequate size of cement to be injected in a given sand sample. It also deals with a numerical modeling of the injection by the Distinct Element Method, which represents an innovation in the matter. In fact, most of the numerical grouting models consider soil and grout as continuum media. However, as most of the grouts are of suspension type, the continuous approach generally presents difficulties by taking into account the particle retention witch presents the main reason of an injection failure. The new numerical model represents each soil and cement grain separately so that the void matrix of the sample as well as cement grains blocking in front of small passages are well taken into account. The injection process is expressed through drag forces applied by the suspension fluid on cement particles. The comparison of numerical results

with experimental ones showed that the numerical discreet approach of grouting is quiet interesting.

Discrete Element Simulation Of Flow Through Porous Media

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The dynamic flow of water and other viscous fluids through granular soils is commonly modeled using Darcy's law with time-independent permeability coefficients. Experimental studies show that this law is not valid for large nonlaminar fluid velocities which may develop under high hydraulic gradients. Furthermore, particle rearrangements leading to substantial variations in porosity are prevalent during soil liquefaction and other extreme flow driven phenomena, such as piping. These variations in porosity affect significantly the soil hydraulic conductivity and stiffness characteristics. This paper presents a coupled micro-mechanical technique to model pore water flow and solid phase deformation of granular soils. The fluid motion is idealized using averaged Navier-Stokes equations, and the discrete element method (DEM) is employed to model the assemblage of granular particles. The fluid-particle interactions are provided by established semi-empirical relationships. The developed model is used to simulate a range of seepage conditions through idealized granular samples. The conducted simulations are validated using published experimental results.

The Arctic Sea Ice Pack: A Large Fracture Mechanics Problem

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The Arctic ice pack is composed of parcels of first-year and multi-year ice interlaced with leads (areas of open water) and pressure ridges (piles of broken ice) covering about 10 million square km. In the past, with interest focused on Arctic basin-scale processes, sea ice models have used continuum rheologies. With the current focus on resolution approaching the scale of individual leads, it makes sense to develop a model that incorporates this level of detail. We have constructed a granular sea ice model that consists of hundreds of thousands of discrete polygonal floes 5-10 km in width. At the beginning of a simulation the ice floes completely fill the Arctic basin and are frozen together. Wind driven deformation of the pack creates relative motion between adjacent floes that stretches the viscous-elastic joints between floes. The stress at each point along thefrozen joints is defined by a constitutive model that follows linear loading and unloading paths. After unloading the joint is broken at that point. Fractures propagate along joints forming fracture patterns in the model ice pack. The fracture patterns define large aggregate floes 10-100 km in width that are aggregates of many individual floes. Subsequent deformation occurs along slip lines defined by the aggregate fracture patterns. Since the usual state of the ice pack is a state of failure, an interesting situation is created in which the initial wind-driven deformation defines the conditions under which subsequent wind-driven deformation occurs. We study the formation of the aggregate under various deformation states and the dependence of the averagearea of the aggregate floes on tensile strength, wind stress gradient, and the size of the individual floes.

Computational Characterization of Materials and Structures

June 3, 2002
13:00
Chair: Harry Shenton III University of Delaware

Computational Modeling of Synthetic-Fiber Ropes

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Within the last few years, the demand for exploration and production of petroleum in deeper and deeper waters has been on the increase. At very large water depths, the use of steel mooring systems in a catenary configuration becomes very expensive and, because of the need to support its large self-weight, operationally impractical. As a result of these limitations, the oil industry has become supportive of using synthetic-fiber ropes in a taut mooring configuration for positioning floating structures in very deep water.

Because of the recognized need to better understand the behavior of synthetic-fiber ropes before they can be put into widespread use, there has been an increasing amount of research in recent years to study the response of these mooring systems in the marine environment. Tests performed on a variety of different rope segments have indicated several possible failure mechanisms. These mechanisms depend upon the nature of the applied loads as well as the characteristics of the test specimen. In addition, deformation characteristics have been shown to be complex functions of the load, load rate, and load history. Because testing large-scale ropes is costly, the current study focuses on the development of a computational tool to provide engineers with a means for developing preliminary designs and performing parameter studies without extensive experimental testing.

In this research, simulation software to represent the response of synthetic-fiber ropes under both monotonic and cyclic loading has been developed. A hierarchical analysis methodology has been employed to allow for flexibility in representing the various rope configurations currently in use. Assumptions related to the kinematics of deformation and nonlinear constitutive behavior lead to a computationally efficient model that is able to capture the essential features controlling rope behavior. The entire rope response is evaluated using a classical equilibrium approach, which is found to be convenient when calculating the contribution of frictional forces. A four-parameter damage model has been included in the constitutive relation to allow for the degradation of rope properties under cyclic loads. Preliminary results have shown good agreement with test data.

Determination of Size and Stranding Pitch of Loose Tube in Fiber Optic Ribbon Cables

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For loose tube cables, shorter stranding pitch gives better durability that ensure optical performance for bending. However, the fiber strains increase as the pitch decreases, and this becomes one of the dominant reasons for attenuation increase. Furthermore high fiber strains reduce the fiber lifetime and the reliability of the system. The strain distributions in optic fibers caused by stranding and twisting are investigated using finite element analysis with the assumption of large deformation to determine the shortest stranding pitch that gives the maximum fiber strains below lifetime limit. Also, it is necessary that the tubes have sufficient size to endure some compressive load and keep the optical performance. The deformation of loose tube cable under compression is calculated using finite element analysis. The sensitivities of tube size on cable deformation are analyzed from this study.

Structural Damage Identification Using Static Dead Load Strain Measurements

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A method has recently been developed for identifying damage in a structure that is based on the redistribution of dead load in the system. The static-based procedure uses only strain measurements at a few degrees of freedom (DOFs) and no additional external force is required. These features make the method ideally suited for long-term monitoring of large civil structures. Damage in the structure is represented by a section of reduced flexural rigidity. The identification problem is formulated as an optimization problem, which is solved using a float-representation genetic algorithm (FGA). The static flexibility-based error function is defined as the difference between the measured strains and the analytically predicted strains obtained from a finite element model. By minimizing the error function, the damage location and damage severity can be successfully identified. The method is demonstrated using on two structures, a fixed-fixed beam and a simple frame. Results show that the procedure can correctly identify the damage with good accuracy, even in the presence of measurement noise.

A NONLINEAR VISCOELASTIC MODEL FOR CONCRETE'S CREEP AND CREEP FAILURE

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Concrete is a complex and very widely used engineering material with different time and length scales. The constitutive behavior of this material has always been a prime area of research for many years. In this work a new nonlinear viscoelastic model for the behavior of concrete is presented. The model has the ability to describe concrete's creep and also creep failure and therefore its failure envelope, as it was obtained by the pioneering experiments of Rusch (1) The proposed model is an important modification and extension of the "The Modified Kuhn Model of Linear Viscoelasticity", developed by J. Lubliner and Panoskaltsis (2). The modified Kuhn Model has both a rheological description, as a series of Kelvin type model as well as an internal variable description and has the unique property that no matter how many Kuhn (Kelvin) elements are used the number of parameters remain the same.

In the present work a non-linear creep function is introduced and equivalently a non-linear evolution equation for its internal variables. The non-linear creep behavior of concrete is described in this way. The creep function is then appropriately modified to obtain the failure curve of concrete also. An efficient algorithm is introduced for the numerical implementation of the model The development here is benefited from some of the ideas of the work by I.Carol and J. Murcia (3) and Bazant Z.P. and Chern J.C (4). An extensive fitting in a nonlinear least squares algorithm is presented. The important concepts of instantaneous and equilibrium curves are also carefully examined and discussed.

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Turbulence Modeling
June 3, 2002
13:00
Chair: Hamn-Ching Chen Texas A&M University

Design and Analysis of a Polysilicon Surface Micromachined Viscous Drag Spiral Pump

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This paper introduces a new viscous micropump that targets the surface micromachining technology. The pump consists of a disk with a spiral protrusion that rotates at a close proximity over a stationary plate. The paper describes the implementation of this concept in five levels of polysilicon using the standard surface micromachining technology SUMMiT, illustrating the mask layouts used in producing the rotating spiral channel. For the purpose of flow field analysis an approximate is used, which replaces the spiral channel with an equivelant straight channel. The geometric conditions under which this approximation is justifiable are discussed and the formulas mapping a spiral channel flow into the straight channel representations are developed. Lubrication solution of the flow field in the plane of symmetry of the straight channel relates the flow rate, torque and power consumption to rotational speed and imposed pressure through simple formulas.

Active Control Of Vortex Shedding In The Far Wake Of A Cylinder

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In this paper, some preliminary results reported from experimental observations of two-dimensional air flows with a Reynolds number of 170 passing a stationary circular cylinder and its active control achieved in the far wake. The free stream velocity of the wind tunnel maintained uniformly at U=80.4 cm/sec during the experiment. The amplitude of velocity fluctuations measured vertically above the cylinder centerline with a hot vire probe positioned at a streamwise station of x/d=7 (far wake) on center under natural and control conditions of the transitional flow in the wake of the cylinder. The feedback hot-wire sensor was located in the upper shear layer of the cylinder at about 0.9d streamwise and about 0.8d above the cylinder axis. After the phase of the feedback signal shifted 180 ±2 degree and the amplifier gain adjusted, perturbations imposed at vortex-shedding frequency on the wake of the cylinder on both sides of the wind tunnel. The induced perturbations were significant and the Karman vortex street responded vigorously to the feedback of the signal from the hot-wire sensor in the wake of the cylinder at vortex-shedding frequency. The power spectrum of turbulence velocity fluctuations significantly reduced at Strouhal frequency. This is interpreted as the control of vortex shedding achieved in the far wake of a cylinder. Thereafter, the amplitudes of velocity fluctua-

tions were significantly reduced in the Karman vortex street. In this experiment, we have been able to demonstrate the suppression of vortex shedding in the far wake of the cylinder at Strouhal vortex shedding frequency of the cylinder wake at transitional Reynolds number 170.

RANS Simulation of Viscous Nonlinear Waves Around Coastal Structures

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A Reynolds-Averaged Navier-Stokes (RANS) numerical method was employed for time-domain simulation of fully nonlinear wave reflection, diffraction, and refractions over submerged coastal structures. Computations were performed first for fully nonlinear waves in a two-dimensional wave tank to illustrate the capability of the RANS method for the generation and propagation of viscous nonlinear waves. Time-domain simulations were then performed for the propagation and transformation of fully nonlinear waves over a submerged trapezoidal shelf. The computed wave profiles were compared with the experimental data to demonstrate the accuracy of the present simulation results. Finally, the chimera RANS method was employed for time-domain simulations of nonlinear wave refraction and diffraction over an elliptic shoal.

Turbulent Flow Induced by Multiple-Ship Operations in Confined Water

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The ship maneuvering and ship-ship interaction in confined water have been important problems in channel design and ship operation in harbors. The problems are very complicated because the shallow water effects as well as ships are operating near other ships or piers. Traditionally, these types of interaction effects are studied using experimental means. However, the presence of pier, bottom topography, and other ships require information more sophisticated than the generic modeling of ship-ship interactions used in open shallow water. In the present study, a Reynolds-Averaged Navier-Stokes (RANS) numerical method has been employed in conjunction with a chimera domain decomposition approach to compute the effects of moving ships on a ship moored next to a pier in a navigation channel. Calculations were performed for two- and three-ship interactions under both the deep and shallow water conditions. The forces and moments acting on the moored vessel were systematically analyzed to investigate the ship sheltering effect while there are more than two ships in the channel.

Structural Control - III

June 3, 2002
14:45
Chair: Satish Nagarajaiah Rice University
Co-Chair: Genda Chen University of Missouri-Rolla

Torsional Response Control Of Asymmetric Buildings Using Smart Dampers

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This paper considers the control of coupled torsional-lateral responses in irregular buildings under lateral seismic excitations. A semiactive control design is developed in which magnetorheological (MR) dampers are applied to reduce the responses of an asymmetric test structure. The MR damper is chosen for this study because it has attractive characteristics for civil applications. Specifically, devices based on MR fluid technology are reliable, inexpensive, relatively insensitive to temperature fluctuations, and require minimal power. Control input determination is based on a clipped-optimal control algorithm which uses absolute acceleration feedback. The performance of this method is studied experimentally using a 2-story building model with an asymmetric stiffness distribution and compared to results of passive control cases where a constant voltage is applied to MR damper.

Vibration Control of a Roof Panel Using MR Dampers

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Roof lifting often occurs for structures in windy environment, which may be either caused by the severe wind sucking force during storms or by deteriorating fasteners due to fatigue damages accumulated through relatively small vibration of roof panels during their service life. This paper presents a case study on control of vibration of a roof panel subjected to wind loading by using Magnetorheological(MR) dampers. . In this study, the roof panel is modeled as a simply supported plate subjected to a simulated distributed wind loading. MR dampers are placed at selected locations. As a semi-active device, a MR damper may produce a controllable damping with a very low power requirement to effectively suppress the roof panel's vibration. Control force of the MR dampers is determined by an optimal feedback control regulator. Dynamic response of the roof panel is simulated using finite element codes in conjunction with the Newmark integration scheme. Results show that MR damper can be used to significantly suppress vibration of the roof panel, which will in turn reduce the fatigue damage of fasteners, improve the roof performance in windy conditions, and increase its service life. Compared with other control devices, the MR damper has high efficiency and reliability, easy design and implementation, and less power consumption. In the case of the control hardware or

power malfunction, MR dampers can still work in its passive mode to provide extra damping. Optimal placement with limited number of MR dampers is also investigated. Application of the MR damper to a real roof structure is under investigating.

Structural Vibration Mitigation using Dissipative Smart Damping Devices

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An important problem in semiactive control of structures using smart damping devices for vibration mitigation is the development of an efficient control algorithm which accounts for the dissipative characteristics of the device. For smart dampers, the dissipative nature is represented as a nonlinear inequality constraint, which cannot be directly imposed on available control strategies using standard techniques. In this paper, linear matrix inequality (LMI) based methods are investigated to include the nonlinear dissipativity constraint in the linear quadratic regulator (LQR) problem to be used in the semiactive control of structures. First, the LQR problem is defined as an eigenvalue problem (EVP) in terms of LMIs. Then, the dissipativity constraint is appended to the EVP in its weak expected value form. The final control algorithm and the effects of the dissipativity constraint are investigated analyzing a 2DOF structure using an ideal semiactive damper. It is found that, the proposed method increases the dissipative nature of the forces considerably compared to conventional LQR approach.

Modeling and Simulation of a Semi-Active Base Isolation System for Earthquake Hazard Mitigation

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An analytical and numerical study of a base-isolated steel frame building subjected to earthquake excitation is presented in this paper. The isolation system consists of elastomeric bearings combined with semi-active dampers. Mathematical models of the isolation system components are developed using data from experimental system identification testing. The mechanical properties of the dampers are modulated based on an optimal control algorithm which was developed to effectively suppress vibrations of the structural system when subjected to various earthquake ground excitations. Numerical simulations are performed using historical earthquake records to evaluate the dynamic response of the structure and the isolation system when different damping mechanisms (passive, semi-active, and active) are incorporated within the isolation system. The numerical simulations demonstrate that semi-active damping is effective in simultaneously controlling the response of the structure and the isolation system. Such control appears to be particularly applicable to structures subjected to disparate ground motions such as frequent, weak earthquakes versus infrequent, strong earthquakes or far-field versus near-field earthquakes.

A Comparative Investigation of Semi-Active Friction Controllers for Structures Subject to Near-Field Earthquakes

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In this paper, performance of passive viscous and friction dampers subject to near-fault ground motion velocity pulses for elastic and inelastic structures has been investigated through numerical simulations. The objective of the investigation is to determine the guidelines for types of structures where a passive damper may be effective in reducing damages during a near-fault ground motion. Simulation results show that viscous dampers are most effective around T/Tg for elastic structures, whereas they are most effective for inelastic structures in range of natural periods T/Tg < 1.0 when both the input energy and hysteretic energy (damage) decrease and dissipated viscous energy increases. Passive friction dampers have good performance for elastic structures around T/Tg , where input energy decreases and energy dissipated by the damper increases. For inelastic structures with m=4, friction dampers have good performance in the range of for 0.3 <T/Tg <2.

Dynamics - Soil Structure Interaction

June 3, 2002
14:45
Chair: Nicos Makris U.C. Berkeley

Passive Earth Pressure Distribution Under Seismic Condition

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Knowledge of passive resistance and its distribution behind the rigid retaining walls under both static and dynamic conditions are important for designing retaining walls, anchors, foundations etc. In this paper, a method of horizontal slices has been suggested for obtaining seismic passive earth pressure distribution by considering seismic forces in a pseudo-static manner. Only planar rupture surfaces have been considered and hence wall friction angle has been restricted upto one-third the soil friction angle. This approach results in the same seismic passive earth pressure coefficients as that obtained by Mononobe-Okabe approach, besides giving additional information about the distribution of earth pressures. The paper presents the results for various wall batter angles, soil friction angles, wall friction angles and the horizontal and vertical seismic acceleration coefficients. It has been found that in the seismic case, passive resistance acts at a point other than at 1/3rd from the base of the wall. Under seismic conditions, the extension of failure zone is more than that under static conditions.

Behavior of Plate on Viscoelastic Foundation under Moving Harmonic Loads

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The dynamic stress and displacement responses of a plate of infinite extent on a viscoelastic foundation subjected to moving multiple harmonic loads with a constant advance velocity have been investigated. Formulations have been developed in the transformed field domain using a double Fourier transform in space and moving space. For a numerical example, a concrete pavement system has been selected as a model of the plate on viscoelastic foundation. The loads applied by moving vehicles have been modeled using moving dual-wheel tandem-axle loads. The effects of viscous damping, load velocity, load frequency, and phase between front- and rear-axle loads on the maximum deflection and stress have been investigated for three different cases of: (1) when the load frequency is zero; (2) when the phase between the loads is zero; and (3) when there are load frequency and phase in the moving multiple harmonic loads.

Nonlinear Dynamic Analysis of Soil and Structure by Discrete Particle Model

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When we deal with non-linearity in the soil-structure interaction problem, the finite element method is generally used. The FEM is inherently based on not discrete particles but continuity of a solid. On the other hand, although the soil shows an elastic property in the small displacement, the phenomena of the discrete particle system including liquefaction dominates the almost domain of the larger displacement. The FEM also decreases its validity for the drastic change of displacement to which the Mohr-Coulombís rule could be applied. Therefore we take a new approach on the whole domain of deformation from an elastic continuity to discrete particles. It consists of a spring for representing an effect of the Poissonís ratio, normal and shear springs which are connected to concentrated masses. Each constant of the initial state is designed to be able to exactly evaluate the linear relations between stress and strain in the small displacement. Since this system is a visible physical model, we can easily reduce a rigidity of springs and cut them corresponding to the stress level in the larger displacement. However in this model we have to deal with a large amount of particles. Therefore we adopt the average acceleration method iteratively applied to each particle even in case of static loading problem as well as dynamic one. This makes it possible to implement a parallel computing for a huge amount of particles.

Differential Equation Cell Method for Dynamic Response Analysis of Foundations in Layered Media

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A differential equation cell method is presented for a layered medium. The method is applied to a simplified soil model to formulate the dynamic responses of foundations partially embedded in layered soils. The finally developed formulations are in simple semi-closed form and found to be capable of predicting the dynamic responses of foundations well.

Probabilistic Methods - I
June 3, 2002
14:45
Chair: Siu Kui Au Nanyang Technological University
Co-Chair: Kurtis Gurley University of Florida

Efficient Wavelet Transform Of Covariance Functions Using Mallat's Tree Algorithm For K-L Simulation

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The feasibility of implementing K-L expansion as a practical simulation tool hinges crucially on the ability to compute a large number of eigensolutions accurately and cheaply. Conventional Galerkin methods employing polynomial or trigonometric bases lead to dense matrices that are very costly to compute and invert. Representation of integral operators using conventional bases also requires approximate integration quadratures that are tedious to evaluate. The difficulty of solving the Fredholm integral equation accurately for higher order eigenvalues and eigenfunctions is quite well known. For processes with non-smooth covariance functions and long weakly correlated processes, high order eigenvalues cannot be neglected without having a very serious impact on the accuracy of the simulation. This paper demonstrates that a discrete wavelet transform scheme based on the Mallatís tree algorithm can be exploited to solve the Fredholm integral equation efficiently for practical K-L simulation. The rate of convergence and CPU time needed to obtain eigensolutions for the exponential and squared exponential covariance functions using Harr wavelets, trigonometrics and Legendre polynomials are discussed.

Stochastic Simulation of Correlated Wind Pressure Fields on Low-Rise Gable Roof Structures

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This paper presents the results of a study to quantify wind loads on the roof of a low-rise building. Wind tunnel data is used to establish a statistical characterization of the pressure coefficients sampled at 14 points in a region of separated flow over a single sheathing panel. The overall fluctuating uplift on the sheathing panel is a function of the probability density function at each tap as well as the degree of correlation between taps. A simulation methodology is applied to generate realizations of wind loads that duplicate the measured characteristics over the sheathing panel. Both the cross-spectral and highly non-Gaussian characteristics of the data at 14 pressure taps are maintained through the use of a multi-variate non-Gaussian simulation algorithm. The level of correlation between taps is varied in the simulations to investigate the effects of assuming cases from no correlation to full correlation. The ASCE 7-98 wind loads are calculated for comparison with these generated aggregate loads. Experimentally determined maximum uplift capacities of sheathing panels are also compared with the simulated loads.

Identification of Damping Ratio Using Monte Carlo Filter Based on Exclusive Non-Gaussian Process Noise

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The Basic study on the application of Monte Carlo filter (MCF) to structural damage detection is discussed in this paper. In this method, each probability distribution is expressed by many of its realization, which are called particles or samples. The advantage of the MCF technique is that it can deal with non-linear and non-Gaussian problems. From the standpoint of damage detection, non-Gaussian non-white noises might be preferable, because the damage tends to be concentrated on a specific part of a structure. From this consideration, we propose the exclusive noise. Based on hypothetical data, the numerical simulations of damage detection with the proposed non-Gaussian exclusive process noise are performed and discussed. The simulation result shows that not only stiffness but also damping ratio of damaged element might be detected from limited number of observation points

Application of Subset Simulation to Seismic Risk Analysis

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This paper presents the application of a new reliability method called Subset Simulation to seismic risk analysis of a structure, where the exceedance of some performance quantity, such as the peak interstory drift, above a specified threshold level is considered for the case of uncertain seismic excitation. This involves analyzing the well-known but difficult first-passage failure problem. Failure analysis is also carried out using results from Subset Simulation which yields information about the probable scenarios that may occur in case of failure. The results show that for given magnitude and epicentral distance (which are related to the 'intensity' of shaking), the probable mode of failure is due to a 'resonance effect.' On the other hand, when the magnitude and epicentral distance are considered to be uncertain, the probable failure mode corresponds to the occurrence of 'large-magnitude, small epicentral distance' earthquakes.

Stochastic simulation of non-Gaussian material property fields in random composite materials

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The effect of microstructural randomness on the local behavior of composite materials is addressed in this work through the applica-

tion of stochastic simulation techniques. In traditional analysis of composite materials with a random microstructure the assumption is often made that the material behavior may be represented by homogenized, or effective composite properties. While this assumption yields accurate results for the bulk behavior of composite materials, it ignores the effects of a random microstructure on local behavior. For example, failure mechanisms such as cracking or local yielding may be predicted by locally high stresses but not by the average stresses developed from models based on effective material properties. In order to perform simulations of a material microstructure directly, very basic assumptions must be made on the size, shape, and spatial distribution of the inclusions in the composite material. These assumptions may lead to a model that does not realistically reflect the random microstructure. Recently, moving-window techniques have emerged as a useful technique for characterizing a random composite microstructure, based purely on a digitized microstructural image. These methods offer the major advantage that no assumptions need to be made as to the shapes, sizes or placement of inclusions. The only constraints in such moving-window analyses are that multiple phases of the composite are visually differentiable and that their individual constitutive behaviors are known.

A moving window micromechanics technique based on the Generalized Method of Cells (GMC) has been applied successfully to generate material property fields for the elastic properties of fiber-reinforced composites. Stochastic simulations of the material property fields, based on the samples obtained from moving-window GMC and assuming that the material properties are defined as Gaussian processes, have been generated. This work demonstrates that the statistics on critical local material behavior, such as mean and variance of the maximum stress, are easily obtained for a given composite material. The quality of these statistical estimates, however, is clearly dependent on the quality of the underlying local material property fields obtained from the given sample and the quality of the assumption that these property fields are Gaussian. In fact, the material property fields have been demonstrated to be clearly non-Gaussian. In the present work, the local material property fields are improved by generating tensor fields of the fully anisotropic constitutive matrix for given composite material samples, using a brute-force moving-window analysis of a finite element model based on the full microstructure. Further, iterative Fourier-based multi-dimensional non-Gaussian simulation techniques are applied in order to eliminate the assumption of Gaussian material property fields while maintaining the proper spatial correlation structure. Based on the simulated samples, statistics on the local stresses are estimated, which will provide the basis for establishing a measure of the material reliability under given loading conditions.

Symposium on Micromechanics of Heterogeneous Materials - Session III

June 3, 2002

14:45

Chair: Jiun-Shyan Chen University of California, Los Angeles

Accurate Micro/macro Field Simulation For Composites Subject To Fiber-matrix Debonding Using High Fidelity Generalized Method Of Cells

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This paper addresses fiber-matrix debonding in composites using a recently developed micromechanics model known as the high-fidelity generalized method of cells (HFGMC). By employing a higher-order displacement field, this model supercedes it predecessor, the generalized method of cells (GMC), in terms of micro-scale field accuracy. Via inclusion of appropriate constitutive relations for inelastic deformation and fiber-matrix debonding, both HFGMC and GMC have been applied to model the transverse deformation of titanium matrix composites, which exhibit obvious effects of interfacial debonding. Results indicate that HFGMC is considerably more accurate than GMC for analysis of composites with debonding, enabling realistic predictions of composites' transverse response.

Influence of Particle Cracking on Plastic Behavior of Discontinuously Reinforced Composites Using Micromechanics Approach

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A micromechanics-based elastoplastic and damage constitutive model is proposed to predict the overall mechanical behavior of particle-reinforced metal matrix composites. Unidirectionally aligned spheroidal elastic particles, some of which contains penny-shaped cracks, are randomly distributed in the elastoplastic metal matrix. These imperfect particles are modeled using double-inclusion concept. An ensemble-volume averaged homogenization procedure is employed to estimate the effective yield function of the composites. The associative plastic flow rule and the hardening law are postulated based on the continuum plasticity theory. The damage evolution of particles is considered in accordance with Weibull's statistical function to characterize the varying probability of reinforcement cracking. The elastoplastic mechanical behavior of particle composites under uniaxial loading condition is simulated and compared with experimental results.

Mesoscale Modeling of Grain Boundary Migration Using Coupled Finite Element and Meshfree Methods

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The process of grain boundary migration involves moving interfaces and topological changes of grain boundary geometry. This can not be effectively modeled by Lagrangian, Eulerian, or arbitrary Lagrangian Eulerian finite element formulation when stress effect is considered. A coupled finite element and meshfree approach is proposed for modeling of grain boundary migration under stress. In this formulation, the material grid carries material kinematic and kinetic variables, whereas the grain boundary grid carries grain boundary kinematic variables. The material domain is discretized by a reproducing kernel partition of unity with built-in strain discontinuity across the grain boundaries. The grain boundaries, on the other hand, are discretized by the standard finite elements. This approach allows an arbitrary evolution of grain boundaries without continuous remeshing.

Interface Behavior ñ Theory and Engineering Application
June 3, 2002
14:45
Chair: Franz-Josef Ulm **Massachusetts Institute of Technology**

Exploratory Evaluation Of Mode-I Fracture Toughness Of Concrete-composite Bonded Interfaces

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Current research on rehabilitation and strengthening of concrete structures has focused on the external bonding of FRP plates or fabrics to concrete, and significant increases in stiffness, strength and seismic response have been achieved by this technique that offers great potential for enhanced durability and service-life. However, there is a concern with the long-term reliable performance of the interface bond, which is critical in the application of this technology. The delamination of the interface can lead to premature failure of reinforced members, and therefore, there is a need to develop proven methods to characterize the performance of concrete-FRP interface bonds under static and cyclic loading combined with bond degradation effects due to environmental exposure.

In this study, a conventional test method - a three-point bending beam (3PBB) specimen, used commonly for determining Mode-I fracture properties of concrete and rock - is adapted to characterize Mode-I fracture of concrete-FRP bonded interfaces. Two types of fiber fabrics: E-glass and Carbon fibers are used, and the epoxy resins are applied to bond the concrete-concrete and concrete-composite interfaces. Mode-I fracture tests are performed using the 3PBB specimens for concrete-concrete, concrete-E-glass/epoxy composite, and concrete-Carbon/epoxy composite bonded interfaces to determine the critical loads and crack tip open displacements, from which the critical strain energy release rates are obtained. The Jacobian Derivative Method (JDM), a finite element post-processing algorithm, is used to predict the strain energy release rate of the TPBB test specimens, and the predictions are compared with experimental results.

Since there are no methods available to rigorously evaluate the interface bond fracture and integrity for concrete structures externally reinforced with FRP, the proposed experimental and analytical methods can be efficiently used to evaluate interfaces for combinations of concrete-FRP hybrid products and to obtain the fracture toughness data for potential delamination under various environmental exposures and static/cyclic loading.

Free Vibrations of Through-thickness Reinforced Delaminated Beams

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The dynamic behavior of laminated beam-type structures presenting delaminations is characterized by stiffness degradation, natural frequency shifts and opening modes during vibration. This paper investigates the influence of a through-thickness reinforcement on the natural frequencies of through-width delaminated beam. A model based on the theory of bending of beams is formulated where the reinforcements are modeled as a uniform distribution of linear springs able to react to longitudinal and transversal relative displacements between the surfaces of the delamination. The natural frequencies of a delaminated cantilever beam are predicted for different lengths of the delamination. The effectiveness of the through thickness reinforcement on the natural frequencies is demonstrated through the transition from damaged (unbridged) to intact beam values upon increasing the stiffness of the springs. An application of the model to a typical stitched carbon-epoxy laminate for aeronautical applications shows that low percentages of through-thickness reinforcements can substantially improve the dynamic response of delaminated beams.

Factors Affecting the Mechanism of Mobilized Shear at Crack or Joint Interface

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Data from 43 tests were used to study the factors affecting the mechanism of shear resistance at joints and cracks. Unlike former studies, the shear resistance is explained in terms of three major components; 1) friction component, 2) shear through component, and 3) dilation component. The friction component is commonly quantified using the material friction angle, while the shearing trough component is quantified using a cohesion intercept that represents the phenomenon of shearing off intact material. The last component is described as the dilation component which represents the tendency of opposing roughness features to override one another and can be quantified as dilation angle. The contribution of each component is found to be dependent on seven major factors; joint opening, aggregate size, age of concrete at time of cracking, the concrete strength at the joint/crack interface, aggregate quality, and overall roughness at the crack interface which are discussed in the paper.

The study showed that at smaller crack widths the shear resistance is mobilized mainly by friction and the shearing through of the asperities. As crack width increases, there is a greater tendency for dilation and when that dilation is restrained higher normal stresses are mobilized at the joint interface as measured during the course of the experimental program. It was found that all specimens that showed dilation tendency were the one that showed the poorest performance. This is mainly due to the fact that as the roughness features over ride one another a significant grinding accompanied with aggregate and matrix breakage took place. It was also found that specimens made with limestone aggregate performed poorly at an aperture ratio, defined as the ratio of crack width to maximum aggregate size, of 10% and they showed a significant performance improvement at an aperture ratio of 5%. For gravel, the corresponding critical values of aperture ratio were on average 13 % and 6%. For trap rock the, poor performance value corresponded to an aperture ratio larger than 15%. These aperture ratio values were found to reflect the contribution of different shear components to the overall shear strength at the joint interface.

Characterization of Stress Separation Relation In Cementitious Materials

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A new approach integrating numerical modeling and experimental work was developed to characterize the stress separation relation in cementitious materials. In this paper, we present the formulation and the algorithm of the numerical modeling. Two weight matrixes, one relates the stresses along the potential crack line to the external loads and the other relates the stresses along the potential crack line to the crack openings, are formed first. The modeling can then be achieved by implementing the stress separation as a boundary condition on the kinetic relation of the stresses, crack opening, and the applied loads. Through a step-by-step iterative process, the relationship between the stresses in the member, load-crack mouth displacement curves, and stress-separation curves can be obtained. Parameter study in exploring the relationship by varying each parameter separately is presented.

Frank L. DiMaggio Symposium on Constitutive Modeling of Geomaterials III

June 3, 2002
14:45
Chair: Victor Kaliakin University of Delaware
Co-Chair: Stein Sture University of Colorado, Boulder

VISCOUS EFFECTS ON THE SHEAR YIELDING CHARACTERISTICS OF SAND

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The viscous aspects of the strength and deformation characteristics of sand (e.g., loading rate effects, creep and stress relaxation) are very important in many full-scale field geotechnical problems. Such important aspects of time effects as above on stress-strain behaviour of geomaterials cannot be simulated and predicted by the classical elasto-plastic theory that is not considering the viscous aspects. Recently a new promising three-component model has been developed, and when limiting to the shear deformation along a fixed stress path (only stress paths at a constant confining pressure), the time-dependent behavior can be simulated very successfully. As a part of a longñterm study into the time-dependent properties (ageing and viscous effects) of geomaterials, several viscous aspects of sand behaviour under more general stress conditions were investigated by performing special triaxial compression tests on Toyoura sand. Using each single specimen, a series of cyclic loading tests were performed at a fixed confining pressure, or at different confining pressures increasing step by step or repeatedly the confining pressure, between two successive shear loading schemes. The following was found: 1. Viscous effects on the yield stress in the one-dimensional stress space: The maximum shear stress (qm) from which the shear unloading was made and the yield shear stress (qy) are not necessarily the same to each other as the classical elasto-plastic theory predicts, but their relative magnitude is affected by viscous effects as a function of strain history. 2. Viscous effects on the yield locus in the two-dimensional stress space: By changing the stress path during a sequence of loading, unloading and reloading with and without a creep stage at the previous maximum shear stress, the uniqueness of yield locus is lost for different strain history (i.e., the history of strain rate), but the yield locus is largely affected by the viscous property as a function of strain history.

In addition, one form of irreversible energy parameter was found to be stress path-independent, while the contours of this strain parameter become the shear yield loci on the stress plane. The relationship between this energy parameter and a certain type of stress parameter was found relevant as the stress path-independent hardening function for shear yielding. The compression yielding characteristics are also discussed in relation to the shear yielding characteristics (i.e., the double yielding concept). Based on the above facts, an existing one-dimensional three-component model for sand (called the TESRA model) was modified and extended to be applied to more general stress condition. The results of simulation of the test results by the model will be presented. It will be shown that the viscous aspects observed under general triaxial compression stress conditions can be successfully simulated by the modified TESRA model.

A MODEL FOR SOIL STRUCTURE MOBILITY AND COLLAPSE

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This paper presents a plastic constitutive model based on the critical state boundary surface theory. The formulation of the yield surface in the Cam Clay model is used as an inner feature cap or small cap to describe the soil structure mobility and collapse. Unlike a traditional yield surface, a stress path can move below, outside or on the small cap to produce plastic strains. The small cap when related to the steady state strength can be used to predict soil structure collapse under both drained and undrained conditions. Excellent agreement between numerical simulations based on this small cap model and actual laboratory measurements verifies that the model can be used to completely describe the complex behavior of sand which includes contraction, dilation, phase change and ultimate failure at the steady state.

MIDDLE SURFACE CONCEPT AND ITS APPLICATION IN GEOMATERIALS

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A new constitutive modeling concept named the “Middle Surface Concept (MSC)” is presented. In contrast to a single yield surface used in the traditional elastoplasticity theory, in the MSC multiple yield surfaces are used. Among them, one is the”true yield surface” and the rest are “pseudo yield surfaces”. The stress point lies on the true yield surface during plastic deformations and the true yield surface is constructed using the pseudo yield surfaces. Different pseudo yield surfaces can represent different features of the mechanical behavior that are difficult to be represented in a combined fashion using a single yield surface. The true yield surface and the pseudo yield surfaces are linked through common quantities and relationships between certain quantities. The application of the MSC to modeling the behavior of sands is first presented. The state parameter concept and stress-induced anisotropy in sands are considered within the critical state soil mechanics for both monotonic and cyclic loading. The use of the MSC to modeling the behavior of clays is then discussed.

CENTRIFUGE AND NUMERICAL MODELING OF SOIL LIQUEFACTION AT VERY LARGE DEPTHS

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The soil liquefaction behavior at very large depth is presently poorly understood, yet this situation commonly occurs at foundations of large earth dams. This paper describes a numerical model, which is used to study the soil liquefaction resistance at high confining pressure. In this research, a two-dimensional numerical model was set up. Base acceleration with different magnitude and frequency were applied to the model. The pore water pressure and effective

stress at different depth in the model were monitored during shaking. It was found that soil liquefaction resistance increases with the increasing of confining pressure at large depths. At a large acceleration magnitude, the liquefaction can occur at virtually any depth.

Cyclic Constitutive Model Based on Fuzzy Set Concepts

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A cyclic constitutive model based on fuzzy set plasticity, which was first introduced by Klisinski (1988) and used as the basis for developments, is presented in this paper. The fuzzy set plasticity model is physically intuitive and easy to visualize, which provides analytical and simple geometrical interpretation to formulate hardening, deviatoric and volumetric hysteresis features, material memory, and kinematic mechanisms without resorting to a complex analytical formulations. Two numerical examples involving granular materials subjected to drained conditions are demonstrated in this paper.

Studies of Bulk Solids and Containment Structures

June 3, 2002
14:45
Chair: Juan Martinez **INSA Rennes**
Co-Chair: Jin Ooi **University of Edinburgh**

The Granular Flow In A Two-dimensional Flat-bottomed Hopper With Eccentric Discharge

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Abstract Employing the kinematic model of Nedderman and Tuzun [1] and the boundary conditions for granular media in a two-dimensional flat-bottomed hopper with eccentric discharge, a boundary-value problem was constructed. The heights of stagnant zone for two kinds of granular materials after hopper discharge were experimentally measured. We postulate that the kinematic constant is proportional to the height of stagnant zone. Employing experimental results and Newton-Raphson method, kinematic constants under eccentric discharge were obtained. The profiles of horizontal and vertical components of velocity were then calculated. The research work reported here provides additional theoretical knowledge about granular flows in the hopper to workers in this field, and also enhances the application of kinematic model to granular flows.

Reference [1]. R.M. Nedderman and U.Tuzun , Powder Tech. 22 (1979) 243.

Effects Of Thermal Loads On Agricultural Silos

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The objective of this work is to perform an analysis of pressure distributions in grain silos subjected to thermal effects. To this end, the commercial ANSYS program, based on the finite-element method is employed. Changes in the temperature along the silo walls produce dilatations and contractions, which cause variations both in the wall stresses and in the grain pressures. These dilatations and contractions increase the Young¥s modulus of the grain, causing the stresses on the silo walls during the contractions to rise with each new cycle. In this paper, results are presented for a 3D model simulating a steel silo with a height of 9 m, a diameter of 6 m and a wall thickness of 2 mm. The SOLID45 element from the ANSYS program is used for the 3D modeling of solid structures, the SHELL63 element for the steel wall and the CONTACT 173 element to represent contact and sliding between 3D target surfaces (TARGE170) and a deformable surface. Elastic and Drucker- Prager behavior patterns were selected for the material. The latter is an elastic-perfectly plastic behavior pattern, thus dilatancy effects could be considered. In previous works developed by the authors

the wall was considered rigid, therefore contact between the grain and the wall was rigid-flexible. However, in this work, due to the wall having to be able to move, in order to simulate its contractions and dilatations, a flexible-flexible contact was chosen. An elastic behavior pattern with steel properties was chosen for the wall. Based upon the results, this paper proposes new methods of analyzing thermal effects in silos. These models combine both the effects on the wall and on the granular material. The results are compared with previous research data and with standard design guidelines. The influence of the different properties of the silaged material, and those of silo shapes on the grain pressures and on wall stresses, are also analyzed.

NUMERICAL INVESTIGATION OF FLOW PATTERNS IN A CYLINDRICAL SILO USING AN ALE APPROACH

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Great effort have been made in the last decades for a better understanding of silo pressures and flow phenomena. Whilst finite element predictions of silo wall pressures, at the end of the filling stage, are in good agreement with experimental observations, the finite element modelling of the wall pressures during discharge are relatively rare and requires more fundamental research. Using a dynamic finite element formulation, Rombach and Eibl [1] have shown time and space variations of wall pressures just at the beginning of the discharging stage. Others works [2] have treated discharge problems using the updated Lagrangian formulation and mesh re-zoning technics to describe large strains and displacements occuring during the discharging stage. In Rennes, flow patterns and wall pressures in silos during emptying have been studied first with quasi-static approaches based on the permanent flow assumption. In such developments [3], a slip line between the flowing material and the static material inside the silo is defined at the end of the transient stage and used for permanent flow stage. The slope of this line, defined as a straight line, is usually related to the internal friction angle of the bulk material whereas recent works have shown it could be more related to the friction angle along the silo wall. The aim of this paper is to present the results of another approach using an ale (arbitrary Lagrangian Eulerian) finite element program. The model takes into account the elastoplastic constitutive law of the ensiled material, the friction law along the silo wall and the modification of the boundary conditions when the outlet of the silo is opening. A comparative analysis of displacements, strain and stress distributions in the silo is performed on a full scale experimental silo, storing wheat. Transient stage results of the discharge are compared with those obtained for an assumed permanent flow. The paper also discusses how the different features of these two approaches, used to simulate the discharge of the ensiled material, affect the flowing zone and wall pressure predictions.

[1] G. ROMBACH and J. EIBL, A Dynamic Finite Element Model for Silo Pressures and Solids Flow, Silos, Fundamentals of theory behaviour and design Edited by C.J. Brown and J. Nielsen, E & FN SPON, pp. 481-494.

[2] Z. WIECKOWSKI, Finite Deformation Analysis of Motion of Bulk Material in Silo, Research Report, TULEA 1994:26, Lulea University of Technology, Sweden, July 1994.

[3] E. RAGNEAU, D. GUINES, B. KEROUR, Investigation on the Boundary of the Flow Area in a Silo during Discharge, Mechanics and Materials Conference, San Diego, USA, June 27-29, 2001.

FINITE ELEMENT PREDICTIONS OF PROGRESSIVE FILLING PRESSURES IN A RING STIFFENED IMPERFECT FULL-SCALE SILO

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Numerical prediction of wall pressures in silos has been a major topic of research in the last in few decades in the international silos research community. Numerous finite element studies have been carried out on filling pressures in silos. Most of these studies were carried out by treating the self-weight of the ensiled solid as a 'switch-on' gravity. However, this approach does not simulate the feature that most silos are filled progressively in practice. Although it is widely perceived that the progressive filling pressure may significantly differ from that simulated by using a switch-on gravity, little information is available in the open literature.

This study conducts a detailed finite element analysis on the wall pressures exerted by the stored iron ore pellets in a full-scale silo, which was purposely designed and built for experimental investigation into solids flow patterns and silo wall pressures by the Silos Research Group at Edinburgh University. Following an early investigation into the effects of ring stiffeners, axisymmetric imperfections and material constitutive models, this paper presents some initial numerical predictions of progressive filling pressures. The results are compared with those predicted using a 'switch' loading process and the differences are highlighted.

EFFECT OF SILO GEOMETRY AND BULK PROPERTIES ON INTERNAL STRESSES AND WALL PRESSURES PRE-DICTED BY DISCRETE SIMULATIONS OF GRANULAR MATERIALS.

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Force transmission within granular materials remains a scientific challenge related to different practical problems dealing with bulk solids handling and storage. Internal stresses as well as wall pressures and tractions developed in silos during filling and discharge are here analyzed in function of the silo geometry and of the mechanical proprerties of the ensiled granular material, using the Distinct Element Method. Different geometrical shapes were considered, including inserts, and numerous simulations were devoted to the analysis of the effect of particle properties (stiffness and friction) on the stress transmission modes. The method is first validated by finding a good agreement between the wall pressures obtained from discrete simulations and those derived from macroscopic models at the end of filling of a flat-bottomed silo. The influence of the silo geometry was analyzed by comparing the stresses obtained in a flat-bottomed silo and in a silo with a hopper. The effect of a circu-lar insert placed on the silo vertical axis was also considered. For analyzing the hopper influ-ence, the same granular material composed of 10,000 particles was used for filling and discharging both a flat-bottomed silo and a cylinder-hopper silo. The latter possesses a conical shape with an inclination angle of 32 degrees relative to the vertical. During the filling stage, the results verify that pressures on the hopper walls are higher than those obtained at the same height in the flat-bottomed silo. During discharge, the arching effect induced by flow pro-duces the so-called switch of the wall pressure at the transition between the cylinder and the hopper. Moreover, the presence of a circular insert changes drastically the stress field : an arch is formed above the insert, producing an increase of the wall pressure at the elevation of the insert top and a decrease below. The effect of the particle properties was analyzed using a flat-bottomed silo filled with 8,000 particles. The values of the friction coefficient at the particle/particle and at the parti-cle/wall contacts cover a large range from perfectly smooth to very rough interfaces. The contact stiffness, common along normal and shear directions, takes values from 0.5 to 50 MN/m. Results at the end-of-filling and during discharge clearly show the influence of the particle stiffness and friction on the stress transmission within the silo. Considering soft parti-cles, the particle/particle friction plays a major role on the horizontal-to-vertical stress ratio both at the end of filling and during the discharge. A high particle/particle friction leads to a high anisotropy of the contact forces that concentrate along the principal direction of com-pression, vertical at the end of filling and horizontal during the discharge. With stiffer parti-cles, the particle/particle friction effect is less pronounced and a more isotropic contact force distribution is observed.

Computational Mechanics - Novel Numerical Methods
June 3, 2002
14:45
Chair: Elisa Sotelino Purdue University

Application Of Modified ART2 Artificial Neural Network In Classification Of Structural Members

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In this research the basic algorithm of ART2 artificial Neural Networks has been modified for proper and efficient classification of vectors. In the basic architecture of ART2 , the length of vectors is neglected. This causes error in sorting; parallel vectors with diffrent length are classifiedin the same category. to overcome this deficiency , a virtual input neuron is added to consider vector length. the modified architecture not only consider the similarity of vectors direction but also considers the magnitude of vectors in sorting. ART neural networks are classified as unsupervised nets, a method is presented for supervised learning of ART2 without general changes in the basic algorithm. Then this method is used for classification of structural analysis result for design of members.

High order hermitian algorithm for integration in time

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This paper presents a step-by-step direct integration algorithm derived in terms of higher order hermitian finite difference operators. This is a fourth-order algorithm, unconditionally stable, presenting no numerical damping ratio. In addition the computational effort is similar to the Newmark method. Particular attention is devoted to the order of accuracy, which is considered in terms of local truncation error, period dispersion and the corresponding exponential truncation error.

Implementation of the Discrete Element Method using reconfigurable computing (FPGAs)

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The Discrete Element Method (DEM) is a numerical method for the simulation of the behaviour of media consisting of discrete parti-

cles. They can be bonded together to represent rock or remained unbonded to represent soil.

It is suggested that the DEM can replace the continuum methods e.g. Finite-element or finite-difference in the future, as these have two main drawbacks. Firstly a suitable stress-strain law may not exist and secondly, localised features (e.g. cracks) are difficult to model with the continuum approaches. However in order to simulate entire engineering structures, which may involve millions of particles, the computer power has to increase as the DEM is very computationally expensive.

The DEM can be run on a parallel computer by farming out different cells onto different processors. However, particles transiting from one cell to another create communication and synchronisation overheads which limit the speed-up achieved by parallel processing. Also, if some cells become much more heavily populated than others, then there will be inefficiencies due to load imbalance between the processors. Communication overhead causes these multiprocessor systems not be able to reach the theoretical speed up. The efficiency in this kind of systems is far less than linear.

The DEM uses simple arithmetic operations in a massively parallel way on a large data set. It is therefore tempting to examine how well it can be accelerated using reconfigurable computing.

Reconfigurable computing is based around the use of field programmable gate arrays (FPGAs) to form coprocessors that can be configured to provide custom hardware accelerators. The types of problem that can benefit from reconfigurable computing are established by the properties of the FPGA. In general, FPGAs are good at tasks that exhibit a high degree of parallelism.

This paper presents the design of a dedicated chip architecture for the DEM implemented on an FPGA. Its performance is compared with an optimised Software version running on a state of the art PC and a significant speed up, of up to 60, was observed.

MechML A Draft XML For Mechanics

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Recent advances in information technology have extended the role of the Internet from a publishing medium to an environment for mediating applications and data exchange. The lack of compatibility and interoperability in most of the scientific oriented software results in a significant loss of opportunity for cooperation between scientists and engineers. In this paper the case for creating a standard markup language for mechanics (MechML) derived from the XML (eXtensible Markup Language) will be presented. A proposed framework for the structure of such a standard will then be described. This framework presents an initial effort at developing an IT syntax for mechanics aimed at sparking further interest from the mechanics community. MechML builds on recent related developments in mathematics and materials science. It will enable the seamless exchange of information between analysis tools located across the Internet. An example is presented demonstrating the significance of this effort to the modeling, characterization and analysis of an engineering system in the context of stochastic mechanics.

An Algorithm for the Nonlinear Dynamic Analysis of Structures in a Distributed Computing Environment

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Several concurrent algorithms have been developed for transient analysis of structures in the past fifteen years. In this work, the Modified Iterative Group Implicit Algorithm (MIGI), a domain-by-domain parallel solution method is extended for nonlinear applications. For the nonlinear case, while MIGI iterates to find compatible and equilibrating interface forces between the subdomains, a global nonlinear iteration is also performed. The integration of these two iterations is investigated. More specifically, the two iterations may be combined and performed in a single process loop or they may be isolated. It is found that the efficiency of the procedure resulting from the isolation of the iterations is superior than the alternative. The developed procedure has been tested via numerical examples. A 20-story model building considering material and geometric nonlinearities under earthquake loading has been simulated. Excellent accuracy in the solution and significant speedup values have been obtained from the simulations, which were performed on an IBM-SP parallel machine.

Mechanical Properties of Selected Materials
June 3, 2002
14:45
Chair: Franz-Josef Ulm *Massachusetts Institute of Technology*

Smart Behavior of Carbon Fiber Cement Composites in Compression

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This paper presents results which indicate that carbon fiber-reinforced concrete has the ability to serve as a smart structural material capable of providing some information as to the conditions of internal stress, strain and cracking in the absence of any visible exterior signs of damage. Simple electrical resistance measurements can be utilized to extract this information about physical integrity from the material. Smart behavior was evaluated by performing unconfined compression tests on cylindrical carbon fiber-reinforced mortar specimens. The signal that was manifested was a reversible change in resistance when cracking was not significant (for example, when stress-strain response was still elastic), and an irreversible increase in resistance when cracking took place. Smart material capability existed even at low fiber volume contents (0.2% to 1.0%).

Complete Stress-Strain Behavior of High Performance Fly Ash Concrete and Its Application to RC Beams

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High performance concrete (HPC) has recently been a widely used concrete construction material for modern buildings, bridges, and pavements, etc. To produce such a better quality of concrete, chemical and mineral admixtures such as fly ash, slag cement, and silica fume, as well as air-entraining agents are commonly used in the field construction. It has been found that fly ash can be used for partial replacement of cement. The percentage of replacement ranges from about 20%(low volume of fly ash) to more than 50%(high volume of fly ash). It has been found that high performance fly ash concrete improve the workability, ultimate strength and durability of the concrete. However the enhancement of ductility in concrete, and concrete structures as a whole is still inconclusive and needs to be studied more. This paper presents a complete stress-strain behavior and its empirical equation of high performance fly ash concrete with and without steel fibers, and with and without steel confinements. The complete stress-strain equation has only two material constants to define a stress-strain behavior and has not been available in the literature. The proposed stress-strain equation has been incorporated into a reinforced concrete (RC) beam analysis computer program to study complete load-deflection behavior of the RC beams. Based on present beam tests, one can conclude that the RC beams with fly ash replacement do affect the flexural behavior of beams and they suffer a loss in ductility as compared to the control beams, although their ultimate load capacities remain almost the same.

Keywords: High performance concrete, fly ash, stress, strain, ductility, beam tests

Identification of a Forging Steel Behavior from Dynamic Compression Tests

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This paper deals with compression tests carried out on a 50CD4 steel (norm EN 10 083) to characterize its behavior at strains (up to 2), strain rates (up to 50 /s) and temperatures (200 to 400×C) corresponding to extrusion application. A specific experimental set-up making it possible to realize tests at velocities up to 9 m/s was used and specific specimens were designed to ensure security during impact. The choice of the specimen shape is discussed and the independence of the results to friction is highlighted. An inverse analysis of a finite element model is used to identify the parameters of a rheological law chosen to well-describe steel behavior at intermediate strain rates.

Experimental and Computational Methods for Shape Memory Alloys

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The unique properties of Shape Memory Alloys (SMA) have drawn the interest and attention of both engineers and scientists alike. The mechanisms that govern these behaviors are still a subject of research and there is a need for the development of reliable constitutive relationships. This work focuses its attention on one such interesting material viz. NiTi that is enjoying the widest application due to its superior memory and structural properties. The first step in developing a constitutive model is to understand the behavior of these materials under combined thermal & mechanical loading cycles. A series of both macro and microscale tests were designed and conducted. The testing methodology and specimen preparation for High Resolution Electron Microscopy is discussed. Finally we present comparisons between our experimental results and those conducted independently by other research groups. A general inelastic framework for the derivation of general three-dimensional thermomechanical constitutive laws for materials undergoing phase transformation is used. The framework is the result of combination of elements from generalized plasticity theory and the theory of continuum damage mechanics. This formulation is capable of accommodating the multiple and interacting loading mecha-

nisms, which is an integral part of the modeling of materials with phase transformations like SMA. This is then used to develop an internal variable thermomechanical constitutive model for SMA materials. The model's predictive capabilities in describing important material charateristics, associated with internal phase transformations are assessed. These include shape memory effect, stress-strain-temperature relations for pseudoelasticity under monotonic and cyclic loading, and energy dissipation of the material that governs its damping behavior.

Dynamics, Identification and Control of Cable Systems

June 3, 2002
16:30
Chair: Vincenzo Gattulli **Universitá di L Aquila**

ANALYTICAL METHOD FOR THE DYNAMIC ANALYSIS OF COMPLEX CABLE STRUCTURES

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The problem of vibration mitigation of stay cables in cable-stayed bridges becomes challenging when the solution that is chosen interconnects the stays by means of transverse cross-ties. The modal analysis problem of the individual cable is therefore transformed into that of a more complex "grid structure", in which the behavior is influenced both by global and local characteristics. A generalized analytical technique, founded on taut-string theory, is first presented; the original theory is extended and applied to the case of cable networks, in which the force-deformation characteristics of the transverse connectors are initially simulated by means of linear models (springs, rigid elements). Subsequently, a modification to the original approach considers the addition of dampers in specific locations of the structure. The use of complex-domain analysis is therefore introduced; in this way a generalized tool for the analysis of a wide class of problems is developed. The procedure is applied to simplified cases, in which the results are compared to closed-form solutions, and subsequently extended to multi-degree-of-freedom systems and large existing structures (e.g., Fred Hartman Bridge).

DYNAMICS OF A STRETCHED STRING WITH A MOVING END

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The response of a string with an axially oscillating end support was investigated analytically. The assumed modes method was used to convert the original continuous system into a series of Hill's equations. First order approximate solutions were obtained using the method of averaging. The impact of the natural frequencies of vibration of the unperturbed system being commensurate was also examined. The transition curves, separating regions of stability and instability, were determined for even and odd combination resonances of the frequency of the axially oscillating end. The influence of the amplitude and frequency of the oscillation of the moving support was discussed.

Analytical Investigation of the Performance of a Damper with a Friction Threshold for Stay-Cable Vibration Suppression

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Because of the problematic large-amplitude vibrations that have been observed on the cables of the Fred Hartman cable-stayed bridge in Houston, Texas, a vibration suppression system is being designed, which will supplement the current cross-tie restraining system with fluid dampers, to be attached to the cables transversely near the anchorages. In the preparation of the damper design, inquiry revealed that fluid dampers typically may have a significant inherent friction threshold even when specified to have a linear force-velocity relationship. When the forces in the damper are below this friction threshold, the damper is completely locked, and no energy is dissipated. Motivated by the potentially large magnitude of the damper friction threshold and the apparent significance of its effect in the measured data, this paper presents an analytical investigation of the influence of a friction threshold on damper performance and summarizes a proposed design procedure that accounts for the friction threshold. This procedure determines the maximum allowable friction threshold, the viscous damper coefficient, and the power dissipation and maximum force capacities.

New Control Mechanism Of Tuned Mass Damper For Strong Wind-induced Coupled Vibration Of Long-span Bridges In Hurricane Prone Area

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In the past decades, the control mechanism of Tuned Mass Damper (TMD) has been well studied for bridges with weak modal coupling. With the increase of bridge span lengths and the tendency of the bridge cross-section being more slender and streamlined, the vibration modes of the bridge are more prone to couple together due to the interaction between the bridge and the strong wind. However,the mechanism of TMD in the control of coupled vibration is still not clear. The objective of this study is to develop a control mechanism that will be efficient not only for the control of resonant vibration, but also for controlling the response component due to modal coupling. For this purpose, a theoretical derivation of coupled buffeting response of the bridge-TMD system is made. With the derived analytical formulation, control theory of TMD on coupled vibration is analytically and numerically investigated. It is found that the TMD can suppress the coupled response through demolishing the modal coupling effects originally existed among modes, in addition to traditionally suppressing the resonant response.

Nonlinear Quadratic Interactions in Cable-Stayed Beams

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An analytical model is proposed to study the nonlinear interactions between deck and cable motions in cable-stayed bridges. The integro-differential problem, describing the in-plane motion of a simple cable-stayed beam, presents quadratic and cubic nonlinearities in the cable equation and at the boundary cable-beam connection. System modal properties analytically derived evidence the occurrence of 1:2 and 1:3 internal resonances in the parameter range of technical interest. Quadratic interactions appearing at lower oscillation amplitude than cubic are the primary object of the study. Two cases of 1:2 resonance, namely, global-local and local-global interactions are analyzed by a 2dof analytical model. In the first case, the cable undergoes large oscillations due to an energy-transfer from lower-frequency (global mode) to higher-frequency (local mode) which are amplified for cable of light weight. In the second case, cable oscillations are induced by global motion at a double frequency of the first local mode through the well-known parametric excitation phenomenon.

Dynamics of Structures II
June 3, 2002
16:30
Chair: Rene Testa Columbia University

DYNAMIC PROGRESSIVE COLLAPSE OF FRAME STRUCTURES

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Current research on the dynamic progressive collapse of frame structures is presented in this paper. Unlike previous studies that have approached the problem without consideration of inertial effects, our research addresses the importance of dynamic load redistribution. For the present study, a computer program has been developed for analyzing dynamic progressive collapse of 2-D frame structures. Newmark's method, in conjunction with Newton-Raphson iterations, is used for computing system response as a function of time. Both geometric and material nonlinearities are considered. A damage index is also computed to account for the effects of strength and stiffness degradation, and it is used to determine the onset of member failure. Following member failure, the analysis continues through the use of a modified member stiffness procedure with releases of end forces. The paper concludes with a discussion of other important factors related to progressive collapse including the prediction of impact forces that may result after a member has failed and strikes a portion of the remaining structure.

RELATION BETWEEN FAILURE STATE OF REINFORCED CONCRETE COLUMNS AND INPUT ENERGY IN LARGE SCALE SHAKING TABLE TEST

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It is widely recognized that the energy values of a seismic wave, such as total input energy and momentary input energy, are general destructive-power indexes of the earthquake, which is independent of structure types. However, adaptability of these indexes to the structures at non-linear state, where the strength of the structure decreases and residual deformation occurs, have not been fully examined. One of the reasons is that time history analysis methods of structures at a strength degradation state is still under development. In this study, large scale shaking table tests of reinforced concrete columns were performed, and the relationship between the failure state of the columns and the input energy was examined. From these test results, the adaptability of the energy input value as a destructive-power index at a strength degradation state was confirmed

EFFECT OF SURFACE IRREGULARITIES ON THE DYNAMIC RESPONSE OF BRIDGE-VEHICLE SYSTEMS

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In a careful investigation of the effects of bridge surface roughness on the dynamical response of bridge-vehicle systems, three important aspects should be addressed. First, the interactions between bridge and vehicles should be accounted for; second, a good representation of bridge surface roughness is necessary; and, finally, the model of the bridge should be as realistic as possible. However, in most of the available literature on the subject, one or more of these elements is downplayed. In this paper, a Monte Carlo simulation technique is employed to study the related random vibration problem. The irregularities in the bridge surface are modeled as a stationary, zero mean Gaussian process with a specified power spectral density (PSD), from which sample functions are generated by Shinozukaís method. To model a slab-girder bridge, a finite element formulation is used. ìMoving massî and ìmoving oscillatorî solutions are obtained. It is found that the ìmoving massî simulation does not give reasonable results and that the distribution of Dynamic Amplification Factors (DAF) can be described well by a double log-normal probability distribution.

MODELING CRACK CLOSURE EFFECTS ON FREQUENCY AND DAMPING

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Because vibration signatures can be used to identify the presence of fatigue cracks and assist in locating damage, it is important to understand how cracks affect modal frequencies and damping. Experimental results are presented here to show how the effect of a crack depends on the crack history and the degree of crack closure. Nonlinear effects are demonstrated. Modeling of the mechanism by which the crack interfaces affect frequency and damping is outlined.

Probabilistic Methods - II
June 3, 2002
16:30
Chair: George Deodatis Columbia University

Optimal Earthquake Insurance in Risk Management

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Seismic risk of a building may be represented by an index R defined by the product of loss L and its probability of occurrence P. In order to reduce the potential risk, there can be various measures considered. If the risk R is large and is plotted in a zone of large L with relatively small P, it can be considered to transfer a part of the potential risk to insurance. This study investigates role of insurance as a supplemental measure for disaster prevention and will propose a methodology on how to determine optimal premium for the owner of a building associated with earthquake disaster prevention. First, the role of insurance in risk management is discussed and a condition required for admissible premium for the owner is derived in terms of expected utility function Eo[U(L(x,T))],the expected loss of owner and Ei[L(x,T)],the premium which is the part of the expected loss transfered to insurance company, plus kEi[L(x,T)], the loading which is the commission of the company, where x is a control parameter vector, T is the period in years, and the cofficient k is the ratio of the commisssion to the premium. Then, a methodology is proposed to find the optimal life cycle cost LCC(x,T), incorporated with a method to find the optimal premium such that the expected annual loss of owner becomes minimum. Finally, a numerical example for an office building is carried out to demonstrate the methodology. It is noted that the LCC is given by LCC(x,T) = C(x) + Eo[U(L(x,T))] + (1 + k)Ei[L(x,T)], where C(x) is the initial cost. Ordinary maintenance costs are excluded in this study. In the optimization of insurance, it is sought to find the optimal maximum payment limit of premium such that the difference between LCCs with and without insurance becomes maximum, while the deduction limit of premium and the ratio k are fixed. Optimization of LCC is made to find x such that LCC becomes minimum.

Simple Estimation Method of Extreme Response to Non-stationary Excitation

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This paper presents simple but accurate expressions to estimate the characteristics of extreme responses subjected to non-stationary excitations. The expressions are empirically determined based on extensive numerical simulations, which are carried out for linear SDOF(Single Degree of Freedom) systems subjected to white noise excitations. A new parameter representing the "strength of non-stationarity" of the response is proposed for organizing the characteristics of extreme responses. The expressions for the peak factor and the coefficient of variation of extreme values are empirically determined as a function of the proposed parameter. The response spectra subjected to filtered white noise excitations are evaluated for verifying the accuracy of the expression of the peak factor. The comparisons with MCS(Monte Carlo Simulation) show that the expression of the peak factor is not only simple but also accurate for non-stationary response.

Correlation Effects on Reliability Assessment of Structural Systems

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Reliability of a structural system is assessed for both noncorrelated and correlated structural components. The existence of correlations among components of structural systems is examined in this paper. Simulation methods are used to model correlations among structural components and to assess the components and system probabilities of failure. Fault tree analysis is used as a method for assessing the reliability of systems. The direct Monte Carlo method is used as a simulation method. The antithetic variate technique is selected as a variance reduction technique and used in the simulation method to improve the simulation efficiency and accuracy. The results showed that correlation among structural components affected the reliability of structural systems. Correlations also affected the sequence of combined failures of components in the system. The use of variance reduction technique improved the simulation efficiency and accuracy.

FORM Analysis using Consistent Approximations

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Using the theory of consistent approximations, we construct an algorithm model for the solution of the optimization problem required in first-order reliability analyses. The algorithm model accounts for approximations in the evaluations of the limit-state function, and uses a test to gradually increase the accuracy of the limit-state function evaluations. The algorithm model leads to a significant reduction in the computational time compared to constantly high-accuracy evaluations of the limit-state function.

Assessment Of Sampling Errors In Peak Wind-induced Internal Forces

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Peak values in time histories of wind effects may be obtained by using the entire information inherent in the time series of the wind effect, a method entailing the estimation of the probability distribution of the peak through the application of the classical Rice procedure extended for non-Gaussian time histories. This paper presents estimates, needed for structural reliability calculations, of the sam-

pling errors inherent in this method. If based on the analysis of one-hour long records generated by Monte Carlo simulation, typical sampling errors in the estimation of peaks of time histories corresponding to windstorms of one-hour duration are about 5 %. If based on 30 min or 20 min records they are about 1.5 times or twice as large, respectively. Consideration of the sampling errors in reliability calculations entails an increase in the requisite safety margins with respect to wind loading of about 3 % if one-hour records are used and somewhat larger if 20-min or 30-min records are used.

Syposium on Micromechanics of Heterogeneous Materials - Session IV

June 3, 2002
16:30
Chair: Chien Wu University of Illinois at Chicago

Multi-pass Homogenization Of Honeycomb Sandwich Plates

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The computations of honeycomb sandwich structures are generally processed by continuum modeling of heterogeneous cellular structures, due to the difficulty of solving 3-D partial differential equations with oscillating coefficients. The existing acquisition of equivalent elastic properties, based on the models without skin faces accounted for, results the computed equivalent stiffnesses erroneous, particularly for sandwich plates with characteristic periodicity e comparable to plate thickness d. To develop an effective and accurate theoretical approach for general cellular sandwich structures, the application of homogenization theory to periodic plates is presented and extended to include transverse shear deformation theory in this study.

Based on the scaling asymptotic expansions about plate thickness d for sandwiches with comparable characteristic periodicity e, the homogenization functions P, U, and V are formulated implicitly in 3-D elliptical equations corresponding to the modes of transverse shear, in-plane stretch and out-plane bending. The solutions of these periodic functions are analytically obtained through a Multi-Pass Homogenization (MPH) technique that includes the first pass of a Geometry-to-material Transformation Model (GTM) and the second pass of 2-D unit cell homogenization. The derivation not only leads to analytical formulas of homogenized÷ elastic stiffness of honeycomb sandwiches but also demonstrates the significance of usually neglected skin effect on honeycomb computations. Finally, a periodic unit cell finite element modeling technique is developed to validate the analytical approach and further complement it with skin rigidity considered.

Studies on Reinforced Cement Deep Mixing Soil (R-CDM) by Discrete Randomly Distributed Fiber (DRDF)

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From the viewpoint of low tensile strength and brittle character of treated soils by CDM, Discrete Randomly Distributed Fibers (DRDF) has been used as a new additional additive. A series of unconfined compression and splitting tension test was conducted on fiber/cement/alluvial soil composite to evaluate the influence of fiber inclusion on their static behavior. Results of the experiments showed that fiber inclusion in addition to solve the problem of brittle failure increased the unconfined compressive and splitting yield tensile strength and significantly increased the ductility and thus; fiber inclusion is expected to play a good role as cost-save factor and may lead to a new generation of soft ground improvement by CDM technique.

Herein, effort has been focused on studying the FR-CDM system quantitatively by analyzing the unit volume of the composite under full saturation condition and physical properties of the composite has been studied with respect to fiber content and cement dosage. Formulas express some important physical properties have been established as an essential step for the future research work in this area.

Antiplane Shear Of Elastic And Viscoelastic Fiber Composites With Nonlinear Interface

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Antiplane shear of elastic and viscoelastic composite cylinders containing interfaces whose shear-slip behavior is captured by uniform Needleman-type cohesive zones is analyzed. Previous work on the elastic problem leads to a constitutive framework consisting of a shear stress-shear strain relation depending on the interface slip discontinuity together with an integral equation governing its evolution. Results for the fiber composite follow from the composite cylinders representation of an RVE together with variational bounding. Here, we present an exact single mode solution to the integral equation and utilize it to treat the single mode elastic and viscoelastic problems. For a rigid fiber embedded in a matrix which is a standard solid in shear we find a pair of nonlinear first order differential equations which govern relaxation response through the time dependent shear stress and interface slip magnitude, and creep response through the time dependent shear strain and interface slip magnitude. Graphs of creep and relaxation response are presented for an interface model that allows for shear interface failure.

Electromigration and the back flo potential in thin films and lines

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Electromigration (EM) in a metal line is the phenomenon of flow of the metal atoms along the line. The flow is driven by the current of electrons and is also affected by the variation of chemical potential along the line. The replacement of atoms leads to a change in eigenstrain, which, in turn, alters the chemical potential. It was first experimentally observed by Blech [1] that a reverse chemical potential gradient could actually produce a back flow of atoms. Since the chemical potential is very often dominated by a stress term, this back flow is very often attributed to the presence of a stress gradient [1, 2, 3]. In microelectronic applications metal lines are usually subjected to the actions of large thermally induced eigenstrain even before the current is turned on. This large eigenstrain, together with the EM-induced eigenstrain, may lead to a nonlinear back flow that may be analyzed by a recent result [4] and is presented in this paper.

[1] I. A. Blech, J. Appl. Phys. 47, 1203 (1976) [2] M. A. Korhonen, P. Borgesen, K. N. Tu and C-Y Li, J. Appl. Phys. 73, 3790 (1993) [3] Z. Suo, Acta mater. 46, 3725 (1998) [4] C. H. Wu, J. Mech. Phys. Solids 49, 1771 (2001)

Coupled Problems in Mechanics of Materials

June 3, 2002
16:30
Chair: Franz-Josef Ulm **Massachusetts Institute of Technology**

Effect of transient high temperature on heavyweight, high strength concrete

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In the present work, 12 mixes were selected to achieve a slump above 100 mm and strength up to 140 MPa at 180 days. To achieve this a 0.24 water/cement ratio and 3.5% superplasticiser were used. The investigation used three levels of silicafume (0, 10%, 20% by weight of cement), two coarse aggregate proportions of total aggregate (0.48, 0.65 by volume) and both magnetite and natural sand fine aggregate were used. The effect of transient high temperature on strength of heavy weight high strength concrete was investigated. There were three exposure durations (0, 1hr, 2hrs.) at temperatures of 100, 300, 500 and 700 C. As the temperature increased to 100 C, the strength decreased compared to the room temperature strength. With further increase in temperature, the specimens recovered the strength loss and reached a peak strength of 10 to 30 % above the room temperature strength. At the temperature 500 and 700 C, the strength in each case dropped sharply.

Autogenous and thermal deformations of low Water/Cement ratio cement paste at early age.

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The influence of temperature on the autogenous shrinkage of cement paste has been studied using the maturity approach based on Arrhenius' law. The external volume change of cement paste was measured by hydrostatic weighing. In order to separate the thermal and autogenous deformations, the Thermal Dilation Coefficient (TDC) was determined at both 20×C and 30×C. Investigations have shown that maturity can be used to predict autogenous shrinkage under realistic conditions as long as temperatures remain between 10×C and 40×C. Outside of this temperature range, the calculated autogenous deformation and measured isothermal shrinkage are quite different and, as a result, autogenous shrinkage appears to be dependent on more than hydration advancement alone.

COUPLED HYDRO-MECHANICAL AND DAMAGE MODEL FOR CONCRETE AS AN UNSATURATED POROUS MEDIUM

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The long-term behavior of concrete is largely dependent, in many applications of civil engineering, of the transfer phenomena of the fluid phases filling the pores, which are governed by diffusion and permeation processes (shrinkage, creep). In this study the concrete is described as a porous medium made up of two phases (solid and liquid) in interaction by using the mechanics of isothermal unsaturated porous media. Two isotropic damage variables are introduced in the formulation for reproducing the degradations appearing in tension and compression, as well as their effects on the hydro-mechanical coupling parameters. The main transfer phenomenon is assumed to be controlled essentially by pore water pressure gradients, and consequently the capillary pressure, related to the saturation degree via the desorption isotherm curve, defines the state of the liquid phase. Under this hypothesis the governing equations are established in function of the capillary pressure in the case of the drying shrinkage of concrete. The analogy between the proposed simplified formulation and the more classical problem of a saturated porous medium is briefly analyzed.

OPTIMIZATION OF MASS CONCRETE CONSTRUCTION USING GENETIC ALGORITHMS

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This paper presents a procedure to optimize the construction of massive concrete structures using genetic algorithms. The main loading condition for such structures corresponds to strains imposed by the effects of the hydration reaction, namely the thermal strains and the autogenous shrinkage strains. The coupled model developed by Ulm and Coussy implemented in a 3D computer code may be used to compute the transient hydration, thermal and stress fields. The decision variables for the optimization process are: the material characterized by its hydration properties; the thickness of the lifts; the placing frequency and the placing temperature. The optimization problem is defined by the fitness function which is the total cost of the construction and the constraint (penalty) which corresponds to thermal cracking. The example corresponding to the layered construction of a concrete block displays the potentiality of the present method as an optimization tool for massive concrete structures.

Frank L. DiMaggio Symposium on Constitutive Modeling of Geomaterials IV

June 3, 2002
16:30
Chair: Majid Manzari **The George Washington University**
Co-Chair: A. (Rajah) Anandarajah **Johns Hopkins University**

A CONSTITUTIVE PLATFORM FOR SAND MODELING

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This paper addresses the issue of sand dilatancy and the impact of fabric anisotropy. A platform model based on the concept of state-dependent dilatancy is introduced first, and a joint invariant, A, of the stress tensor and a second-order fabric tensor is developed afterwards. With this objective measure of the sand anisotropy state, the dilatancy and plastic hardening are formulated, and the critical-state line is assumed non-unique in the e-p-q space but unique in the e-p-q-A space. This simple approach is rigorous and correct within the fundamentals of anisotropic constitutive modeling and captures some of the most important features of stress-strain-strength responses of sand including the impact of inherent fabric anisotropy under proportional loading condition.

DAMAGE MODELING OF SATURATED ROCKS IN DRAINED AND UNDRAINED CONDITIONS

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This paper deals with constitutive modeling of saturated brittle rocks in drained and undrained conditions. Induced anisotropic damage is an essential feature of brittle materials like rocks and concrete. A macroscopic poroelastic damage model is proposed, based on relevant results from micromechanical considerations. We use a second rank tensor to represent density and orientation of microcracks. The constitutive equations are derived from a thermodynamic potential. The damage evolution is directly related to microcrack propagation condition. Effective poroelastic coefficients of damaged material are determined from micromechanical analysis. The validity of effective stress concept is discussed. The model is applied to a saturated typical brittle rock in drained and undrained conditions. We have obtained a good corroboration between model's predictions and experimental data.

A Continuum Damage Approach of Asphalt Concrete Fatigue Tests

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To forecast pavement fatigue cracking, fatigue performances of asphalt mixtures are assessed using laboratory cyclic fatigue tests. A damage model is implemented to predict the behavior of asphalt mixtures during these tests. Under sinusoidal loading, the evolution of the complex modulus of the material is defined as the damage variable associated to a microcracking mechanism. Its evolution during fatigue tests is described by an elasticity based, nonlocal damage model. A cycle based time treatment is implemented into a finite element code, to simulate high cycle fatigue tests. The damage model parameters identification is performed using uniaxial fatigue tests. With these parameters, bending fatigue tests simulation results are discussed. The comparison between simulated results and experimental data points out a good approximation of the fracture process before damage localization in the specimen.

A Theoretical Analysis of Hysteretic Matric Suction and Effective Stress in Unsaturated Sandy Soils

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An analysis is conducted for modeling the constitutive relationships among water content, matric suction, and capillary cohesion in unsaturated granular soils. By considering changing meniscus geometry, matric suction and effective stress are evaluated as functions of water content for spherical soil particles under the pendular porewater regime. The contact angle at the interface between the porewater and the soil particles is considered as an arbitrary variable so that its effects on the hysteretic behavior of matric suction, effective stress, and capillary cohesion may be evaluated. The analysis provides a theoretical basis for describing several well-known phenomena in unsaturated soil behavior. Varying the contact angle from 0× to 40× to simulate drying and wetting processes respectively is shown to have an appreciable impact on hysteresis in the constitutive behavior of the modeled soils. The observations afford an improved understanding of the behavior of real unsaturated soils undergoing natural wetting and drying processes.

Experimental and Computational Modeling of Elasto-Plastic Constitutive Behavior of An Unsaturated Soil Under True Triaxial Stress States

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Computational constitutive drivers are implemented for the numerical simulations of suction-controlled conventional triaxial tests on unsaturated soils using two elasto-plastic critical state based formulations: Barcelona model and Oxford model. Simulations are obtained from both explicit and implicit integration techniques. The algorithms support numerical analyses in a deviatoric stress plane by using a mixed control constitutive driver in conjunction with a Generalized Cam-Clay model, within a constant-suction scheme. Results from a series of suction-controlled conventional triaxial tests on 10-cm side cubical specimens of compacted silty sand, using a controlled stress and suction cubical test cell, are used for validation of both models. Matric suction states in the specimens were induced and maintained constant during testing via axis-translation technique.

Experimental Methods for Particulate Materials - I
June 3, 2002
16:30
Chair: Anil Misra University of Missouri
Co-Chair: Jin Ooi University of Edinburgh

FAILURE AND SHEAR BANDING IN THREE-DIMENSIONAL EXPERIMENTS ON LOOSE SANDS

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An experimental study on the effects of non-plastic silt on the three-dimensional drained behavior of loose sands was performed employing a true triaxial testing apparatus. Laboratory experiments were performed on clean sand and sand containing 20% non-plastic silt. Results indicate the failure stress levels and the overall trends of the stress-strain behavior were similar for both sands. However, the volume change behavior is significantly influenced by the presence of silt. The silty sand exhibited higher degrees of volumetric contraction during shearing than the clean sand. Relative density was used as the basis of comparison. Shear band development appears to have caused failure in all true triaxial testing performed, except in triaxial compression. This form of instability appears to increase its influence on the experimental results as the participation of the intermediate principal stress increases. The formation of shear bands also appears to coincide with the cessation of contractive volumetric strains.

EVOLUTION OF GVHMAX UNDER ISOTROPIC AND DEVIATORIC STRESS PATHS IN GRANULAR MATERIALS

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The effect of the mean effective stress on the elastic properties of unbound granular materials is a well-known experimental result. Power laws between the mean effective stress and the shear modulus Gvhmax of three natural sands are established for isotropic stress paths using bender elements. Triaxial test results reveal that such power laws are also suitable for contracting deviatoric stress paths whereas it is no longer the case for dilating deviatoric stress paths. Fabric changes during shearing are therefore highlighted. These observations seem to be a typical feature of the behavior of granular materials.

EFFECTS OF STRAIN RATE IN COHESIONLESS SOIL

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Jerry Yamamuro *University of Delaware*

Cohesionless specimens composed of coral sand are tested over a wide range of strain rates, varying from traditional static rates to approximately 1100 %/sec measured globally. Due to the high loading rates associated with transient testing, drained triaxial compression tests using evacuated axisymmetric specimens are performed. High-speed film photography coupled with digital image analysis techniques are used to capture specimen deformations and piezoelectric load cells measure the load for transient tests. A traditional style load cell and loading frame is used for static testing. A custom designed loading apparatus and triaxial cell are used to perform the transient testing. Photographic images are presented that illustrate changes in specimen deformation patterns for high strain rate tests. Preliminary results suggest granular materials experience measurable strain rate effects. Two separate series of tests under medium and loose configurations are presented.

VOIDS DISTRIBUTION OF SAND SPECIMENS BY MRI

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This paper presents the void distribution of sand samples prepared by under-compaction method. Three different particle sizes of Ottawa sands are used in this study. The samples were prepared with a newly fabricated non-metallic triaxial cell. The triaxial cell was then put inside the magnetic core for Magnetic Resonance Imaging (MRI). The MRI at New Mexico Resonance have a resolution of one part in 512 which is 0.1 mm for a 5-cm specimen making it suitable to study the void distribution. We captured the image of the voids (filled with water) between solid particles. Measurements yield the initial packing of the specimens. Uniformity of the samples can be detected. This study will demonstrate the feasibility of using MRI to study the void distribution of sands.

Fluids - Hydrodynamic Modeling
June 3, 2002
16:30
Chair: John Edinger **J.E.Edinger Associates, Inc.**

A Three-Dimensional Finite-Element Model of Saltwater Intrusion in Kings and Queens Counties, New York

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Clifford Voss

A three-dimensional version of the U.S. Geological Survey's SUTRA ground-water flow model code (acronym for Saturated-Unsaturated TRAnsport , available at http://water.usgs.gov/software) is being tested for simulation of saltwater intrusion in the ground-water system of Kings and Queens Counties on Long Island, New York. This model solves two equations: a fluid mass balance for unsaturated and saturated ground-water flow, and a solute mass balance. The solute concentration corresponds to the mass fraction of total dissolved solids, and density dynamics driven by solute concentration are accounted for. An extensive geographic information system of the region is the basis for representing complex model geometry and boundary conditions in three dimensions. The direct-banded matrix solver that is typically used with two-dimensional SUTRA models has large computer-memory and processing requirements and was replaced with an iterative solver.

Hydrodynamic Modeling of the Hudson River Estuary

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In this paper the authors describe the development and preliminary application of a two-dimensional hydrodynamically based transport model for the Hudson River Estuary between the Troy Dam and Hastings-on-Hudson. The model is based upon equations describing the conservation of mass and the conservation of momentum in two horizontal directions with appropriate closure schemes for bed friction and turbulent shear stresses. The resulting equations are solved in a non-orthogonal coordinate system, which allows for the easy application of the collected bathymetry data as river cross-sections. The model is applied to the Hudson River Estuary, NY, and is shown, at least qualitatively, to reproduce the hydrodynamic behavior of the estuary. Discrepancies between model results and observations are explained and future implications for transport modeling are discussed.

Systematic Calibration of a Hydrodynamic and Water Quality Model

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This paper examines the problem of calibrating a coupled hydrodynamic and water quality model, WQDPM, that consists of 11 state variable equations with over 40 interrelated parameters and coefficients. The analysis is directed toward the question of how to systematically find the values of the parameters and coefficients by comparing model results to field data. Proper calibration of the water quality model requires having accurate representation of the inflows or loads of nutrients into the water body and selecting appropriate model parameters.

Fate of Pesticides in Upper Chesapeake Bay

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The fate and transport of atrazine, including effects of photodegradation and a potential reaction with polysulfides, in the Upper Chesapeake Bay is investigated. A hydrodynamic model that includes all relevant physical and chemical processes is used to show that atrazine is transported vertically down the water column to the sediment water interface where it may react with naturally occurring polysulfides. Limited field data supports these results. Based on reaction rates reported in the literature, model results show that neither photolysis nor the reaction with polysulfides decrease the concentration of atrazine in the Upper Bay in any significant amount. Our modeling study shows that the minimum reaction rate required to decrease the concentration of atrazine in the bottom layer is 1012 M-1s-1. The wide range of reaction rates used to obtain these preliminary results suggests that a potential reaction between an herbicide or pesticide and polysulfides is not a significant removal mechanism for agrochemicals in the Upper Chesapeake Bay.

Combined Hydrodynamic and Water Quality Modeling

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Zooplankton grazing in an important process in transferring particulate organic carbon, organic nitrogen, and organic phosphorous from phytoplankton in the nutrient cycle. The organic carbon oxidizes to simpler forms of carbon, the organic nitrogen is transformed to ammonium, and the organic phosphorous is transformed to phosphate phosphorous. The zooplankton grazing rate has been traditionally formulated as a linear rate proportional to phytoplankton density. More recent studies have indicated that density dependent grazing rates that dependent on the square of the phytoplankton density might be more realistic.

The two grazing functions are compared theoretically, and then tested in a tidal estuary situation that has sufficient data to determine how well the linear rate and the density dependent rate allows estimating different water quality parameters within the estuary. A three dimensional hydrodynamic model is used to accurately represent the estuary spatial and temporal velocity field that transports the water quality constituents. The advantages of using the density dependent relationship are shown.

Tuesday - June 4th, 2002
Session Abstracts

Health Monitoring Benchmark Problem
June 4, 2002
9:45
Chair: Dionisio Bernal Northeastern University

Flexibility-Based Damage Localization Employing Ambient Vibration

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In recent years, Structural Health Monitoring (SHM) has emerged as a new research area in civil engineering. Most existing health monitoring methodologies require measurement of inputs for implementation. However, in many cases, there is no easy way to measure these excitations ñ or even to excite the structure. Therefore, SHM methods based on ambient vibration become important in civil engineering. In this paper, an approach is proposed to extend the Damage Location Vector (DLV) method to handle the ambient vibration case. This flexibility-matrix based method is combined with a modal expansion technique for SHM. An approach to select the analytical model for this modal expansion technique is also given. Finally, a numerical example, which analyzes a truss structure with limited sensors and effect of noise, is provided to verify the efficacy of the proposed approach.

Solution for the Second Phase of the Analytical SHM Benchmark Problem

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This paper addresses the second phase of the IASC-ASCE Structural Health Monitoring (SHM) benchmark problem. This problem was created to improve the understanding of SHM techniques by comparing their performance using a common structure and set of damage cases. The structure selected for this benchmark problem is a four story 2 bay by 2 bay steel frame. Numerical models of the structures have been developed. Damage is simulated by reducing stiffness in members of the structure. The methodology presented here in uses the Natural Excitation Technique (NExT) and the Eigensystem Realization Algorithm (ERA) to identify the natural frequencies and mode shapes of the structure. Using these natural frequencies and mode shapes it is possible to determine the stiffness coefficients of structural memebers through a least squares solution of the eigenvalue problem. Two different identification models are used and the results are compared. The proposed methodology is shown to be effective in the detection, quantification and location of damage in civil structures.

Progress of Phase II Study of the ASCE Health Monitoring Benchmark Data Using Wavelet Approach

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This paper, as a continuation of the authors' previous work on application of the wavelet analysis for damage detection for ASCE health monitoring benchmark data, addresses feasibility of the wavelet approach for detection of local stiffness loss using the benchmark study Phase II data. The acceleration response data were generated by finite element codes provided by the ASCE Task Group on Health Monitoring for a four-story prototype building structure subjected to simulated stochastic ambient loading. Two 120-DOF reference models (braced and unbraced structure) are considered in Phase II, but only results for the braced model are presented in this paper. Damage patterns are mainly those specified in Phase II of benchmark studies. Some other damage patterns are also included for comparison. It was found that a sudden local damage which may result in small change of less than 4% in the first few natural frequencies and the time when it occurs can be detected by spikes observed in the high-resolution wavelet details. A sensitivity study of the method in respect to damage location and severity, measurement noise, and types of analyzing wavelets is discussed. The results illustrate a great promise of wavelet analysis for the structural health monitoring due to its merits of less-model dependence, sensitivity to a local damage, simplicity in algorithms and efficiency in computational efforts, and feasibility for on-line implementation.

Application of the Damage Index Method to Phase II of the Analytical SHM Benchmark Problem

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This paper presents research that utilizes the Damage Index Method to detect the location and severity of damage to the Second Phase of Analytical Studies of the Structural Health Monitoring Benchmark Problem developed by the ASCE Task Group on Structural Health Monitoring (TGoSHM). This method utilizes the ratio of curvature in the mode shape of the damaged structure vs. the undamaged structure. A shear-building model is utilized for damage detection of the unbraced frame system, both with full and partial sensor data. The location and severity of damage is carried out using the Damage Index Method for both existing damage patterns established by TGoSHM.

Phase II of the ASCE Benchmark Study - Performance of the DLV Approach

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The Task Group on SHM (Structural Health Monitoring) of the Engineering Mechanics Division of ASCE has designed and conducted a series of analytical studies on a 4-story 3-D steel benchmark structure. Phase I of the investigation started in 1999 and was completed in the summer of 2001. The second phase of the study, whose definition is described in this paper, was prepared to test the sensitivity of various damage identification techniques to a more realistic simulation of the errors that arise from the inevitable discrepancies between the 'real system' and the identification model. Specifically, while in Phase I the modeling errors were realized by forcing the identification models to be simpler than the truth model, in Phase II they are a byproduct of imprecise knowledge and no constraints on the nature of the identification model are imposed. In the truth model, for example, the masses and the centers of mass deviate from the nominal values in the drawings and the connections between the steel beams and columns are treated as semi-rigid with a rotational stiffness that varies from one connection to the next around a certain mean. The fictitious problem of 'reversed modeling error' i.e., the case where the model selected for updating includes features not included in the 'truth model', is avoided by providing the user with a description of the general nature of the truth model. For example, users are aware that the connections are semi-rigid, that floor slabs are considered rigid in their own plane and that the base of the structure is treated as fully fixed (no Soil-Structure-Interaction).

This paper describes the general philosophy that has guided the work of the SHM Task Group and defines in further detail Phase II of the benchmark study. The results obtained for this phase using the recently developed Damage Locating Vector Approach are presented in detail.

Fiber Reinforced Plastics (FRP)

June 4, 2002
9:45
Chair: Arup Maji University of New Mexico

An Analytical Study of an FRP Deck on a Truss Bridge

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Many of the old truss bridges in the New York State are posted due to superstructure deterioration and an increase in live load. By replacing the heavy decks of these bridges with lighter ones, the load-carrying capacities of these bridges can be improved, avoiding the need for replacement or costly repairs. Two years ago, a lighter FRP deck was used on an experimental basis to replace a concrete bridge deck on a deteriorated truss bridge in New York to improve its service life. Load-tests, conducted to evaluate the deck performance under service loads, indicated that the methods used for the design of the new fiber reinforced polymer (FRP) decks were very conservative. Thus validated finite-element models were developed to improve on these designs, and predict the failure modes of this bridge when subjected to overload and thermal effects. This presentation summarizes the results of load tests and analytical studies.

Simplified Load-Deflection Calculations of FRP Strengthened RC Beams Based on a Rigorous Approach

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The external FRP flexural and shear strengthening of RC beams is a well-established practice for structural rehabilitation and upgrade. For establishing a deflection calculation procedure, some investigators have proposed empirical modifications to the current ACI equation. Others used numerical analysis to generate such deflection computations. Alternatively, the present work develops an analytical solution for the same calculation at any load stage. The solution assumes a trilinear moment-curvature response. This model incorporates some tension stiffening effects and assumes the section to be fully cracked only upon or near steel yielding. A closed form equation is presented for the case of four-point bending as well as uniform loading. Comparisons with experiments indicate the effectiveness of the procedure for properly anchored plates. An extensive parametric study is conducted to reveal a single linear relationship between the cracked moment of inertia of the section and the overall effective beam moment of inertia at yielding for a wide range of geometric and material parameters. A similar relationship holds between the moment of inertia of the section at the ultimate

moment and the corresponding effective value for the entire beam. This greatly simplifies the deflection calculation as illustrated by comparisons with the rigorous analytical approach and the experimental results.

Mechanical Modeling of Glass and Carbon Epoxy Composites

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A test program was conducted to measure the monotonic tension and fatigue response of glass/epoxy and Carbon/Epoxy composites. The Carbon/epoxy composites were manufactured using a woven mesh. Uniaxial tension tests were conducted in the fiber direction and transverse to the fiber direction. Tension-tension fatigue tests were conducted for up to 10,000 cycles and the stiffness degradation as a function of cycles of load was monitored. Results of the experimental program were used to calibrate a theoretical model for the load deformation response of a unidirectional lamina in the longitudinal and transverse directions. Tsai-Wu Criterion was used for each lamina and the stacking sequence was utilized to obtain the overall stiffness matrix. A damage law was introduced to account for the evolution of damage due to fatigue loading. A scalar damage parameter as a function of the apparent strain in the sample was used. Theoretical and experimental results were compared using the load elongation response.

Effects Of GFRP Reinforcing Rebars On Shrinkage And Thermal Stresses In Concrete

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Jeong-Hoon Choi ***West Virginia University***

The use of Glass Fiber Reinforced Polymer (GFRP) rebars instead of conventional steel rebars as the reinforcement in Continuously Reinforced Concrete Pavement (CRCP) gives solutions to the problems caused by corrosion of reinforcement. However, it is necessary to know what effect this replacement has on the development of concrete cracks, which is inevitable in CRCP. Concrete shrinkage and temperature variations are known to be the principal factors for early-age crack formation in CRCP. By employing an analytical model, this study presents the shrinkage and thermal stress distributions in concrete due to the restraint provided by GFRP rebars in comparison with that provided by steel rebars. It reveals the advantages of using GFRP rebars as reinforcement in CRCP in terms of internal tensile stress reduction in concrete. Numerical calculation of the concrete stress distribution in a GFRP reinforced CRCP section subjected to thermal change is also presented.

Blast-proofing of Unreinforced Masonry (URM) Walls with GFRP

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The objective of the research was to develop and experimentally validate a methodology for designing GFRP retrofits for unreinforced masonry walls to withstand blast loading. The pressure-time history of blasts on a wall was modeled by a special code 'BLASTX' developed by the US Army. Readily available material properties of the glass fiber, the epoxy resin, the masonry blocks and the mortar was be used to predict the elastic stiffness of GFRP retrofitted masonry beams (representing wall segments) and their deflection at failure. These can be used to develop a 1st order design of retrofits to withstand specific types of explosives, using a single degree of freedom model. The actual nonlinear load-deformation behavior from static flexure tests of beams can be used for a more accurate prediction of the effect of blast loading. The intent of this approach is to develop a lower cost alternative to retrofit testing, based on simple static tests, rather than more expensive blast tests. This approach is being validated by correlating the results of laboratory scale beam tests to the full-scale blast tests on walls with the same GFRP retrofit. These tests will be conducted by the Defense Threat Reduction Agency (DTRA) at the test facilities at Kirtland Air Force Base in Albuquerque, NM.

Probabilistic Modeling - Session I
June 4, 2002
9:45
Chair: Takeru Igusa The Johns Hopkins University

NUMERICAL METHODS TO ESTIMATE THE COEFFICIENTS OF THE POLYNOMIAL CHAOS EXPANSION

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The polynomial chaos expansion, part of the stochastic finite element method, has been studied in recent years as a means of forming finite-dimensional approximations to general random processes. Because the coefficients of this expansion are themselves functions of the process being approximated, their accurate calculation, with minimal computational effort, is of prime importance during implementation. A sampled averages approach has been explored in previous work to estimate these coefficients. This method proves viable, however, only when samples of the process being approximated are computationally inexpensive to attain. In this paper, numerical integration techniques are utilized to estimate the coefficients. In many cases, this method may require significantly fewer function evaluations and, as a result, can be applied to those problems where each function evaluation requires significant computational resources. The method will be demonstrated on a simple example, as well as a complex engineering application.

A PROBABILISTIC TREATMENT OF UNCERTAIN BOUNDARY CONDITIONS IN CFD APPLICATIONS

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The solution of stochastic CFD equations faces some specific challenges. Frequently, in CFD applications the differential equations theoretically have to be integrated over a (semi-)infinite domain. In practice the integration domain is cut-off at some ''far field'' boundary. Some deterministic correction methods for the introduced error exist.

In this paper, we assess the impact of the uncertainty modeling on the far field boundaries on the statistics of the solution in the interior of the integration domain. We anticipate that the developed techniques will also be of interest for geo-technical and other applications where we can find semi-infinite domains.

The nonlinear generalized Burgers equation is used as a model problem. For selected expressions of the flux, analytical closed-form solutions exist. This exact solution is the gold standard against which numerical results obtained using the midpoint and locally averaged discretization method or polynomial chaos expansions, are compared. We assess the convergence of the algorithms in terms of the number of grid cells, the order of the chaos, and the quality of the boundary condition modeling.

IMPACT OF UNCERTAINTY IN CATASTROPHE LOSSES ON INSURANCE DERIVATIVES

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Roger Ghanem *Johns Hopkins University*

The amount of economical losses associated with natural disasters has significantly increased in recent years reflecting such factors as the increased frequency and severity of the hazards as well as the increase in property wealth. As insurance companies are concerned about the risk of insolvency, they turned to the financial market to provide them with the capability of handling catastrophe exposure.

Insurance products are valuated based on stochastic models of losses where two sources of uncertainty are noted: the choice of the stochastic model itself and the estimated values of the parameters used in these models.

This paper aims at quantifying the uncertainty in assessing catastrophe losses and its impact on the pricing of insurance derivatives. Simulations of several models is carried out with an emphasize on quantifying the significance of the uncertainty in the parameters on the financial securities pricing.

This uncertainty can be reduced through better information management. As such, this paper can be viewed as providing a motivation to some of the recent work in applying advanced technologies to catastrophe loss estimation.

STOCHASTIC ANALYSIS OF AN AEROELASTIC SYSTEM

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Buckling of the wing of a unique aircraft structural design concept, the joined-wing, is examined in a stochastic context. This non-traditional design might induce coupling between buckling and aeroelastic instabilities; furthermore, the geometric, structural, and aerodynamic nonlinearities inherent to this design increase the potential of ignored or poorly modeled uncertainties to promote unexpectedly severe response. We emphasize modeling stochasticity in the wing joint and the wing roots because of their importance in determining the response characteristics of the coupled structure. Gaussian randomness in the Young's modulus is introduced into an existing deterministic finite element model at these locations to approximate the effect of uncertain joint fixity.

SPECTRAL STOCHASTIC HOMOGENIZATION

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An original method of stochastic homogenization is developed and applied to a class of PDEs that is representative of a large number of problems in science and engineering. The starting point is a governing differential equation whose coefficients are modeled as stochastic processes with multi-scale oscillatory components. Even the deterministic versions of these equations present great challenges to numerical analysis methodologies, justifying various approaches to homogenization. The difficulty in the present situation is compounded by the explicit stochastic modeling of the variability in the heterogeneous coefficients. The present situation, therefore, corresponds to a situation involving highly heterogeneous materials with stochastic variability. A new system of stochastic differential equations is then obtained with random variables as effective coefficients. These coefficients are obtained through an asymptotic analysis that effectively identifies a macro-scale system as the limit of a micro-scale representative volume (REV) as this volume goes to zero. This resulting system of equations can then be resolved by relying on standard numerical integration schemes.

The above methodology is integrated with the polynomial chaos representation of stochastic processes resulting in computationally tractable algorithms for evaluating the homogenized coefficients. These algorithms involve simple quadratures over the REV.

An application to a multi-scale stochastic diffusion equation is used to highlight the theory, implementation and features of the proposed methodology.

Recent Advances in Materials Characterization and Modeling of Pavement Systems I

June 4, 2002
9:45
Chair: Thomas Papagiannakis **Washington Statre University**
Co-Chair: Erol Tutumluer **University of Illinois**

THE ROLE OF PAVEMENT MECHANICS IN THE FUTURE OF PAVEMENTDESIGN, CONSTRUCTION, PERFORMANCE, AND MANAGEMENT

Robert L. Lytton ***Texas A&M University***

As computers become faster and have larger memories, they can handle far more effectively than even in the recent past many of the complex tasks that will be needed in the pavements of the future: laboratory and field testing, data reduction, materials characterization, damage prediction, analysis and design of mixes, new pavement, and rehabilitated pavement structures, prediction of future performance and remaining life, nondestructive testing and its associated inverse analysis, and the use of all of these in the future programs of performance-based specifications and warranties. One of the main advantages of the rigorous use of pavement mechanics, when seen from the point of view of the big picture, is that it alone has the ability to reduce the variance of construction, maintenance, and rehabilitation operations, to reduce uncertainty and risk in these and in the pavement management processes generally, to stabilize profits for pavement contractors, and to provide ample economic rewards to those in both the public and private sectors and to taxpayers for supporting the continuing development of the analytical tools that pavement mechanics provides.

In this symposium are several examples of the kind of tools that are in their development phases that will be needed to provide these benefits to the pavement industry of the future: both asphalt and concrete pavement, the use of 2-D and 3-D Finite Element and Discrete Element numerical approaches, micromechanics, microfracture and healing, generalized damage, wetting and dewetting surface energy measurements, all used in the prediction of different types of pavement distress. The testing techniques include x-ray tomography and digital imaging, piezo-electric sensors, and dilatometry to give advance warning of the potential of alkali-silica reactivities in concrete pavements in addition to the more commonly expected laboratory tests. Many different materials are represented: asphalt, concrete, base courses, and unsaturated granular materials, generally. Various characterization methods are used including rheological models, viscoelastic and viscoplastic constitutive relations, continuum damage, fracture, and microfracture. The structures of the pavement materials are assumed to be isotropic, cross-anisotropic, or to have microstructure that is dictated by the shape, gradation, size and texture of the aggregates. The types of distress considered are rutting, fatigue cracking, alkali-silica reaction, and some types of moisture related damage. The poor pavement engineer who has not been introduced to all of these important and essential ways of looking at pavement materials can be excused for wondering if there is any way of ever making practical use of this chaotic array of mechanics approaches. He may even suspect that the intuitive, empirical, or phenomenological tools that have been used in the past offer a safe refuge from the bewildering brave new world of pavement mechanics. It may never occur to him that what all of these approaches have in common is a very simple, straight-forward, consistent, easy-to-implement way of obtaining accurate, low variance measurements of the required material properties and then of using them together with an appropriate numerical method to make all of the future projections of the future life of the pavement. There will be no further need to construct costly and time-consuming phenomenological samples which bring with them large systematic errors that are inherent in the interpretation of the test results. Elimination of these systematic errors alone will reduce the variance of the estimated pavement lives by over 50, and sometimes over 90 percent dependent upon the type of distress that is being projected. Contractors are well aware that large variances raise uncertainty and risk, reduce profits, and may even lead to loss.

This opening address will give an overview of the type of testing, both in the laboratory and nondestructively in the field, and the types of numerical analysis that will be needed to provide the suite of coordinated analytical tools that are required to support the future progress of pavement design, construction, field performance and management. The focus of the laboratory tests is to obtain an identified material property, and not to simulate, however imperfectly, some condition in the field. This leads to simplicity in the test setup and accuracy in the results. The nondestructive testing in the field will use the backcalculation of the viscoelastic properties of asphalt pavements using the Falling Weight Deflectometer and the use of Systems Identification to extract the composition of pavement layers from reflected Ground Penetrating Radar signals. Some note will be taken of the recently published Federal Communication Commission regulation concerning restrictions of the radiated power in the GPR frequency bands. Finally, a review will be given of the past, present, and future use of various numerical methods in the numerous tasks for which they will be needed in the deployment of pavement mechanics in the design, construction, performance prediction, and management of pavements.

Alkali-silica Reactivity Test for Class C and Class F Fly Ash-Cement Mixtures Using Modified ASTM C 1260 Method.

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Dan Zollinger ***Texas Transportation Institute***

The benefits of using fly ash in concrete are well known. Additionally, its use ensures environmentally safe recycling of industrial by-products. The primary objectives for using a pozzolanic material such as fly ash in concrete pavement are to enhance its mechanical strength and improve resistance to many physico-mechanical and chemical attacks. Fly ash has often been used as a supplementary cementing material to control expansion due to alkali-silica reaction (ASR) in concrete. Tests performed to determine the effectiveness of fly ash in reducing expansion due to ASR involves highly accelerated testing conditions that do not necessarily represent actual field conditions under which the concrete is exposed. The ASTM C 1260- Accelerated Mortar Bar Test is a classic example, but is also one of the most commonly used methods because results can be obtained within as little as 16 days. A general criticism about this test method is the severity of test conditions. It is not uncommon for aggregates with good performance track record and no history of ASR to test as reactive by ASTM C 1260 method. An experimental program is in progress to evaluate the effect of modifying some of the C 1260 test conditions. The effectiveness of Class F and Class C fly ash in controlling expansion due to ASR is being studied based on modified ASTM C 1260. Three different levels of alkalinity of NaOH solution have been used to test the reactivity of predetermined reactive and potentially reactive aggregate in the presence of fly ash in the range of 20% to 35% by mass of cement. The other variables in this program include high- or low alkali cement with Na2Oeq. Of 0.59 and 0.51 respectively, extended curing time of 28 days, and extended testing period from 14 to 28 days. The results of the effectiveness of Class F and Class C fly ash in controlling expansion due to ASR using the modified test conditions are presented.

Quantification of the Specific Aggregate Surface Area Using X-ray Tomography

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David Frost ***Georgia Institute of Technology***

This paper presents a new method using x-ray tomography imaging to quantify the specific surface area of aggregates. The method reconstructs the three-dimensional (3D) representation of individual particles and computes the specific surface area and the sphericity (a shape factor) of individual particles. The quantified specific surface area of a limestone aggregate in the sieve size range (3/8ð-No.4) indicates that the specific surface area and the sphericity have a large variation among individual particles. However, the overall specific surface area of the aggregate particles within the same sieve size range can be accurately obtained using about 25-30 particles. It has been found that the specific surface area of the aggregates is much larger (84%) than that of the spheres of equivalent size.

Characterization of Cross-Anisotropic Aggregate Base Behavior from Stress Path Tests

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A new methodology is presented in this paper for determining cross-anisotropic aggregate properties, i.e., directional dependency of moduli and Poisson's ratios, from stress path testing. The proposed laboratory characterization procedure requires conducting large stress excursion tests performed under slightly different stress path slopes at similar stress states that are representative of pavement wheel loading conditions. In accordance, cross-anisotropic aggregate properties are determined by varying slightly the stress path slopes during testing and then by employing an error minimization approach to interpret the test results. The solution methodology adopted also satisfies the cross-anisotropic modular ratio criterion proposed by Graham and Houlsby (1983) and the positive strain energy criteria by Pickering (1970). Such an anisotropic material property set obtained from following the proposed methodology would essentially be useful in the finite element analysis of the anisotropic and stress dependent granular material behavior often observed in unbound pavement layers.

Stability of Beams and Girders
June 4, 2002
9:45
Chair: Dewey Hodges **Georgia Institute of Technology**
Co-Chair: Hayder Rasheed **Kansas State University**

Lateral Buckling Of FRP Composite Cantilever I-beams

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Pultruded Fiber-reinforced plastic (FRP) shapes (beams and column) are thin-walled or moderately thick-walled open or closed sections consisting of assemblies of flat panels. Due to the high strength-to-stiffness ratio of composites and thin-walled sectional geometry of FRP shapes, buckling is the most likely mode of failure before material failure for FRP shapes.

In this study, a combined analytical and experimental approach is used to characterize the lateral buckling of pultruded FRP composite cantilever I-beams. An energy method based on nonlinear plate theory is developed, and shear effects and bending-twisting coupling are accounted for in the analysis. Three types of buckling mode shape functions (i.e., transcendental function, polynomial function, and half simply-supported beam function), which all satisfy the cantilever beam boundary conditions, are used to derive the critical buckling loads, and the accuracy and convergence of these approximations are studied and discussed. The effects of fiber orientation and fiber volume fraction on the critical buckling loads are investigated. Four common FRP I-beams with different cross-sectional geometries and various span lengths are experimental tested, and the critical buckling loads are measured. A good agreement among the proposed analytical method, experimental testing and finite-element modeling is observed, and a simplified explicit equation for lateral buckling of cantilever I-beams with the applied load at the centroid of the cross-section is formulated. The proposed analytical solution can be used to predict the lateral buckling loads for FRP cantilever I-beams and to assist practitioners to perform buckling analyses of customized FRP shapes as well as to optimize innovative sections.

Lateral-torsional Buckling Of Coped Girders (Subtitle: Comparison Between Laboratory Tests And Numerical Model)

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In a coped girder, a part of the upper flange and the web is removed to be able to level the upper flanges of main and secondary girder. Sometimes, short endplates are used in joints. Copes or short endplates may affect lateral-torsional buckling stability of the girder due to greater torsional flexibility and local web deformation. Verification methods for lateral-torsional buckling in codes apply only for girders with uniform cross-section along span and for joints that prevent deformation of the web. Therefore coped girders or short endplate joints are not within the scope of these verification methods.

In order to study the buckling capacity of coped girders, a geometrical and physical non-linear model is developed in the FEMcode DIANA. To check whether the model provides correct capacities, it is validated by experiments, carried out in the Stevin I laboratory. This paper intents to describe the way followed to validate the numerical model.

Flexural Torsional Buckling Of Three Dimensional Thin Walled Elastic Beam

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The full 3-D analysis of thin walled beams is extremely complex in case of general loading and restrained boundary conditions. The behavior of thin walled beams depends to a large extent on the cross sectional geometry and specifically, whether the section is open or closed. Many studies have proposed different warping functions depending on the type of the profile (open or closed). In this paper, derived from Proki? work, the same warping function is used for arbitrary open or/and closed cross section. Starting from the virtual work equation, a finite element formulation is presented for the numerical analysis of the behavior of three dimensional beams. An updated corotational Lagrangian formulation is presented in order to study the flexural torsional buckling problem. The criterion to determine the buckling state is the singularity of the tangent stiffness matrix of the structure. Numerical examples are presented to show the accuracy and efficiency of the proposed warping function for Eulerian stability analyses of thin walled beams and columns. Results are compared with those obtained with standard analytical solutions of stability problems for beam-columns with open cross section.

Load-carrying capacity of plate girders subjected to bending and shear

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Plate girders are usually subjected to bending and share. Therefore, the bending-shear load-carrying capacity should be calculated and taken into consideration for the safety and economical design of plate girders. The paper contains original thedretical analysis of the bending-shear load-carrying capacity of plate girders with compact typical I cross-sections. They are combined from different steels where flanges are from higher sterngth steels and web is from middle steel. The homogeneous cross-section represents only limit case of the universal cross-section.The ultimate plastic stage is there considered as the perfect plastification of the web in decisive cross-section. The results of the theoretical analysis are equations for the calculation of the ultimate shear load, ultimate bending moment and bending-shear load-carrying capacity of different hybrid and homogeneous cross-sections. In accordance with theoretical results the simple interaction formulae for practical calculation and judgement of homogeneous and hybrid cross-sections and plate girders are presented.

TOWARDS RESOLVING ISSUES CONCERNING TORSIONAL AND LATERAL-TORSIONAL BUCKLING OF THIN-WALLED OPEN-PROFILE BARS

Morris Ojalvo *Ohio State University*

(not submitted electronically)

Hydrodynamics I

June 4, 2002
9:45
Chair: Nikolaos Katopodes U of Michigan
Co-Chair: Chiu-On Ng The University of Hong Kong

NON-LINEAR WIND-GENERATED WAVES FORCES ON A VERTICAL WALL

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The statistical properties of some narrow-band second-order processes in the mechanics of sea waves in front of a vertical wall are investigated. The wave force and the overturning moment on the vertical wall are derived by analytical integration of the fluctuating wave pressure. It is obtained that for a fixed threshold of the probability of exceedance, if kd is smaller than 1.38 (being k the wave number and d the bottom depth), positive peaks of the wave force process (that occur with the wave crests of free surface displacement on the wall) are greater than absolute value of negative peaks (that occur with the wave trough). The wave force is a quasi-symmetric process for kd=1.38: the non-linearities are weak and both the positive peak distribution and the negative peak distribution (in absolute value) are given by the Rayleigh law with good approximation. Finally it is noteworthy that for kd>1.38 we find that the wave troughs produce negative peaks of the wave force that are (in absolute value) greater than positive peaks produced by wave crests.

MODELING PROPAGATION OF NONLINEAR SHALLOW-WATER WAVES PAST A POROUS BARRIER

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Formulations of a set of Boussinesq-class equations for nonlinear shallow-water waves in the domain of a porous medium are presented in the paper. A numerical method based on the predictor-corrector finite-difference scheme is developed. The porous-medium wave model is applied to simulate solitary waves propagating past a finite-thickness porous breakwater. The process of wave reflection and transformation is reasonably predicted. The predicted wave elevations show good agreement with other published numerical results. The propagation of cnoidal waves past a porous barrier is also studied. The periodic evolution of partially reflected and partially transmitted waves is presented to demonstrate the performance of the present porous-medium wave model.

Nonlinearity and Spectral Width Effects on Ocean Wave Height Distribution

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In the practice of marine structure designs, it is often required to extract design wave heights from irregular wave trains in order for a monochromatic wave design approach to be applied. Attempting to analytically derive relationships among various representative wave heights, one must presume a mathematical model for the wave height distribution. Since Longuet-Higgins (1952) first theoretically derived the Rayleigh distribution as the wave height distribution under the assumption that the wave spectrum consists of a single narrow frequency band and that the wave elevation is a Gaussian random process, the Rayleigh distribution has been adopted by design manuals to describe wave heights. However, one should realize that a realistic ocean wave train is neither containing only a single narrow frequency, nor being a Gaussian random process (It amounts to assuming a linear ocean wave model). As a result, the wave height distribution might deviate from a Rayleigh distribution. It is known that the Rayleigh distribution is a special case of the Weibull distribution that has its shape parameter equal to 2. Therefore, using a Weibull distribution is a practical and convenient way of introducing some flexibility in the wave height model to account for the variation of wave non-linearity and the frequency bandwidth associated with the wave spectrum. The present study demonstrates that a better mathematical model for wave height distribution under realistic ocean environment is a Weibull distribution. The specific objectives of this study are to investigate the non-linearity (non-Gassianity) and spectral width (multi-frequency wave spectrum) effects on the shape parameter for the Weibull wave height distribution.

Discrete and Continuum Modeling of Granular Materials III

June 4, 2002
9:45
Chair: Jin Ooi University of Edinburgh

Interface Behavior Of Polydisperse Granular Materials: Discrete Numerical Simulation Of A Ring Simple Shear Test

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The two-dimensional code PFC2D is used to simulate a ring shear test with constant confining pressure where the interface has an intrinsic and geometrical roughness. In present work, we analyze the effects of: - the granulometry: the media is a binary or ternary assembly of disks (with important size ratios). The distribution of contact is studied in terms of distribution of types of contact. - the contact law is either a linear or non linear elastic and frictional law. The effect of the local law on the global behavior is important since the contact stiffness depends on the type of contact in non linear polydisperse cases. The numerical simulations give particular insight on the resulting global behavior defined by the the initial elastic behavior. They are used to validate a theoretical approach based on statistical homogenization which defines the shear modulus as a function of local parameters. The process of homogenization can take into account the granulometry and the contact law, and allows to describe the effects of both local parameters on the global shear behavior.

Analysis Of Granular Material Behaviour From Two Kinds Of Numerical Modelling

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The Distinct Element Method (DEM) has stridden further ahead in mechanical computations for the granular materials modelling, as this method allows analysing the behaviour of granular samples from a micro-mechanical point of view. In this study, two different approaches are used and compared in the aim to analyse the mechanical behaviour of a granular sample. The first approach is based on a smooth contact intergranular law and the second does not consider any regularizing assumptions. While under quas-static loading the global responses are very similar, still important differences appear at the micro scale with some variables: the contact spatial distribution, the sliding contacts, the contact forces and strains which are similar only considering a representative volume greater than few grain diameters. Under dynamical loading, the computed behaviour is very dependent from the numerical dissipation respectively used un both methods.

Development Of A Continuum Representation Of A Discrete Granular Medium

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David Horner ***ERDC***

The discrete element method (DEM) has become a popular tool for understanding granular mechanics. A central theme of DEM research to apply micromechanical concepts to improve constitutive relationships for continuum models. In particular, recent work has been directed at micro-polar models that account for an independent rotation field. Such models have applications for capturing important mechanism associated with localization and provide an avenue for formulating mathematically well-posed problems for materials subject to instability. A key step in applying micromechanics is the homogenization of the discrete quantities describing the granular media to equivalent continuum quantities. In this paper we discuss this process from that standpoint of homogenizing the equilibrium equations for the DEM by application of a smoothing function in a manner similar to the weighted residual method. The process results in equations of equilibrium for a Cosserat continuum and the associated boundary conditions from which well-known relationships between contact forces and continuum stress is recovered. The deformation measures that are conjugate to stress variables are considered in detail.

Meso-scale Continuum Model And Discrete Model For Granular Materials

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In this paper, a meso-scale continuum model is derived by considering the mechanical interaction of six particles in contact. The geometry of the particles forms an octahedron, for which the kinematic description is derived by using a so-called 'best-fit hypothesis'. The elastic particle interaction is described by means of a Hertz contact law, while particle sliding is incorporated by allowing the shear contact stiffness to evolve in accordance with the mobilised friction. A final expression for the meso-scale constitutive relation is obtained by requiring the rate of internal work in terms of micro-scale variables and meso-scale variables to be equal.

Subsequently, it is investigated if the meso-scale particle configuration is capable of adequately simulating the frictional behaviour of an assembly of a large number of particles. The response of the continuum model to axi-symmetric stress conditions is considered in relation to the response computed by a discrete element model. The paper concludes with analysis of the failure contour in the deviatoric plane of the principal stress space (pi-plane), which is composed by tracing various radial deviatoric stress paths.

Integrating particle dynamics and machine dynamics in Discrete Element Analysis

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Recent trends in modelling of granular flows suggest that discrete element (DE) analysis is changing from being purely a research tool to a method for simulating industrial scale problems. This paper describes developments that address a critical aspect of modelling industrial granular flows, namely the representation within the DE framework of the geometry and kinematics of complex boundary surfaces such as containing structures and machinery that interact with particulate media. Methodology for modelling the 3D surface profile of machine elements of arbitrary shape and for applying arbitrary kinematic properties is described. The surface of the machine (or any structure) is first defined as an ACIS-type model, which is then tessellated into discrete surface elements using techniques common to finite element meshing. These elements can be grouped and the groups translated and rotated as desired. A machine element can also respond to loading from particles and change position depending on how it is constrained. The method works well with sphere-based shape descriptors such as single or multi-sphere particles, and provides a flexible system for integrating particle and boundary kinematics.

Computational Mechanics - Failure and Fracture Mechanics
June 4, 2002
9:45
Chair: Jeen-Shang Lin University of Pittsburgh

THE SIF FOR DEEP SEMI-ELLIPTICAL SURFACE CRACK IN FINITE THICKNESS PLATES DETERMINED BY THE NODAL DISPLACEMENT METHOD

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Reliable computational solutions for SIF of surface cracks have been reported by many researchers such as Newman. However, all solutions have a limited range of validity for the crack depth ratio (the ratio of crack depth to member thickness is less than 0.8). For cracks grow beyond this barrier, SIF are obtained by extrapolation e.g. BS7910. Precision of this approach is still questioning. To investigate the detailed process of crack growth until breaking through occurs, solutions for SIF not available are necessary. It has been common to calculate the SIF based on the J integral. However, in the case of deep surface crack, ligament left for carrying out the J integral is very limited and leads to a questionable accuracy of SIF. Consequently, a localised approach, nodal displacement method,was adopted. All computational works were carried out based on finite element code ABAQUS in which the node displacement close to the crack tip were determined. Post-processing of these extracted displacement was then carried out to determine the desired SIF.

LOAD - DISPLACEMENT CURVES OF SQUARE REINFORCED CONCRETE COLUMNS BASED ON FRACTURE MECHANICS

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In this paper, the loadñdisplacement behavior of reinforced concrete columns with square cross section, have been studied under increasing axial load. The behavioral model assumed for concrete is an elasticñplasticñfracture model, while the failure criterion is a Willam ñ Warnk one. An elasticñperfectly plastic model has been used for the reinforcing steel. A smeared crack hypothesis has been used for the concrete cracking. Specifically, the J-Integral method has been utilized for evaluation of the stress density factor. The above has been utilized in a finite element program using octahedral and bar elements for the concrete and reinforcement, respectively. Experimental results of "Sheikh and Uzumeri" and "Priestly and Park" have been used to verify the results. The comparison shows a general correlation between the results, while there is noticed certain discrepancies which could result from the separation of the concrete cover from the reinforcement, the lack of perfectly plastic behavior by steel reinforcement, or the error caused by the finite element mesh utilized.

THE INFLUENCE OF LOW TEMPERATURE ON THE FATIGUE DAMAGE PROCESS OF CRACKED ASPHALT PAVEMENT

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A finite element analysis is developed for the influence of temperature on the fatigue damage process of cracked asphalt pavement based on the theory of continuum damage mechanics. The pavement with surface cracks and reflected cracks, which is selected from Shen-Da Expressway - the first highway in China, is modeled as an inhomogeneous, laminate structure. The elastic modulus is assumed to be temperature-dependent and the temperature field to be a non-liner one. The numerical results demonstrate an interesting behavior that the maximum stress exists not in the crack tips but in the interface between damage zone and non-damage field. The theoretical prediction on the fatigue damage life indicates the results in reasonable agreement with that of the observation.

COMPUTATION OF STRESS INTENSITY FACTORS FOR BI-MATERIAL INTERFACE CRACKS USING WEIGHT FUNCTION METHOD

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The stress intensity factor is an important parameter in linear elastic fracture mechanics, in terms of which the fracture criteria can be formulated. In the present work, the stress intensity factors for a bimaterial interface crack are obtained using the weight function method, which has been well established for homogeneous bodies.

Weight function method gives a boundary integral representation for the stress intensity factors. Since the weight functions are universal functions for a body specified by a particular crack, material combination and boundary conditions, once determined, the same weight functions can be used for the computation of stress intensity factors for any other loading using integral representation. This reduces the computational effort, which otherwise has to be put in analyzing each time for a newly applied load.

The weight functions are determined using the finite element technique based on variational principles to determine the displacement fields for bodies with unbounded strain energy. The selection of approximate singular fields for the weight functions are discussed.

SIMULATION OF SLOPE FAILURE USING A MESHED BASED PARTITION OF UNITY METHOD

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A mesh based partition of unity method, known as the manifold method, is used in simulating the evolution of a slope failure. The

problem configuration consists of a simple slope that has pre-existing tensile cracks along its crest. The slope failure is triggered by rainfall which raises water pressure in the crack. As the tensile stress around the crack tip increases, an existing crack grows and a failure surface is eventually developed. The maximum stress criterion is adopted in determining the crack growth and growth direction. After a failure surface is formed, the unstable soil mass, bounded by the failure surface, slides down the slope. This sliding process is also modeled.

Applied Elasticity in Geomechanics

June 4, 2002
9:45
Chair: Bojan Guzina University of Minnesota

Micromechanics And Effective Moduli Of Random, Multiphase Fiber-reinforced Composite Materials With Homogeneously Imperfect Interfaces

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Steven Crouch *Theodore W. Bennett Professor*

This paper presents a specialized boundary integral method to solve problems involving an infinite, isotropic elastic plane containing a large number of randomly distributed circular elastic inclusions with homogeneously imperfect interfaces. This model can be used to represent a suitably oriented plane section through a unidirectional fiber-reinforced composite material. The method is capable of representing thousands of inclusions with no restrictions on their locations (except that the inclusions may not overlap), sizes, and elastic properties. The tractions on the inclusion interfaces are assumed to be continuous and proportional to the corresponding displacement discontinuities between the inclusions and the material matrix. The analysis is based on a semi-analytical solution of a complex hypersingular integral equation with the unknown tractions and displacement discontinuities at each circular boundary approximated by a truncated complex Fourier series. The method allows one to assess both micro and macro-mechanical properties of the material. Numerical examples are included to demonstrate the effectiveness of the approach.

Numerical Modelling Of Road Traffic Induced Vibrations In Buildings, Based On A Dynamic Soil-structure Interaction Formulation

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Geert Degrande *Professor*
Geert Lombaert *PhD. Student*

Road and rail traffic induced vibrations in buildings are a matter of growing environmental concern, especially in densely populated regions. Vibrations may cause malfunctioning of sensitive equipment, discomfort to people and structural damage. Regarding the cost of vibration isolation measures, there is a clear demand to develop accurate numerical tools. A numerical prediction model, incorporating a moving source, and accounting for dynamic soil-structure interaction at the source and the structure is developed. Use is made of an existing source model that computes the incident wave field due to the passage of a truck on an uneven road, accounting for dynamic interaction between the road and the layered soil (Lombaert et al., 2000) and that has been validated by means of in-situ experiments (Lombaert and Degrande, 2001). It is assumed that the incident wave field is not influenced by the presence of adjacent structures. The response of a structure due to the incident wave field is computed with a subdomain formulation MISS (Aubry and Clouteau, 1992) for dynamic soil-structure interaction

problems, that is currently used in earthquake engineering. A transfer of the technology from the area of earthquake engineering to the study of traffic induced vibrations is realised. In the substructure approach, the most adequate solution technique is applied to each. A finite element formulation is used for the structure. An important reduction in the number of degrees of freedom is obtained when a decomposition on the rigid body modes and the eigenmodes of the structure is employed. A boundary element method is used for the unbounded soil domain. This method only requires the discretisation of the contact surface between the structure and the soil, reducing the dimensions of the problem by one and making threedimensional calculations feasible. Using the Green's functions of a layered halfspace, the radiation condition is automatically taken into account. An important discretisation effort is required at the foundation-soil interface as the frequency content of traffic induced vibrations is larger than for earthquakes. The soil displacement vector is decomposed into the incident wave field, the locally diffracted wave field and the scattered wave field. Displacement continuity is enforced along the interface between the foundation and the soil, while a weak variational approach is used to enforce stress equilibrium along the interface. Discretisation of the displacement vectors transforms the scalar virtual work equations into vector-matrix form equilibrium equations. The experimental results of an elaborate in situ measurement campaign, that has been performed in and near a single family dwelling located near a busy road with a concrete plate pavement with joints (Pyl et al., 2002), will be used to validate the numerical prediction model. The present paper will primarily concentrate on the modelling aspect, however.

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The Elastic Moduli Of Soils With Dispersed Oversize Particles

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To calculate the elastic deformations experienced by soils subjected to static or dynamic loads, knowledge of the elastic moduli is required. The elastic moduli are normally evaluated in the laboratory using conventional triaxial compression tests on cylindrical samples. For meaningful test results, it is necessary to maintain a ratio of sample diameter to the maximum particle size of approximately 6 to 1 or greater. However, some soils have large and dispersed oversize particles that make it impossible for them to be tested in the conventional triaxial apparatus. This paper presents the application of a theoretical method developed by Hashin that calculates the elastic moduli of a composite made of an elastic matrix containing large dispersed particles. The Hashin method requires only knowledge of the elastic moduli of the matrix coupled with the concentration by volume of the large particles in order to calculate the elalstic moduli of the mixture. The Hashin method was applied to a clay-sand mixture, and it was found to predict very well its measured elastic moduli.

Transient Response Of Three Dimensional Rigid Structures Interacting With Visco-elastic Soil Profiles

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A methodology to synthesize the transient response of 3D foundations resting on a viscoelastic half-space is outlined in the present paper. The method is based on stationary half-space compliance functions which have been accurately synthesized for high frequencies. The transient response is obtained by the FFT algorithm. The procedure is applied to investigate the effects of distinct viscoelastic soil models and parameters. The constant hysteretic, the Kelvin-Voigt and a ramp-like damping models are investigated. The effects of the viscoelastic models on the causality of the transient response is also reported. The transient response of 3D foundations possessing inertia properties is also addressed.

Dynamic Stiffness of Pile Groups: Simplified Solution for Stiff Piles

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Starting from an exact formulation, a simplified computational method is developed for the dynamic soil-pile interaction problem by relaxation. Numerical results are provided to illustrate the range of validity and accuracy of the approximate scheme for vertical, horizontal and rocking response using the benchmark solution.

Seismic Response of Bridges

June 4, 2002
11:30
Chair: Joel Conte University of California at San Diego

Study of Seismic Isolation System of Jamuna Multipurpose Bridge, Bangladesh

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This paper examines the use of bearings and energy dissipating devices for seismic isolation of Jamuna Multipurpose Bridge over the Jamuna River in Bangladesh. The 4.8km long bridge is located in a seismically active region and over an alluvial flood plain. The designers used lubricated sliding bearings and steel dampers for protection against possible seismic events. The isolation system and the mechanism of operation are described here along-with the layout and the general arrangement. Other integral components of the system and the installation details are also investigated. Summary of the laboratory tests performed on the bearings and the seismic devices are reviewed to verify the properties of the system. Maintenance procedure and rehabilitation strategies for the system after possible seismic damage are explained. Investigation of the design philosophy and mechanism of the seismic devices show that the although the isolation system can be helpful in reducing seismic damage potential of the structure in case of weak or moderate events, it has some serious shortcomings in terms of strong earthquakes or long-term performance basis.

Increasing Structural Safety Of Long-span Bridges By Active Control

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Summary The effectiveness of active multiple mass damper system (AMMD) for suppressing wind-induced vibration response of long span bridges and, hence, increasing the structural safety will be investigated in the proposed research work. The three components of buffeting wind forces are numerically simulated using an improved algorithm introduced also in this paper. The target wind velocity field is assumed to be one-dimensional multivariate stochastic process. The fast Fourier transform is used to enhance the efficiency of computation. The equations of motion of the system with dampers will be introduced. A bridge mounted by AMMD and subjected to simulated wind forces is solved. A comparison between passive and active system is performed. Numerical example results reveal that the active control system performs better than its passive counterpart. Comments on the performance are finally made.

Probabilistic Seismic Demand Models For Multi-span Highway Overpass Bridges

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Probabilistic Seismic Demand Models (PSDMs) are a component of the PEER probabilistic performance-based seismic design framework. A PSDM gives the probability of exceeding a value of a structure-specific Engineering Demand Parameter (EDP) given a value of a seismic hazard Intensity Measure (IM). This paper presents PSDMs developed for multi-span highway overpass bridges typical for California. These overpass bridges, designed following 1999 Caltrans Bridge Design Specifications and Seismic Design Criteria, have two, three or four spans. Finite element models of an array of parametrically varied bridge designs were developed in OpenSees. Each bridge model was then subjected to 80 ground motions recorded in California, and its response was computed using a non-linear time-history solution procedure. Statistical analysis of the computed responses was used to develop a suite of bridge PSDMs. PSDMs that demonstrate the influence of multiple bridge spans on their seismic behavior, such as the effect of higher mode response, are presented in this paper. They help to illustrate the effect of variation span length and span number on bridge performance.

System Identification Of The Vincent Thomas Long-span Suspension Bridge Using Earthquake Records

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A combination of linear and nonlinear system identification techniques is employed to obtain a complete reduced-order, multi-input-multi-output (MIMO) dynamic model of the Vincent Thomas Bridge (Los Angeles) based on the dynamic response of the structure to the 1987 Whittier and 1994 Northridge earthquakes. Starting with the available acceleration measurements (which consists of 15 accelerometers on the bridge structure and 10 accelerometers at various locations on its base), an efficient least-squares-based time-domain identification procedure is applied to the data set to develop a reduced-order, equivalent linear, multi-degree-of-freedom model. Results of this study yield measurements of the equivalent linear modal properties (frequencies, mode shapes and non-proportional damping) as well as quantitative measures of the extent and nature of nonlinear interaction forces arising from strong ground shaking. It is shown that, for the particular subset of observations used in the identification procedure, the apparent nonlinearities in the system restoring forces are quite significant, and they contribute substantially to the improved fidelity of the model. Difficulties associated with accurately estimating damping for lightly damped long-span structures from their earthquake response are discussed.

Nonlinear Seismic Analysis Of A Bridge Ground System

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This paper presents a two-dimensional yet advanced nonlinear finite element model of a real bridge system, the Humboldt Bay Middle Channel Bridge near Eureka in Northern California, and its response to a seismic input motion. The computational model of the Middle Channel Bridge is developed using the new software framework OpenSees developed by the Pacific Earthquake Engineering Research (PEER) Center to combine advanced structural and geotechnical seismic response simulation capabilities. The model incorporates soil-pile-structure interaction. Realistic nonlinear material models are used for the concrete (confined and unconfined), reinforcing steel, and soil materials under cyclic/dynamic loading. The materials in the various layers of the supporting soil medium are modeled using an effective-stress, multi-surface plasticity model incorporating liquefaction effects. A seismic response analysis is presented, with soil properties weaker than the actual ones, in order to test the robustness of the numerical framework, and explore potential effects of liquefaction on the various components of the bridge system. The simulated response shows that liquefaction-induced lateral spreading may have severe implications on the seismic demand imposed on the bridge structure (piers, piles, approach slab).

Mechanics of FRP Strengthened Concrete Structures
June 4, 2002
11:30
Chair: Christopher Leung HKUST
Co-Chair: Arup Maji University of New Mexico

Fiber Reinforced Concrete Members Under Combined Loading

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Steel fiber reinforced concrete (SFRC) technology has grown over the last three decades into a mature industry in North America and Europe.Improvements are continually being made by the researchers to optomize its application in the construction industry. A current need is to consolidate the available knowledge for SFRC and to incorporate it into design codes.

A method of analysis applicable to SFRC members subjected to combined loading is presented. Well accepted theory used for designing conventional reinforced concrete members is extended to incorporate the effects of steel fibers. The derived equations are validated by test results reported by several investigators. Design examples are used to illustrate the use of the developed equations.

Characterization and Modeling of Debonding in RC Beams Strengthened with FRP Composites

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Use of fiber reinforced plastic (FRP) composites for strengthening reinforced concrete (RC) beams have become a frequently used method in the last decade. However, the method is yet to become a mainstream application due to a number of economical and design related issues. From structural mechanics point of view, an important concern regarding the effectiveness and safety of this method is the potential of brittle debonding failures. Such failures, unless adequately considered in the design process, may significantly decrease the effectiveness of the strengthening and may even make the member less safe due to decreased ductility. Despite considerable research progress, continued research in this area is needed to develop the necessary analysis and design procedures and related codes and standards. This paper summarizes the findings of a comprehensive experimental and preliminary analytical research work aimed at modeling debonding failures in FRP strengthened RC beams.

CFRP Strengthening Of Concrete Structures - Design Guidelines In Sweden

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Rehabilitation and strengthening of existing concrete structures has become more and more in focus during the last decade. All over the world there are structures intended for living and transportation. The structures are of varying quality and function, but they are all ageing and deteriorating over time. Of the structures needed in 20 years from now about 85-90 % of these are already built. Some of these structures will need to be replaced since they are in such a bad condition. However, it is not only the deterioration processes that make upgrading necessary, errors can have been made during the design or construction phase so that the structure needs to be strengthened before it can be used. New and increased demands from the transportation sector can be another reason for strengthening. If any of these situations should arise it needs to be determined whether it is more economical to strengthen the existing structure or to replace it. There exist many different ways to strengthen an existing concrete structure, such as sprayed concrete, different types of concrete overlays, pre-tensioned cables placed on the outside of the structure, just to mention a few. A strengthen method that was used quite extensively during the mid 70-ties is steel Plate Bonding, this method has gained renaissance the last decade, but now as FRP (Fibre Reinforced Polymers) Plate Bonding. This technique may be defined as one which a composite plate or sheet of relatively small thickness is bonded with an epoxy adhesive to in most cases a concrete structure to improve its structural behaviour and strength. The sheets or plates do not require much space and give a composite action between the adherents. Extensive research and laboratory testing has been carried out all over the world and at many different locations. These investigations shows that the method is a very effective and considerably strengthening effect can be achieved. Nevertheless, if the method shall be successfully used it is of utmost importance that a proper design forms the base for the strengthening work to be carried out. Therefore, design guidelines must be compiled. In Sweden this was first made for Steel Plate Bonding in the end of the 80-ties and during the end of the 90-ties design guidelines for FRP Plate Bonding was written and incorporated in the Swedish Bridge Code: BRO 94. However, before this was possible a great number of laboratory tests have been carried out and analysed together with literature reviews as well as thoroughly theoretical studies in the area. In addition several full scale tests have been undertaken with the Plate Bonding Method is Sweden since the end of the 80-ties. This paper presents a summary of the existing guideline for FRP Plate Bonding used in Sweden. Both design for bending and shear as well for torsion and fatigue are presented and a short discussion about safety factors the execution work are made.

Retrofit Efficiency Using FRP Sheets : Mechanics Viewpoint

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The greatest potential of Fiber Reinforced Plastics (FRPs) in the near future will be in the areas of repair, strengthening, and rehabilitation of existing structures, such as externally bonded composite fabrics or jackets on beams, columns, and bridge decks. Significant improvements in compressive, shear, and flexural behavior of bonded concrete elements are obtained. In an effective retrofit with external FRP sheets, a layer of dry fiber sheet is placed on the top of a coat of polymer resin that will harden to bond the fiber sheet to the concrete structure. In this paper, fracture mechanics based micromechanical models are presented to describe the retrofit effect of using FRP sheets on concrete structures. The interaction between concrete crack and applied FRP sheets is treated by creating opposing bridging stress acting across the concrete crack flanks as a result of the FRP stretching. Such interactions depending on loading conditions will be discussed in terms of retrofit efficiency in this paper.

A Fracture-Based Model for Debonding of FRP Plate from Concrete Substrate

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For concrete beams and slabs strengthened with bonded fiber reinforced plastic (FRP) plates, failure may occur in a brittle manner through debonding of the plate from the concrete substrate. In this paper, the debonding process is modeled as the propagation of a crack along the FRP/concrete interface, with frictional shear stress acting behind the crack tip. Following experimental results, the magnitude of the shear stress is taken to decrease linearly with interfacial sliding. Considering crack propagation to occur once the net energy release rate of the system equals the interfacial fracture energy, the applied load on a bonded FRP plate corresponding to any debonded length can be found. From the analytical results, an interesting observation can be made. With the definition of an effective interfacial shear strength, the relatively simple strength-based analysis can produce very similar results to the more complicated fracture-based analysis. With this finding, debonding analysis in the general case can be greatly simplified.

Probabilistic Modeling - Session II

June 4, 2002
11:30
Chair: Steven Wojtkiewicz Sandia National Laboratories

Quantifying Prediction Uncertainty In Reservoir Modelling Using Streamline Simulation

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Predicting the performance of oil reservoirs is inherently uncertain: data constraining the rock and rock-fluid properties is available at only a small number of spatial locations, and other measurements are integrated responses providing limited constraints on model properties. Calibrating a reservoir model to observed data is time consuming, and it is rare for multiple models to be 'history matched'. Uncertainty quantification usually consists of identifying high-side and low-side adjustments to the base case.

The Neighbourhood Algorithm is a stochastic sampling algorithm developed for earthquake seismology. It works by adaptively sampling in parameter space using geometrical properties of Voronoi cells to bias the sampling to regions of good fit to data. The algorithm evaluates the high dimensional integrals needed for quantifying the posterior probability distribution using Markov Chain Monte Carlo run on the misfit surface defined on the Voronoi cells.

This paper describes the use of the Neighbourhood Algorithm for obtaining multiple history matched reservoir models and using the ensemble of models to quantify uncertainty in reservoir performance forecasting. We describe the changes needed to generate multiple history matched models, and to sample from the posterior probability distribution to quantify uncertainty in forward predictions.

Effective quantification of uncertainty can require thousands of reservoir model runs, each of which can take several minutes for a relatively coarse grid to several hours for a fine grid. As part of this paper, we describe the use of approximate streamline simulations to rapidly explore parameter space. This allows us to switch to slower conventional simulation in regions of good fit to the data.

We demonstrate the performance of the algorithm on the SPE 10th Comparative Solution Project dataset. This is a benchmark dataset for which a fine grid reservoir description is known. We take this as "truth" and use a coarser model to match the history data for a limited period of time. We then predict both the maximum likelihood performance and the uncertainty envelope for the remaining time. The maximum likelihood solution is close to the truth case for much of the time, and the true solution always lies within the uncertainty bounds predicted by the algorithm.

Computational Model Validation Under Uncertainty

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This paper develops a methodology to assess the validity of reliability computation model using the concept of Bayesian hypothesis testing, by comparing the model prediction and experimental observation, when there is only one computational model available to evaluate system behavior. Time-independent and time-dependent problems are investigated, with consideration of two cases: with and without statistical uncertainty in the model. The Bayesian hypothesis-testing concept is extended to life prediction problems. Bayes factors, that measure the probability of obtaining the given test data with the assumed model, are used for model validation. The developed method provides a rational criterion to decision-makers for the acceptance or rejection of the computational model.

With the existence of statistical uncertainty in the model, in addition to the application of a predictor estimator of the Bayes factor, the uncertainty in the Bayes factor is explicitly quantified through treating it as a random variable and calculating the probability that it exceeds a specified value. In the case of model uncertainty, when there exist several possible models to describe a phenomenon, a Bayesian approach can be used to include all the candidate models by assigning model weight (the probability of each model being correct) and integrating the effects of all the models. When there is observation/data available, the model weights may be updated and shifted to the more appropriate model. It is assumed that the validity of a model is judged only through its output and the data used in the model prediction and the observation are assumed to be correct, and the computational errors are neglected. The inconsistency between the observed data and the model prediction is caused solely by the adoption of the wrong model.

The paper also proposes a new method to assess the validity of large-scale computational models by combining system reliability concepts with a Bayesian model validation approach. A large-scale computational model may be modeled through system-level concepts. While full system testing may be impossible, component-level testing may be possible to validate smaller modules of the computational model. The concept of the Bayes factor for a single limit state or a single computational or stress prediction model could be extended to a multiple limit state or system level problem where there is interaction among the component states. If system-level tests were possible, then system-level Bayes factors could be computed in exactly the same manner as in component-level validation. When system-level testing is not possible, system-level validation measures are derived for situations with and without statistical uncertainty.

This derivation of system level validation measures depends on the knowledge of inter-relationships between component modules in the system configuration. If such knowledge is uncertain, either Bayesian or Evidence theory-based approaches could be used to derive system-level validation measures, when multiple competing system configuration models are possible. The Bayesian approach uses a weighted sum estimate, with the weights updated with system-level tests. The evidence theory-based approach uses evidence combination rules to combine subjective opinion and ignorance on the relative validity of multiple competing models. The proposed methods are illustrated with several numerical examples.

MODELING UNCERTAINTY OF ELLIPTIC PARTIAL DIFFERENTIAL EQUATIONS VIA GENERALIZED POLYNOMIAL CHAOS

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We present a generalized polynomial chaos algorithm to solve the elliptic boundary value problems suject to stochastic uncertain inputs. In particular, we focus on the solution of the Poisson equation with random diffusivity and forcing. The stochastic input and solution are represented spectrally by employing the orthogonal polynomial functionals from the Askey scheme, as a generalization of the original polynomial chaos idea of Wiener (1938). A Galerkin projection in random space is applied to satisfy the equations in weak form. The resulting set of deterministic equations is solved iteratively by a block Gauss-Seidel technique. Both discrete and continuous stochastic distributions are considered and convergence is demonstrated for model problems.

MODEL INCOMPLETENESS: IMPLICATIONS ON STATISTICAL INFERENCE AND ANALYSIS BY CLASSIFICATION TREES

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In the search for the optimal design of a system, approximate models are often needed. Before such models are used, a regression is usually performed to fit the model to a more accurate, reference model. Inherent in such a fitting procedure is a statistical model for the errors. In this extended abstract, the model errors is examined for potential use in the optimal design problem. With the randomness in the errors, a probabilistic view is still needed, however, the approach developed herein is fundamentally different from that used in statistical regression. With the focus on design, it is shown that the outliers, which are ignored or otherwise discounted in statistical regression, can be used to identify system features that may potentially lead to improved design.

COMPUTATIONAL PROCEDURES FOR PROCESSING UNCERTAINTIES IN STRUCTURAL MECHANICS

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It is now widely recognized that a quantitative assessment of the effects of uncertainties in structural analysis and design plays an important role in context with quality assurance programs and reliability estimation. Hence the development of methods for their processing is in the focus of interest. While analytical procedures for this purpose were most useful in the early stage of development ñ and in fact still are ñ computational methods are needed for treating problems of larger dimensions, i.e. structures of engineering interest. Moreover, these procedures have to be compatible with currently used methods in deterministic analysis, such as FE procedures, etc.. Experience shows, that uncertainties are not only involved in loading conditions but also in structural, i.e. material and geometrical properties. Hence in addition to the mechanical modeling of the structural systems statistical procedures, probability as well as stochastic processes and fields are used as a modeling tool for uncertainties. While for time invariant problems the modeling by random variables suffices, a large class of quantities involving random fluctuations in time and space is adequately described by stochastic processes, fields and waves. Typical examples of engineering interest are earthquake ground motion, sea waves, wind turbulence, road roughness, imperfections of shells, fluctuating properties in random media, etc. The choice of the respective probabilistic models depends both on physical aspects and statistical evidence respectively. Particularly when analyzing larger size structures, the complexity both in mechanical and stochastic modeling respectively leave the Monte Carlo simulation (MCS) almost as the only procedure available to solve such types of problems. For the purpose of MCS sample points or functions of the involved random phenomena have to be generated. This sample information should represent accurately the stationary, homogenous, or non-homogenous, one-dimensional of multi-dimensional, uni-variate or multi-variate, Gaussian of non-Gaussian characteristics depending on the requirements of the accuracy of the realistic representation of the physical behavior and, of course, on the available statistical information. The most common representations of, e.g. sample functions are: autoregressive moving average, autoregressive models, filtered white noise, shot noise and filtered Poisson white noise, covariance decomposition, Karhunen-Loève and Polynomial Chaos expansion, spectral and wavelet representation, respectively, etc.. For the purpose of the evaluation of the structural response a clear distinction between the properties of the structural model is essential, i.e. whether the uncertainty of the structural properties (geometry and material properties) have to be taken into account (e.g. Stochastic Finite Element analysis (SFE) or maybe safely neglected, whether it responds linearly or non-linearly, respectively, etc.. Two aspects should be kept in mind when taking into account the uncertainties in structural analysis and design: (1) The accuracy and goodness of the mechanical modeling should match that of the current state of deterministic analysis. (2) Stochastic procedures should allow to analyze higher dimensional problems as generally encountered in engineering practice. Naturally, both of these requirements can only be met by applying computational procedures. In this paper various computational procedures are discussed, where methods for increasing the computational efficiency, i.e. reduction of dimension, parallel processing as well as improved MC simulation algorithms, etc. are given preference. The methodologies are then applied to a number of numerical examples.

Recent Advances in Materials Characterization and Modeling of Pavement Systems II

June 4, 2002
11:30
Chair: Erol Tutumluer University of Illinois
Co-Chair: Yacoub Najjar Kansas State University

Simulation of Cracking Behavior of Asphalt Mixtures Using Random Assemblies of Displacement Discontinuity Boundary Elements

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This paper describes the use of random assemblies of displacement discontinuity boundary elements to model the cracking behavior of asphalt mixtures. These random assemblies of boundary elements form particles of varying sizes, which are arranged to simulate the discrete nature of mixtures. To account for the aggregate and mastic properties, each particle is connected to other particles by specifying the cohesion, friction, and tensile properties of the material between particles. The crack initiation and crack growth are simulated using two distinct crack growth laws, based on sequential and parallel crack growth rules. Cracks are allowed to grow either along particle boundaries or through internal weak paths inside particles. A series of simulations were performed off the load-deformation and cracking behavior of a typical mixture commonly used by the Florida Department of Transportation. The effects of crack growth rules, particle size, and localization to geometric effects were studied. In summary, the method presented appears to provide a valuable tool for studying the mechanistic behavior of asphalt mixtures.

Asphalt Mix Master Curve Construction Using Non-linear Least Squares Optimization

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This paper presents a new simplified method of constructing a master curve of asphalt mix using test data covering a large range of temperatures from -18×C to 55×C. It utilizes sigmoidal fitting function and compressive dynamic (complex) modulus test data obtained at matrix combination of different frequencies and test temperatures. In the master curve construction, the time temperature superposition was modeled two different ways. First, using known time-temperature superposition equations, and second shifting test data experimentally, i.e., not assuming any functional form for the time-temperature relationship. The master curve construction was done using an Excel spreadsheet with the Solver Function, which is a tool for performing optimization with non-linear least squares regression technique. The analysis of over sixty mixtures indicated that the experimental approach agreed the best with Arrhenius shifting equation, correlation coefficient R2 being 0.995. Also, the experimental shifting was most flexible, producing the best fit among the studied shifting equations due to the fact that it has the most degrees of freedom. The master curve construction using sigmoidal fitting function will be used in the new 2002 Guide for the Design of Pavement Structures, which is under development in the National Cooperative Highway Research Program (NCHRP) 1-37A Project.

Artificial Neural Networks for the Analysis of Slabs under Simultaneous Aircraft and Temperature Loading

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This study focuses on the development and performance of a comprehensive artificial neural network (ANN) model for the analysis of jointed concrete slabs under simultaneous aircraft and temperature loading. Using the results from the ILLI-SLAB finite element program, a comprehensive artificial neural network model was trained for the different loading conditions of gear load only, temperature load only, and simultaneous aircraft and temperature loading cases. Special consideration has been given to the loading of a typical jointed slab assembly under the tri-tandem type gear of the Boeing 777 aircraft. It is also shown that the principle of superposition is not valid for simply adding the critical pavement responses (slab deflections and bending stresses) obtained under gear loading only and temperature loading only cases. The typical ANN prediction time is about 0.3 million times faster than the average ILLI-SLAB finite element solution. The use of an ANN-based design tool is deemed to be very effective for studying hundreds or thousands of ìwhat ifî scenarios for including the temperature effects in pavement analysis and design.

Modeling the Joint Deterioration Behavior of PCC Kansas Pavements Via Dynamic ANN Approach

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Joint Deterioration of PCC pavement is a process that is controlled by a variety of quantifiable and other non-easily quantifiable parameters. Artificial neural network (ANN) approach was used herein to correlate the time-dependent joint deterioration behavior with quantifiable experimentally-based aggregate durability parameters. To achieve this objective, the historical Kansas' pavement management system database along with corresponding aggregate and core durability reports for a number of PCC sections were combined to produce the needed time-dependent joint deterioration database. The resulting database was split into training, testing and validation sub-bases. Upon a number of ANN training, testing and validation processes, a time-dependent ANN-based joint deterioration model was developed. The developed model utilizes a number of aggregate durability factors to project the time-dependant joint deterioration behavior for up to 17 years after construction. According-

ingly, model predictions for year n are sequentially used as inputs for predictions for year n+1. Overall, model predictions are noted to be logical and in good agreement with field observations.

Stability of Plate and Shell Structures

June 4, 2002
11:30
Chair: Hayder Rasheed Kansas State University
Co-Chair: Dewey Hodges Georgia Institute of Technology

ULTIMATE BENDING STRENGTH OF STEEL BOX GIRDERS SUJECTED TO NEGATIVE MOMENT

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Steel box girders are extensively used for bridges. Since relatively slender plates are usually used for box girder flanges, stability consideration is very important. Thin flange plates are, in general, stiffened by longitudinal and transverse stiffeners in order to increase the buckling strength. The current design approaches of the stiffened compression flanges can be placed into two categories: (1) strut approach and (2) discretely stiffened plate approach. The basis of the strut approach is to treat a stiffened flange as a series of unconnected compression struts. A strut consists of longitudinal stiffener acting together with an associated width of plate that represent the plate between stiffeners. The strut approach is not applicable when a small number (one or two) of longitudinal stiffeners are used. In the discretely stiffened plate approach, a rectangular panel divided by stiffeners is treated as a separated plate supported along four edges.

The current AASHTO LRFD specifications (1998) adopt the discretely stiffened plate approach in order to evaluate the nominal flexural resistance of the stiffened compression flanges. Either yielding or buckling controls the design of the stiffened compression flanges depending upon the slenderness ratio of separated panels. The region where buckling governs the design is, again, divided into two zones: (1) transition zone where inelastic buckling may take place due to residual stresses and initial deformations; and (2) elastic buckling zone. In the case where buckling occurs prior to yielding, the AASHTO LRFD specifications consider the buckling as the strength limit state of a stiffened flange.

Meanwhile, it has been known that rectangular plates supported along all the four edges are able to exert considerable postbuckling strength depending upon the slenderness ratio after buckling. However, this reserved strength has not been utilized in the practical design mainly due to lack of comprehensive research.

In the present study, the postbuckling strength capabilities of stiffened compression panels were investigated through the nonlinear finite element analysis. The results reveal that the panels are capable of carrying considerable additional loads after buckling especially when sub-panels are relatively slender. Then, through a parametric study of the nonlinear analysis results, an equation to determine the ultimate compressive strength of stiffened panels including the postbuckling strength is suggested.

Also, an experiment was conducted in order to investigate the overall ultimate bending strength behavior of open-top steel box girders in negative flexure and the ultimate strength of compression panels themselves as well. It was found from the test that the girder specimens were able to carry even further beyond the ultimate strength points of the compression flanges predicted by the equation suggested in this study. This is because the compression flanges were still able to maintain the original cross-section even after reaching the predicted ultimate strength, and as a consequence the remaining section consisting only of the webs and tension flanges was still effective against bending after complete loss of the strength of the compression flanges including the postbuckling strength. Therefore, it appears that the design method for the nominal flexural resistance in current AASHTO LRFD specifications may be too conservative for steel box girders in negative flexure because of exclusion of this reserved strength.

In the present study, open-top box girder models on small scales only were tested. In order to develop a new design method that incorporates the reserved bending strength in the design of box girders in negative flexure, further theoretical and experimental research is recommended. Especially, experiment using box girders on full scale is necessary to affirm the capability of wide compression (bottom) flanges to retain the original cross-section beyond buckling of the flanges.

Buckling Strength of Thin Cylindrical Shells under Localized Compression

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The buckling strength of a thin cylindrical shell is important in many applications in civil engineering. On the one hand, current design rules are principally based on an empirical interpretation of test data and hence very simple loading conditions are applied. On the other hand, experimental and theoretical observations show significant stress non-uniformity and hence a deviation from the buckling strength expected under uniform load occurs. Reliable quantification of this effect is still challengingly difficult.

This paper presents a comprehensive parametric study, which examines the effect of non-uniform loading on the buckling strength of geometrically perfect and imperfect shells. In this study, local zones of compression are set up by applying shear stresses to the shell wall over a limited extent. Special emphasis is placed on understanding the effect of the meridional extent of the compression zone. Local axisymmetric weld depression imperfections are used in conjunction with several analysis types. The paper defines a revised set of rules, which may be implemented in future design standards.

Stability Behavior of Composite Thin-Walled Members Displaying Arbitrary Orthotropy

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An overview of the formulation of a 2nd order GBT to analyze the stability behavior of thin-walled members displaying arbitrary orthotropy is first presented. The theory is an extension of the Vlassov-type beam theory developed by Bauld & Tzeng (1984) which is formulated in GBT "language" and accounts for the cross-section in-plane deformations (local deformations). The main steps and procedures involved in the derivation and solution of the GBT system of equilibrium equations and boundary conditions are described and briefly discussed, always in the context of general asymmetric orthotropic members. Next, the paper addresses the issue of whether the eigenvalue loads obtained from member linear stability analyses correspond to true bifurcations or simply provide asymptotic limit loads, and a systematic procedure to detect true bifurcations is proposed. Finally, the application and capabilities of the 2nd order GBT are illustrated by means of a set of numerical results (GBT-based buckling mode shapes and corresponding bifurcation stress values) dealing with the local and global buckling behavior of laminated plate lipped channel columns and beams exhibiting asymmetric orthotropy.

Elastic Stability of Generally Anisotropic Rings Under External Pressure

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Inplane buckling of laminated rings is considered based on a nonlinear theory for stretching and bending of geometrically and materially symmetric anisotropic beams having constant initial curvature in their plane of symmetry. The ring is formed by initially curving the laminated beam out of the plane of the laminate. For the kinematics, the geometrically exact 1-D measures of deformation are specialized for small strain, and a 1-D constitutive law is developed via an asymptotically correct dimensional reduction of geometrically non-linear 3-D elasticity. The reduction assumes small strain and comparable magnitudes for the initial radius of curvature R and the wavelength of deformation along the beam reference line. Other small parameters include the ratio of cross-sectional thickness h to initial radius of curvature (h/R) and the ratio of cross-sectional thickness to cross-sectional width (h/b). A very simple final expression for the second variation of the total potential is obtained with the only restriction on the buckling analysis being that the prebuckling strain remains small. The buckling load obtained exhibits features not found in published formulae.

The instability analysis of chalk cliffs of the Blanc Nez Cape (Pas de Calais Area, France)

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This work is undertaken in the framework of a collaboration between Hydrology Soil and environment team (HSE) of the LAMH (Mechanical and Housing Artois Laboratory) and the Regional Laboratory of the Highways Department of Lille (LRPC). It treats the problem of the ground movements and particularly of the cliffs instability . The chalk cliffs of the Blanc Nez Cape located in the littoral fringe of the northern France, and on front of the English cliffs of Dover, is the seat of natural phenomenon of erosion and collapses of various sizes. Several collapses were observed at the site of Escalles since the beginning of the year 1998, and have destabilized the top of cliff by opening cracks there. . The Blanc Nez Cape attended by one million tourists a year approximately, classified as a national site, worried the French authorities. Those called upon the LRPC to study and to follow-up these phenomena in order to

determine the zones which represent a danger collapse, to mark out them. Following an observation campaigns, an instrumentation was installed to measure the cracks opening. With these same devices, vertical displacements were evaluated. In this first study, a treatment of these measurementís data showed the existence of a relation between the opening of these cracks and the increase of the water table level firstly, and between precipitations and the opening of the cracks secondly. This report does not seem to be the only factor of the instability, thatís why the study must integrate another approaches and ground measurements to support and confirm the first results. The observations carried out on ground reveal a link between the surfacial cracks apparition and the depth fracturing which is of tectonic origin. In addition, studies carried out in the area showed that a flow of subsoil waters is of the fissural type . The theory of flow in fissured area leads us to make a systematic cartography of the fractures distribution of and associated permeabilities. The advantage of this cartography will be seen on two aspects. At one, it will make possible to supplement the existing data and to link the flows to the tectonic facts at the second time. The second phase of our current study, consists in checking the various relations between the surface movements and deep dynamics. For that, several methods are listed: -a total statement of the fracturing by direct measurements, - an electric prospecting for the localization of the surfacial cracks and the cracks of tectonic origin, -a fine characterization which specifies various materials implied in the collapses.

The acquisition of these data will enable us to: firstly, correlate them and secondly, to confront them with those which already exist. Therefore, we can proceed to the elaboration of an explicit model which will take account at the same time of the space variability of mechanical and physical properties of rocks and soils met, and of existing discontinuities.

Fluids - Sediment Transport

June 4, 2002
11:30
Chair: Keh-Han Wang University of Houston
Co-Chair: Donald Drew RPI

River Bed Surface Roughness Analysis Using 2D Wavelet Transform-based Methods

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This paper describes the analysis of riverbed sediment surface data using the two-dimensional discrete wavelet transform. When sedimentation occurs in a channel the topography of the bed surface will change which in turn will affect the flow characteristics. It is therefore important to be able to characterise the bedsurface topography. In this study the sediment surface data was analysed using the wavelet transform - a relatively new mathematical tool for data analysis. Interest in this analysis method has increased during recent years, and today it can be found in a number of areas in both science and engineering. The sediment data set was decomposed into a range of scales using the Daubechies 12 wavelet for the analysis. By determining the energy in the scale ranges a novel distribution, the form size distribution, of the bed forms was computed.

An Elastic Contact Mechanics Fracture Flow Model

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The study of flow through fractured rock is a challenging research topic. The inherent complexity of the geometry of natural surfaces in contact, the lack of knowledge regarding flow behavior in a small and extremely irregular space and the deformation of the confining solids, make for a difficult landscape of study. In this paper, a classic theory in the area of contact mechanics, first applied to optics and lenses in contact by Hertz, is used to obtain a simple model of a deforming fracture. The model accounts for elastic deformations of the solids in contact and assumes laminar flow in the created voids. Results are presented and compared to experimental tests carried out by and presented inGale (1975).

Momentum-Based Model for Sediment Transport

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Many current models of sediment transport use single-phase flow equations to determine liquid flow velocity profiles and then use these to compute suspended load and bed load transport. A two-phase or two-fluid approach is more desirable because it allows mechanistic modeling of interfacial effects as well as turbulence effects within the near-bed layer. This also seems to be a more natural approach than some existing two-fluid models, which often couple a conservation of momentum equation for the liquid (continuous) phase and includes a diffusive flux of dispersed material in the conservation of mass equation for the dispersed phase.

The basic equations for two-phase flow are presented and applied to the simplified case of steady-state two-dimensional fully-developed flow in a rectangular channel over a flat bottom. The equations for balance of mass and momentum are discussed for low sediment concentration, and a turbulence model is considered. Parameters which affect the sediment volume fraction are determined through nondimensionalization of the model equations. The system is found to be singularly perturbed, with a boundary layer near the bottom. Singular perturbation analysis of the system is performed, with ìlaw of the wallî boundary conditions coming from the near-bottom analysis. Subsequent numerical solutions for the sediment volume fraction show that this treatment of the equations produces reasonable results when compared with experimental data.

A 3-D Sediment Transport Moel In A Large Shallow Lake

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This manuscript describes the validation and application of the sediment transport sub-model of the Lake Okeechobee Environmental Model (LOEM). This sub-model simulates the sediment resuspension and transport due to wind driven currents and waves. The LOEM was run for a year, from 10/1/1999 to 9/30/2000. The model reasonably simulated suspended sediment concentrations in the validation period. The strong relationship between observed wave height and suspended sediment concentration in Lake Okeechobee supports the hypothesis that sediment resuspension is primarily a result of wind generated waves. To simulate this sediment resuspension, the processes of wind generated waves and the resulting stresses on the lake bed were added to the LOEM. The LOEM is used as a management tool to predict the impact of sediment processes in the lake under different management scenarios and environmental conditions (sediment removal/dredging, high/low lake stages and storm events/hurricanes). The LOEM allows managers to predict how phosphorus-rich mud sediments move in the lake and under what conditions they are most likely to be resuspended and transported.

Discrete and Continuum Modeling of Granular Materials IV
June 4, 2002
11:30
Chair: Jin Ooi University of Edinburgh

Accurate Handling of Pressure Peaks in FE - Simulations of Granular Media

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Numerical simulations of granular flow in silos are discussed and compared to measurements in full scale silos. The Finite Element Model presented, which is formulated within a so called mixed Lagrange - Eulerian frame includes nearly all aspects of the simulations hitherto performed within the FEM - frame used during the filling and discharging processes of a silo. It is based on the work done by Haeussler and Rombach. Important new aspects included for the filling are: - new non-linear models for the bulk material (including density) - appropriate modelling of the filling of a silo like e.g. distributed and centred filling - element mesh - independent filling method satisfying the continuum frame used Some important aspects for the emptying phase are: - update of the upper surface of the bulk as well as the density - full solution of the equation of motion including all effects resulting from the displacement, velocity and acceleration

Numerical simulations of granular flow have to be carried out with great care. Many publications of the past show phenomenae, which seem to be the result of numerical assumptions, simplifications and predictions made by the authors. This is demonstrated for two examples: Results may depend on the size of the finite element chosen and on the methods used to simulate the flow phenomena.

One important aspect in silo design is the switch phenomenon, a great pressure peak which occurs in reality for mass flow silos at the junction between the hopper and the cylindrical part of a standard silo structure. Numerical models based on the Finite Element Method published in the past show also very high wall loads in this region. But it has been demonstrated that these pressure peaks are caused by corner singularities.

Methods to overcome this problem are either a rounding of the corner (engineering style) or to use scaling functions (mathematical way). So far, both methods do not lead to a satisfactory, mesh independent solution enabling reasonable results. Especially for the rounding, the methods so far known to the authors dealt with full slope compatibility though the rounding, still leaving a numerical pressure peak at the junction between the straight walls and the rounding. Elements known being used for 2D - simulations of these problems include 8-node and 12 - node Serendipidy elements. These elements may include a full slope compatibility, although for the case of 8 - node ones only for special cases. Curvature compatibility, necessary for the computation of the stresses cannot be achieved for 12 - node bi - cubic elements, as the second derivative of such elements are linear functions. Therefore elements with bi ñ quintic shape functions are required to obtain a full slope- and curvature compatibility.

Results obtained with theses elements and the new features included, seem to provide useful information for silo design and for other codes than those presented by the authors.

Granular Shear Flows: Constitutive Relations And Internal Structures

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Granular shear flows can behave as a rate-independent (plastic) or rate-dependent (non-Newtonian viscous) material. Most of the real granular flows may lie in the regime between these two extremes. While kinetic theory captures the constitutive behavior of the inertia dominant regime, in which stress depends on the square of the strain-rate, there is no theory that explains the transitional behavior. This paper presents a conceptual theory that describes the importance of the internal structure in the transitional regime for granular materials.

Conditions for Localized Compaction of Porous Granular Materials

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Compaction bands are a form of localized deformation found in field and laboratory specimens of high porosity rock, consisting of planar zones of pure compressional deformation, forming perpendicular to maximum compression. Recent experimental results indicate that compaction bands and/or shear bands (angled to maximum compression) occur in high porosity sandstone during a transitional loading regime where multiple damage mechanisms may be active. Therefore, a two-yield surface constitutive model is employed to examine localized deformation conditions. The first surface corresponds to a dilatant, frictional mechanism, while the second is a cap, corresponding to a compactant mechanism. A bifurcation approach to localization is used, revealing that localization conditions are strongly influenced by the choice of constitutive model. Using a single yield surface constitutive model shear bands, but not the observed compaction bands, are predicted. However, the two-yield surface model predicts both experimentally observed band types for reported values of key material parameters. Additionally, shear band angles predicted by the two-yield surface model generally agree with experimentally observed band angles.

DEM simulations of the direct shear test

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In the direct shear test, the top half of the specimen is translated relative to the bottom half resulting in the formation of a horizontal shear band across the mid-height of the specimen. In particle technology this is performed in a Jenike shear cell that is circular in cross-section whereas in soil mechanics the Casagrande shear box (square cross-section) is used. In both cases, the applied vertical and horizontal forces are measured and the ratio of horizontal to vertical load is assumed to provide an estimation of the average ratio of shear to normal stress acting in the shear band and thereby provide a direct measure of the Coulombic bulk friction. It is, however, unclear how reliable this traditional interpretation is since the exact state of stress within the shear band is unknown.

DEM simulations of the direct shear test have been performed under both constant normal stress and constant volume conditions. Results are presented to show how the state of stress in the shear band evolves. Comparisons with boundary force calculations are made and implications for laboratory measuements are discussed. The results are also interpreted in terms of Mohr's circles of stress and strain rate and the corresponding flow rules are identified.

A first-gradient stress-strain model for granular materials using microstructural approach

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High-gradient model has recently received a great deal of attention in the analysis of strength with size dependency. The paper shows that similar size effect also exists in the elastic bending modulus of granular material based on the results of DEM simulation. Since the classic stress-strain law cannot model the behavior of size effect, we derive a continuum higher-order stress-strain law that account for the couple stress and can model the behavior of size effect. The derivation of the higher-order stress-strain model is based on a microstructural approach. Thus it includes an internal length scale, and the material constants can be explicitly expressed by the inter-particle stiffness and particle size. Using the derived higher-order stress-strain law, we then show that the DEM experiments can be modeled by the continuum analysis.

Computational Mechanics - Topics in Concrete and Composites
June 4, 2002
11:30
Chair: Giuseppe Davi' University of Palermo

Computer Analysis of Reinforced Concrete Columns Subjected to Biaxial Sustained Loads

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A generalized analytical approach is presented in this paper to predict the behavior both of slender and short reinforced concrete columns under sustained biaxial eccentric load.

The present analysis proposes equations established at a cross section of a reinforced concrete column by combining force equilibrium, constitutive law, and compatibility conditions. The strain and curvature of each section and the deflection of the column can then be obtained and resolved.

During the sustained loading process, creep and shrinkage strains have occurred and they are added and combined to the total strain and curvature of each section.

The established creep computation models, recommended separately by American Concrete Institute (ACI) 209-82 and the Comiteí Euro-International du Beíton (CEB)-FIP 1990 Model Code have been used to calculate creep and shrinkage for a member under a constant elastic compressive concrete strain for a given period.

This present analysis also proposes a computerized method for time and strain adjustment. With this method, named as the Time and Strain Adjustment of Creep Method, combining a creep calculation model for a constant elastic strain, such as those mentioned above, the creep strain at each cross section can then be calculated, stored and adjusted to age of concrete, load changes and deflection modifications during each time increment phase.

In the conventional load-deflection analysis process, with projected transformations, a spatial deflection curve is resolved into a couple of planar curves located separately in two orthogonal plans. Given coordinates of a point at a cross section, the axial strain of that point can be calculated by additionally knowing curvatures of the two planar curves and the maximum concrete compressive strain at a corner. Based on the force equilibrium equations of inner force at a column section, a set of three simultaneous non-linear differential equations are derived to establish the relationships between the planar curve functions with the eccentric load upon the top of column. It has been proved that a solution of equations is uniquely existed. Using the Greenís Integral Formula, the strain and stress nonlinear functions and column section properties can be solely integrated into a few important coefficients of the differential equations. Thus, it makes the approach also suitable for columns with non-rectangular sections and any kinds of constitutive laws of materials.

The present rational computer analysis results have been compared with the existing bi-axial and uniaxial experimental data, which are available in literature. They indicate that the results from the proposed analysis correlate with experimental data well.

Keywords: Slenderness, reinforced concrete; column; sustained load; creep; strain; stress; biaxial (bending); spatial (deflection); eccentricities

Nonlinear Limit State Analysis of Composite Laminated Plates by p-Version of F.E.M.

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A p-version finite element model based on degenerate shell elemet is proposed for the analysis of orthotropic laminated plates. In the nonlinear formulation of this model, the total Lagrangian formulation is adopted with large deflection and moderate rotations being accounted for in the sense of von Karman hypothesis. The material model is based on Huber-Mises yield criterion and Prandtl-Reuss flow rule in accordance with the theory of strain hardening yield function. The model is also based on extension of equivalent-single layer laminate theory with shear deformation. The integrals of Legendre polynomials are used for shape functions with p-level varying from 1 to 10.Gauss-Lobatto quadrature is used to calculate the stresses at the nodal points. The validity of the proposed p-version model is demonstrated through several comparative points of view in terms of ultimate load, shape of plastic zone, convergence characteristics and nonlinear effect.

Nonlinear analysis of woven composites with reinforcement imperfections

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A simple procedure is presented for the determination of a Periodic Unit Cell (PUC) for a plain weave fabric composites with reinforcement imperfections. The objective is to determine selected geometrical parameters of the PUC so that the PUC resembles the real geometry of a composite, obtained from digitized micrographs of plain weave cross-sections and horizontal projections, as close as possible. Two different approaches to judge the quality of equivalent periodic unit cells are proposed and the optimization procedure for the derivation of PUC parameters is outlined. In the first approach, the optimal periodic unit cell is found by matching binary imagines of the real material and the PUC. In the second approach, the procedure searches for an optimal PUC witch is statistically equivalent to the real microstructure up to two-point probability function. In either case, the optimization problem is solved with the help of genetic algorithms. Once the desired geometrical parameters are found, the Finite Element model of a woven composite is formulated and used to predict the overall elastic response of the composite by a homogenization method. An extension to the modeling of inelastic response of the composite subjected to moderate loads is also discussed.

An Evaluation Of Constitutive Models Of Concrete In LS-DYNA Finite Element Code

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Dynamic non-linear finite element methods are extensively used to analyze vehicle-to-barrier crashes. The underlying challenge in this analysis is the capability of the constitutive models of concrete to represent a realistic response of the barrier under impact loading. LS-DYNA, a commercial FE code for crashworthiness analysis offers four major constitutive models for concrete. The performance of each of these models is assessed by making a comparison between numerical simulations and some benchmark stress-strain data, obtained from triaxial experiments conducted on plain concrete. Two of the constitutive models failed to produce realistic simulations beyond the elastic range. The smooth transition to non-linear regime and the observed post-peak response of concrete were well captured by Material Model 16 and 72, which relies heavily on a set of empirically obtained curves. Using the calibrated material models, a vehicular impact/crash scenario is then simulated to investigate the prediction of these constitutive models for the concrete barriers subjected to vehicular impact. The findings of the triaxial compression and vehicle-to-barrier crash test simulations are discussed along with the shortcomings of the constitutive models for concrete in LS-DYNA code.

Angle-Ply piezoelectric composite laminates by BEM

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The present work falls within the studies directed to verify the potentiality of piezoelectric composites for structural applications. In this paper an alternative and efficient boundary integral formulation for the analysis of piezoelectric composite laminates is used to assess the behavior of angle-ply piezoelectric composite laminates subjected to axial loading, bending and twisting. The proposed approach gives a convenient basis for a numerical solution by the boundary element method. Interlaminar stress and electric displacement distributions are analyzed for angle-ply laminates having different stacking sequence and width to height ratio. The features of the method are exploited in order to assess the behavior of piezoelectric composite laminates, the effects of the electromechanical coupling and the characteristics of the boundary-layer. The results presented show the potentiality of the proposed approach and prove that it is able to accurately and efficiently describe the laminate piezoelastic behavior. Moreover, the analyses performed show some interesting features of the electromechanical response of piezoelectric composite laminates.

BEM and Dynamic Problems in Mechanics

June 4, 2002
11:30
Chair: EUCLIDES MESQUITA UNICAMP -STATE UNIVERSITY AT CAMPINAS

A general viscoelastic analysis by the Boundary Element Method

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From basic assumptions of viscoelastic constitutive relations and weight residual techniques a Boundary Element procedure is achieved for both Kelvin and Boltzmann models. Imposing spatial approximations and adopting convenient kinematical relations for strain velocities, a system of time differential equations is achieved. This system is solved adopting linear approximations for displacements, resulting in a time marching methodology. This approach avoids the use of relaxation functions and makes easier changes in boundary conditions along time, natural or essential. An important feature of the resulting technique is the absence of domain discretizations, which simplify the treatment of problems involving infinite domains (tunnels and cavities inside the soil). Some examples are shown in order to demonstrate the accuracy and stability of the technique when compared to analytical solutions.

Integral Equation Approach For Anisotropic Elastic And Piezoelectric Cracked Bodies

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The extensive use of composite and piezoelectric materials and the subsequent need for their structural integrity analysis has led to the development of different numerical tools for the study of crack problems in those materials. The mixed Boundary Element formulation based on displacement and traction integral equations for anisotropic media is generalized in this paper and its use extended to cracked elastic and piezoelectric anisotropic domains. Particular atention is paid to half-plane problems where a simple fundamental solution is used. The hypersingular integrals appearing in the formulation are transformed into regular ones, which are numerically evaluated, plus very simple singular integrals with known analytical solution. The generality of the present method permits the use of general straigtht and curved quadratic boundary elements. In particular, quarter-point elements are used to represent the crack-tip behavior. Several examples with different crack geometries are studied to ilustrate the possibilities of the method. The stress intensity factors (SIF) are accurately computed from the nodal crack opening displacement along the crack tip element.

2-D General Anisotropic and Piezoelectric Time-Harmonic BEM for Eigenvalue Analysis

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We derive the fundamental generalized displacement solution for two-dimensional piezoelectric solids using the Radon transform and present the direct formulation of the time-harmonic Boundary Element Method (BEM). The formulation includes the general anisotropic solids (and the dielectric solids), as the special case, when the piezoelectric constants disappear. The fundamental solution is separated into the static singular and the dynamics regular parts. The former, being the fundamental solution of the static problems, leads to the static BEM for piezoelectric solids, while the latter leads to the dynamic part of the BEM. Thus, the time-harmonic BEM consists of the static singular boundary element (SSBE) and the dynamic regular boundary element (DRBE). The unique feature of the boundary integrals in the DRBE is that, after evaluated analytically along the boundary element, they are reduced to simple line integrals along the unit circle. We apply the BEM to the determination of the eigen frequencies of piezoelectric and general anisotropic solids. We make a comparative study of non-linear eigenvalue solvers: QZ algorithm and the IRAM.

Analysis Of The Fundamental Solution For Anisotropic Thin Plates

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In this paper an analysis of the fundamental solution for anisotropic thin plate is presented. The bending fundamental solution in a completely anisotropic media is computed for small and large values of radius. Their results are compared with the isotropic fundamental solution using quasi-isotropic material properties. It was shown that the anisotropic fundamental solution has good agreement with the isotropic one only when large values of radius are used. Future application of the anisotropic fundamental solutions is proposed for static as well as dynamic problems.

Transient Crack Propagation Using Boundary Elements

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The aim of this paper is to present a procedure to simulate crack propagation in elastic two-dimensional media. The analysis is carried out in the time domain and the Transient Stress Intensity Factor is calculated in the propagating crack tip. The procedure is powerful enough to consider the general case of unknown path and propagation velocity. The problem is modeled by Mixed Boundary Elements, combining standard and hypersingular elements. This procedure is specially well suited for this problem, since the re-meshing after crack propagation is reduced to a minimum. The boundary is discretized using isoparametric quadratic elements, while in the time interval, step and linear wise interpolation functions are employed. The crack tip transient asymptotic behavior is modeled using several alternative elements: quarter-point elements and centered elements with special shape functions. Besides the geometry and shape functions, different alternatives exist regarding to the collocation point. The results using different options are compared against analytic solutions and the best alternatives are tested with numerical results obtained by different authors.

System Identification I
June 4, 2002
14:30
Chair: Andrew Smyth Columbia University
Co-Chair: Raimondo Betti Columbia University

Identification of Linear and Nonlinear Structures Using Seismic Response Data And Hilbert Transform

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A damage identification approach based on the Hilbert-Huang spectral analysis is proposed and applied to the ASCE structural health monitoring benchmark structure. In this approach, the structural parameters, including stiffness and damping before and after damage are identified based on the noisy measurements of acceleration responses due to white noise excitations. Then the location and severity of the damage are assessed by a comparison. Simulation results demonstrate that the accuracy of the proposed method in identifying the structural damages is very plausible, and it represents a viable damage identification approach for linear structures.

Damage Detection of Structural Systems with Noisy Incomplete Input and Response Measurements

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A probabilistic approach for damage detection is presented using noisy incomplete input and response measurements. In [1,2], a Bayesian approach is developed for the case of using complete input and incomplete response measurements, where noise in the input is ignored in [1] but not in [2]. This paper extends this approach to handle the case of using noisy incomplete input and response measurements. This situation may be encountered, e.g., when a structure is instrumented with accelerometers that measure the input ground motion and structural response at a few locations but the wind excitation is not measured.

A substructuring approach is used for the parameterization of the mass and stiffness distributions. Damage is defined by reduction of the substructure stiffness parameters compared with those of the undamaged structure. The probability of various damage levels in each substructure can be calculated based on the available data. A benchmark building is considered for demonstration.

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Parametric Frequency Domain Identification in Multiconfiguration Structures

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One difficulty that often arises in structural health monitoring (SHM) via global vibration response measurements is the low sensitivity of global vibration characteristics to typical damage mechanisms. Characteristics such as natural frequencies, modal damping and mode shapes often change very little from localized damage unless the damage is of great severity. This paper proposes using smart structures technologies, such as variable stiffness and damping devices (VSDDs) to improve this sensitivity for more accurate structural health monitoring. VSDDs are already being used to improve the performance of structures subjected to natural hazards by mitigating vibration response. In addition to providing near optimal control strategies for vibration mitigation, these low-power and fail-safe devices can also provide parametric changes to increase global vibration measurement sensitivity for health monitoring. While this approach can be used with other identification methods, it is here investigated in the context of a parametric frequency domain identification to determine structural parameters. The VSDDs are assumed to have discrete stiffness settings. Some examples from simulation are used to demonstrate the proposed method.

Issues in Reduced Order Modeling of Mechanical Systems

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A common modeling technique in investigating the dynamics of mechanical systems is the use of second order matrix differential equations. In such a formulation, the coefficient matrices contain the physical mass, damping, and stiffness parameters of the system, which in turn affect the vibrational parameters such as the natural frequencies and modeshapes. The construction of a mass--damping--stiffness model based on material properties and the system's geometry, as done in finite element analysis, is a relatively straight forward procedure and is widely employed. The identification of such a model from the measured dynamic response, on the other hand, has proven to be a tough challenge, and it is often referred to as the ‘‘inverse vibration problem".

Recently the authors have presented a solution to this problem based on identified state space realizations. This approach uses measured input and output data in the Observer/Kalman filter IDentification (OKID) algorithm to identify the Markov parameters of the system, which are then used in the Eigensystem Realization Algorithm (ERA) to realize the discrete time first-order system matrices. This initial state space model is further refined by minimizing the output error between the measured and predicted response using a non-linear optimization approach based on sequential quadratic programming techniques. Once the final form of the state space model is obtained, the physical parameters of the second-order (finite element) model are retrieved from this state space model using complex eigenvalues and properly scaled complex eigenvectors. This solution has proven to be more flexible and general than the previously presented solutions to the problem, and it has been used effectively in estimating the physical parameters of various models.

On the other hand, even though the requirements on the number of available sensors and actuators for a full order identification has been improved with the aforementioned solution, the question of obtaining reduced order models in the absence of full instrumentation has not been fully investigated yet. This study represents a first attempt at providing some alternate formulations that address the problem of insufficient instrumentation. The discussions are devoted to the review of the full order modeling problem, effects of insufficient instrumentation, possible reduced order modeling schemes, and alternate formulations that can be developed by employing assumptions that are often used in the literature, such as having a diagonal mass matrix and/or a classically damped system.

Analysis of Volterra/Wiener Neural Networks for Adaptive Identification of Nonlinear Hysteretic Systems

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This study attempts to demystify a powerful neural network approach, Volterra/Wiener Neural Network (VWNN), for modeling nonlinear hysteretic systems and in turn to streamline its architecture to achieve better computational efficiency. Artificial neural networks are often treated as "black box" modeling tools, in contrast, here the authors examine problem formulation and network architecture to explore the inner workings of this neural network. Based on the understanding of the dynamics of hysteretic systems, some simplifications and modifications are made to the original VWNN in predicting accelerations of hysteretic systems under arbitrary force excitations in an off-line or even in an adaptive (on-line) mode. The VWNN is able to yield a unique set of weights when the values of the controlling design parameters are fixed. One training example is presented to illustrate the application of the VWNN.

Experimental Analysis - I

June 4, 2002
14:30
Chair: Laurence Jacobs **Georgia Institute of Technology**

Shear Strengthening of RC Beams Using Carbon Fiber Reinforced Polymer Strips

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The use of carbon fiber reinforced polymer (CFRP) in strengthening reinforced concrete (RC) structures has become an increasingly popular retrofit technique. The technique of strengthening reinforced concrete structures by externally bonded CFRP laminates was started in 1980s and attracted researchers around the world.

Strengthening with externally bonded CFRP laminates has been shown to be applicable to many kinds of structures. Currently, this method has been applied to strengthen such structures as columns, beams, walls, slabs, etc. The use of external CFRP reinforcement may be classified as flexural strengthening, improving the ductility of compression members, and shear strengthening

A lot of studies have been conducted to explain the behavior of externally bonded CFRP laminates used to increase the moment capacity of flexural members. However, not many studies have specifically addressed the shear strengthening.

Shear failure is catastrophic and occurs usually without advanced warning, thus it is desirable that the beam fails in flexure rather than in shear. Many existing RC members are found to be deficient in shear strength and need to be repaired. Deficiencies occur due to several reasons such as insufficient shear reinforcement or reduction in steel area due to corrosion, increased service load, and construction defects. Externally bonded reinforcement such as CFRP provides an excellent solution in these situations.

In order to investigate the shear contribution of externally bonded CFRP, ten RC beams having cross-sectional dimension of 6x9-in. were cast at the concrete laboratory of New Jersey Institute of Technology. After the beams were kept in the curing room for 28 days, Carbon fiber strips and fabrics made by SIKA Corp. were applied on both sides of the beams at various orientations with respect to the axis of the beam.

All beams were tested on a 220-kip MTS testing machine. Results of test demonstrate the feasibility of using externally applied, epoxy-bonded CFRP system to restore or increase the load-carrying capacity in shear of RC beams. Diagonal side strips (45 and 135 degrees) outperformed vertical side strips in terms of shear crack propagation and ultimate shear strength. The CFRP system can significantly increase the serviceability, ductility, and ultimate shear strength of a concrete beam, thus restoring beam shear strength using CFRP is a highly effective technique. Based on the experiments and analysis carried out at NJIT and the results from other researchers, a new analysis and design method for shear strengthening of externally bonded CFRP has been proposed as well.

Keywords: Experiments, Shear, Reinforced Concrete, CFRP

Strengthening, Analysis, Design Method.

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Strength and Deformability of Low Strength Concrete Confined by Carbon Fiber Composite Sheets

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Lack of adequate confinement and low concrete quality are among major deficiencies for existing structures. These may cause structural damage leading to the collapse of structures during earthquakes. To overcome these problems, concrete members can be wrapped by carbon fiber reinforced polymer (CFRP) composites.

In literature, there is a number of experimental work on the behaviour of CFRP wrapped concrete. However, these experiments are on normal and high strength concrete specimens. In this study, 14 low strength concrete cylinder specimens are tested under compressive loads. 12 of these specimens are wrapped by CFRP composites of varying thickness before testing, while the remaining 2 specimens are tested as plain concrete.

According to the test results, significant enhancement is observed both on compressive strength and deformability. Consequently, energy dissipation characteristics of the CFRP wrapped specimens also enhanced notably.

Analytical expressions proposed for the compressive strength and corresponding strain of CFRP wrapped concrete by the authors before are extended to cover the effect of low strength concrete.

Crack Tip Deformation Fields in Ductile Single Crystals

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Crack tip deformation fields in ductile single crystals are studied experimentally. A new type of fracture specimen is created by joining two single crystals of aluminum with a ductile interlayer of tin of thickness on the order of 10 - 20 microns. A precrack is introduced in the bicrystal by selectively etching away part of the tin interlayer. The resulting fracture specimen is loaded in Mode I after which the deformed specimen is sectioned along its centerline. The in-plane rotation component of the deformation gradient tensor is measured under plane strain conditions on the center section using Electron Backscatter Diffraction (EBSD). Results are compared to theoretical predictions of crack tip displacement fields and provide evidence of all the predicted features, especially the existence of kink-shear sector boundaries (not previously identified) that emanate from crack tip. A new crystal dislocation structures necessary to create the boundary is deduced to explain the change in crystal orientation across the boundary. The results emphasize the role of dislocation mean free path length in determining plastic constitutive relations.

Soil/structure interaction of integral bridge with full height abutments

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The behaviour of integral bridges with full height abutments is dominated by the cyclical temperature changes in the bridge deck and the resulting imposition of cyclical displacements to the backfill soil of the abutments. It is known that the lateral earth pressures over the back of the abutments escalate to values considerably larger than those at the time the structure entered service. However, the upper limits of the stress escalation and distribution are not known. The paper describes an investigation of this problem. Results are presented to indicate that two distinct mechanisms are responsible for the stress variations namely Granular Flow and Granular Arch. The Flow mechanism relates dominantly to the large wall rotations. This mechanism allows the soil to deform continuously in a unidirectional ratcheting manner under a steady repeating stress state. The Arch mechanism relates dominantly to small wall rotations where flow becomes progressively unimportant. This mechanism creates "arches" to reduce the vertical stresses acting on the soil behind the lower half of the wall, thus resulting in lower horizontal earth pressures there.

Experimental Analysis of Microstructure and Fracture in Three Dimensions

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A high resolution three-dimensional scanning technique called x-ray microtomography was used to measure internal crack growth in small mortar cylinders under compressive loading. Tomographic scans were made at different load increments in the same specimen. Three-dimensional image analysis was used to measure internal crack growth during each load increment. Load-deformation curves were used to measure the corresponding work of the external load on the specimen. Fracture energy was calculated using a linear elastic fracture mechanics approach using the measured surface area of the internal cracks created. The measured fracture energy was of the same magnitude a that is typically measured in concrete tensile fracture. A nominally bilinear incremental fracture energy curve was measured. Separate components for crack formation energy and secondary toughening mechanisms are proposed. The secondary toughening mechanisms were found to be about three times the initial crack formation energy.

Stochastic Modeling
June 4, 2002
14:30
Chair: Dan Ghiocel STI Technologies
Co-Chair: Mircea Grigoriu Cornell University

PROBABILISTIC ASSESSMENT OF SERVICE LIMIT STATE FOR OFFSHORE PLATFORMS IN MEXICO

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Fixed Offshore platforms are generally well designed regarding structural safety and integrity. However, ordinary environmental forces and particularly flexible components may be important sources of dynamic excitation and significant vibrations. In general, service limit states for offshore platforms have not been as widely studied as the safety limit states.

A Mexican quarters platform was monitored and its dynamic characteristics were identified in order to prevent excessive displacements and accelerations. The platform was modeled as a single degree of freedom with elasto-plastic behavior and the dynamic properties were calibrated from records obtained throughout a monitoring campaign of response displacements and accelerations on the platform. Fourier amplitude response spectra are generated and, on the basis of Monte Carlo simulation of time history accelerations, the probability to exceed prescribed thresholds for lateral displacements, accelerations and lateral strength are estimated. These probabilities are conditional to the occurrence of the wave height exciting the platform. In order to get the unconditional probabilities, the conditional ones are convoluted over the probability of occurrence of the wave heights for the site of the platform.

Lateral strength of the platform is calculated by assuming a failure mechanism composed by the simultaneous formation of plastic hinges at the ends of the platform legs.

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ASYMPTOTIC INDEPENDENCE OF MATERIAL FAILURE AT DIFFERENT SCALES: THE ROLE OF SMALL-SCALE FLUCTUATIONS

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Most materials are heterogeneous and aperiodic at micro and nanoscales; the properties, interaction etc. of the heterogeneities are random functions of space and time. An adequately detailed probabilistic description is required for modeling material behavior and failure at all scales of interest. While material surfaces can be observed down to nanometer resolutions, it remains a challenge to observe internal microstructural evolution in situ at a comparable resolution, and indirect methods are required for modeling small-scale damage. It is important to include both spatial and temporal aspects of the smallscale fluctuations. This paper proposes a general model of how the random material microstructure, composed of a matrix and embedded defects, evolves in time and space as a specimen is subjected to external actions. Local stationarity, strong mixing and dispersed extremes are assumed and the limiting distributions of the local average and the local maximum response are elicited. The asymptotic independence of extremal processes and hence failure (first passage of a space-time process) at widely different scales is demonstrated.

USE OF EXISTING EXPERIMENTAL DATA TO EVALUATE METHODS FOR DESIGN AGAINST UNCERTAINTY

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An efficient experimental approach for probing for weakness in methods for design against uncertainty, using existing databases containing sample values of random variables is presented. The method allows use of existing data from different fields to construct and solve simple design problems and mimic real-life design decisions, and then evaluate the outcomes. One can efficiently investigate a method for design under uncertainty many times to obtain robust conclusions and learn lessons that are difficult to learn from an examination of the theoretical foundations of the method. The approach is demonstrated for a database including results from experiments involving building stacks of dominoes until they collapse. The database is used to simulate the problem of choosing a performance target for a new computer chip. We used probability and possibility for choosing the target, and examined the effect of inflating the standard deviation of a probability distribution or the support of a possibility distribution when data is scarce. We found that fitting errors of the probability distributions of the random variables can lead to an advantage of possibility over probability. Probability performed better with scarce data. Furthermore, a hitherto unnoticed difference between probability and possibility was discovered, in that inflating the standard deviation causes probability to pay less attention to an inflated failure mode and causes possibility to give it more weight. Finally, it was found that the practice of inflating the standard deviation for scarce data was counter-productive. We believe that these lessons can help one understand better methods for design against uncertainty and can augment those lessons learnt by examining the axiomatic foundations of theories of uncertainty.

Reliability Of A Linear Vibrating System Under A Partially Specified Gaussian Load

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The reliability of a linear dynamical system driven by an incompletely known Gaussian load process, specified only through its total average energy, is studied. A simple dynamic parallel or series system reliability model is investigated for the failure analysis using the out-crossing theory of stochastic processes. The input critical power spectral density (PSD) which maximizes the mean crossing rate of a parallel or series system emerges to be fairly narrow-banded which may not represent the erratic nature of the random input realistically. Consequently, a trade-off curve between the maximum mean crossing rate and the disorder in the input, quatitatively measured through its entropy rate, is generated. Mathematically, the generation of the trade-off curve leads to a highly nonlinear multi-criteria optimization problem with conflicting objectives. A recently developed Pareto optimization technique in conjunction with a multi-criteria genetic algorithm has been used to solve the optimization problem. The optimally disordered inputs which create the worst performance of the system, consisting of a spring-supported coupled rod assembly, has been studied as a numerical illustration of the mathematical formulations.

Stochastic Field Models for Approximating Highly Nonlinear Responses

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The paper discusses different stochastic field models for approximating highly nonlinear responses. A key requirement for a good stochastic modeling is to be intimately related to the physics of the problem. Simple approximation procedures that have been popular in the past, may not work for many real-life problems. Classical Response Surface Method (RSM) is often insufficiently accurate for applications that involve highly nonlinear relationships. The paper describes different stochastic field modeling techniques that based on the authorís experience are adequate for high-complexity applications. These techniques are: (i) stochastic field expansion techniques, (ii) stochastic field interpolation techniques and (iii) stochastic local-averaging expansion techniques. Each category of these stochastic techniques has advantages and disadvantages that the analyst should understand before using them for a real application.

Recent Advances in Materials Characterization and Modeling of Pavement Systems III

June 4, 2002
14:30
Chair: Yacoub Najjar Kansas State University
Co-Chair: Eyad Masad Washington State University

Dynamic Response Of Pavements By Stiffness Matrix Approach

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The background and application of the stiffness matrix approach in the dynamic analysis of pavements is presented. The stiffness matrix approach involves a triple transformation of the problem. The first is transformation of loading from the time to the frequency domain. The second and third are spatial transformations of loading, leading to the solution of the problem in the frequency-wave number domain. Inverse transformations are used to return the pavement response to the original spatial-time domain. The most important advantage of the stiffness matrix approach is that the infinity (radiation condition) of the half-space and lateral boundaries is perfectly satisfied. The other advantage is that a single complex stiffness matrix provides a theoretically exact description of a single pavement layer. Application of the method in modeling and analysis of the response of a pavement to dynamic loads, and simulation of nondestructive tests, like Falling Weight Deflectometer (FWD) and Spectral Analysis of Surface Waves (SASW), is presented.

Modeling of pavement materials - numerical and experimental aspects

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Tom Scarpas ***Delft University of Technology***
Andre Molenaar ***Delft University of Technology***

Results of an extensive experimental and numerical research project on the response of Asphalt Concrete (AC) are presented. In the project a material model for AC is being developed and implemented in the Finite Elements package CAPA-3D. Also, the test set-ups, instrumentation and test procedures necessary to characterise the material and determine the model parameters were developed. In an early stage of the project it was recognised that failure in tension and compression followed a different mechanism and needed to be described separately in order to capture the response to alternating loads. From the results of uniaxial tension tests it became apparent that also in tension a pronounced non-linearity occurred prior to the peak load. The adaptations necessary to incorporate this in the model are presented in this paper. The response predicted by the model relations is compared to that observed in laboratory tests to validate the model relations and it can be seen that the observed behaviour is described quite well by the model.

Measurement of Base and Subgrade Layer Stiffness During and After Construction Using Bender Element Technique

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Lei Fu ***Case Western Reserve University***

Base and subgrade soil stiffnesses are important parameters of material characterization in highway construction. During and after pavement construction, it is very important and cost-effective to have a reliable technique that can measure the stiffness of in-situ base and subgrade layers accurately and quickly. The new highway construction guide proposed by AASHTO requires such measurement be conducted. At present, there is no such device available. A new field-testing technique has been developed to measure small-strain shear modulus (which can be converted into elastic modulus) and in-situ K0 value of soils utilizing the bender element method, which has become a popular experiment to measure shear wave velocity and K0 in soils in recent years. The device used in this study includes a pair of cone penetrometers, each fitted with two bender elements, which can be pushed into the base, subbase and subgrade layers. The distances between the transmitters and receivers are controlled by the frame supporting the penetrometers. A pulse generated by a function generator is used to activate the transmitters. Vibrations of the transmitters produce shear waves that propagate through the soil in the horizontal and two inclined directions are captured by the receivers. Signals produced by the receivers are recorded by a laptop computer equipped with a high-speed data acquisition card, from which the travel time of the shear waves from the tip of a transmitter to the tip of a receiver can be determined. Then from the measured shear wave velocities in different shear planes, anisotropic materials stiffness and the insitu K0 value can be determined. The technique is applicable to a wide range of materials used in base layer construction such as compacted aggregates, cemented aggregates mixtures, lime stabilized soil, as well as natural soils.

Characterization of Load-Deformation Behavior of Asphalt Concrete Samples by Triaxial Shear Tests with Pore Pressure Measurements

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The characterization and load-deformation behaviors of asphalt concrete are studied. The laboratory test samples are prepared using the Static Compaction Method and the SuperpaveTM Gyratory Compactor. Tests are performed employing unconsolidated undrained triaxial compression tests with pore pressure measurements under temperature controlled conditions. A special triaxial compression test apparatus and an environmental control chamber were developed. The change in the shear strength properties of the bituminous mixture at different testing temperatures and asphalt cement contents are investigated according to sample preparation methods. A total of 72 test samples are prepared to represent 4 temperatures, 3 asphalt content values, 3 different chamber pressures, and 2 types of sample preparation methods. Correlations are made with respect to mixture design parameters, including percent air voids, voids in mineral aggregates, Hveem Stability Number and percent asphalt contents. The analysis of the experimental data indicate the encountered deficiencies of the samples prepared by the gyratory compactor, and confirm that the performance of asphalt pavements can be represented by using shear strength parameters of the hot-mix-asphalt mixture.

Modelling The Changes In Pavement Layers During Rehabilitation And The Effect Of These Changes On The Structural Capacity

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Pavement rehabilitation usually involves the re-use and retention of existing pavement layers. Often, these layers are retained as sublayers with the addition of strength in terms of new layers on the top of the pavement. A structural capacity analysis of the rehabilitated pavement, using mechanistic analysis procedures, requires the effective elastic moduli of the newly constructed pavement layers as well as that of the existing underlying pavement layers to be accurately modelled. The aim of this paper is to highlight the changes in stiffness values that take place during the rehabilitation and the effect this has on predicted structural capacity. An experimental section of road was evaluated before and after rehabilitation and the stiffness and associated stresses were determined in-situ for the different uniform sections. The material properties and the changes of the material properties for the different pavement layers were modelled using deflection bowl measurements of high frequency (every 4-6 m). These changes were compared and the influence of the rehabilitation actions on the structural capacity for the rehabilitation (before &after) phases was assessed.

Multi-Scale Modeling of Materials - I
June 4, 2002
14:30
Chair: George Voyiadjis Louisiana State University
Co-Chair: Rami Haj-Ali Georgia Institute of Technology

Modelling of concrete structures in dynamics with a coupled damage-plasticity approach

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This study deals with the aspects of the concrete behaviour under dynamic loading such as impacts or explosions. For these kinds of sollicitations concrete experiences compaction (a decrease of porosity), plastic strains in compression and also cracking in tension. It is relevant to be able to represent, at the same time, the phenomena of compaction of material, as well as the rupture by extension. Recently, new dynamic experiments performed on confined concrete (to obtain compaction), made it possible to highlight a significant effect of the strain rate on the spherical behaviour of concrete. Following these experimental observations, a viscoplastic and visco-damage model was developed. This model is based on Perzyna viscoplasticity associates with a modified Gurson yield function and on a visco-damage model. This constitutive model for concrete is able to represent the rate effect experimentally observed. The model presented was implemented in the finite element code LS-DYNA3D. Simulations of tests carried out on structures allowed to validate the numerical implementation, as well as the model for fast dynamic loading.

Discrete Element Modelling of Concrete and Identification of the Constitutive Behaviour

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The use of a 3D Discrete Element Method (DEM) is proposed to study concrete structures submitted to dynamic loading. The aim of this paper is the correct identification of parameters of the DEM model from usual test results to simulate elastic and inelastic deformation as well as fracture of concrete. A particular growing technique is used to set a densely packed assembly of arbitrarily sized spherical particles interacting together at their contact points. An important difference from classical DEMs where only contact interactions are considered, is the use of an interaction range, which allows the setting of an interaction between two elements not necessarily in contact. The SDEC model exhibits complex macroscopic behaviours such as strain softening, and fracture that arise from extensive microcracking throughout the assembly. The influence of the assembly size distribution, of the packing, and of the interaction range on the material behaviour is shown. The model produces a quantitative match of strength and deformation characteristics of concrete in terms of Young's modulus, Poisson's coefficient, and compressive and traction strengths.

Micromechanics-based Prediction Of Thermoelastic Properties Of High Energy Materials

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High energy materials such as polymer bonded explosives are commonly used as propellants. These particulate composites contain explosive crystals suspended in a rubbery binder. However, the explosive nature of these materials limits the determination of their mechanical properties by experimental means. Therefore micromechanics-based methods for the determination of the effective thermoelastic properties of polymer bonded explosives are investigated in this research. Polymer bonded explosives are two-component particulate composites with high volume fractions of particles (volume fraction $>$ 90\%) and high modulus contrast (ratio of Young's modulus of particles to binder of 5,000-10,000). Experimentally determined elastic moduli of one such material, PBX 9501, are used to validate the micromechanics methods examined in this research. The literature on micromechanics is reviewed; rigorous bounds on effective elastic properties and analytical methods for determining effective properties are investigated in the context of PBX 9501. Since detailed numerical simulations of PBXs are computationally expensive, simple numerical homogenization techniques have been sought. Two such techniques explored in this research are the Generalized Method of Cells and the Recursive Cell Method. Effective properties calculated using these methods have been compared with finite element analyses and experimental data.

Fracture Testing and Micromechanical Analysis of Pultruded Composites

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An experimental and analytical study is carried out to characterize the fracture behavior of fiber reinforced plastic (FRP) pultruded composites. The composite material system used in this study consists of roving and continuous filament mat (CFM) layers with E-glass fiber and polyester matrix materials. Eccentrically loaded single-edge-notch-tension ESE(T) fracture toughness specimen were cut with the roving transverse to the loading direction from a monolithic 0.5" thick plate. The fracture toughness of this material is characterized for a notch parallel to the roving direction. A three-dimensional (3D) micromechanical constitutive model is developed and calibrated for the composite material system. This nonlinear model is a combination of nested micromechanical models for the roving and CFM layers. The 3D constitutive model is used with a cohesive layer in a finite element analysis (FE) to study the fracture response. The properties for the cohesive layer were calibrated from an ESE(T) specimen with the ratio a/W=0.5. Good prediction from the proposed model is reported for a range of notch sizes and geometries.

NONLOCAL PLASTICITY FORMULATION INCORPORATING GRADIENT OF KINEMATIC HARDENING

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In this proposed work, nonlocal behavior is introduced through the second gradient of kinematic hardening models to introduce a microstructural characteristic length into the model and to introduce long-range microstructural interactions that allow the response of a material point to depend on the state of its neighborhood in addition to the state of the point itself. It is intended to develop a consistent and systematic framework for the gradient approach that will enable one to better understand the nonlocal effects of material inhomogeneity on the macroscopic behavior and the material instabilities. The internal state variables and the corresponding gradient terms are assumed to be independent internal state variables with respect to each other with different physical interpretations and initial conditions which allows these two different physical phenomena to be identified separately. The second order gradient of the kinematic hardening is introduced through the Helmholtz free energy and through the plastic potential function. Computational issues of the gradient approach are introduced in a form that can be applied using the finite element approach.

Hydrodynamics II

June 4, 2002
14:30
Chair: James Hu **University of Rhode Island**

HYDRODYNAMIC MODELING OF BOLINAS LAGOON, CALIFORNIA

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This paper describes the development and verification of a two-dimensional model for Bolinas Lagoon, California. Bolinas lagoon is situated on the Pacific Coast of California, just north of San Francisco. Accuracy of the model is examined through statistical analysis and comparison of present and historical data measurements in the area, including recorded tides, currents, and bathymetric surveys. All aspects of model application were investigated during the verification process. The model mesh and timestep were rigorously tested. The ability of the model to reproduce the system was verified to acceptable limits using field data. The two-dimensional hydrodynamic modeling tool developed is capable of evaluating and comparing marsh wetting and drying, channel deepening, flow rerouting, and intertidal water level fluctuations associated with the lagoon.

A CLOSED-FORM TIME-VARYING DIFFUSIVITY MODEL FOR DISPERSION IN OSCILLATORY TURBULENT CHANNEL FLOW

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Many transport models were developed in the context of turbulent oscillating flows, and yet they have for analytical simplicity adopted constant or time-invariant eddy diffusivities. The instantaneous interdependence of turbulent mixing and the flow is hence not accounted for in these models. The need to assess the effect of time dependency of eddy diffusivity on dispersion has motivated the present study. In this paper, a theory is advanced for the shear dispersion in a turbulent channel flow forced by a purely oscillatory pressure gradient. The flow is described by an algebraic eddy viscosity model, in which the instantaneous flow and viscosity are made interdependent. Both eddy viscosity and eddy diffusivity contain a second-harmonic time-varying component. The effective transport equation is derived using a two-time scale perturbation analysis, which also yields a closed-form expression for the dispersion coefficient. Numerical results demonstrate that for this problem the time-varying component of the eddy diffusivity is to have a finite effect on the dispersion coefficient.

Spatio-Temporal Structure of Long Wave Propagation in Open Channel Flow

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Propagation of long water waves in a one-dimensional, unsteady, viscous turbulent open-channel flow is studied theoretically. Shallow water wave movement in channel flow can be mathematically approximated by the Saint-Venant equations or their approximations. The Laplace transform method is implemented to obtain first-order analytical spatio-temporal expressions of upstream and downstream channel response functions for various wave approximation models. Wave propagation characteristics such as translation, attenuation, reflection, and distortion of each wave approximation can be deduced from the wave structures. Furthermore, the Froude number effect on such a spatio-temporal structure of various water waves is discussed. Based on the mathematical properties and physical characteristics for each wave approximation, it is shown that the downstream effect can be accommodated by two physical mechanisms: the negative characteristic wave and the instant pressure gradient transmitted upstream. Results also reveal that the noninertia wave model, regardless of its neglecting both convective and temporal inertia terms in the momentum equation, gives a better approximation of the full dynamic wave than the Quasi-steady dynamic wave model.

Mathematical model for 1D two-phase flow

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In this paper a mathematical model for 1D, two-phase flow in a duct is presented. Such kind of flow is frequently met when the pressure attains the saturation value so that bubbles of vapour and gas are released in the flow. The model is defined considering the balance equations of mass and momentum for the mixture constituted by both phases and the balance equations of mass and energy for the vapour phase [1]. Such a model consists of four partial, differential, first order equations, whose characteristic directions are all real. The initial value problem corresponding to the proposed model is then well posed [2]. Numerical simulations were compared with experimental data found in literature and the agreement is found to be satisfactory.

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Experimental Methods for Particulate Materials - II

June 4, 2002
14:30
Chair: Anil Misra University of Missouri
Co-Chair: Ching Chang University of Massachusetts

Physical Evidence of Shear Banding at Granular-Solid Interfaces

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The interface between granular materials and continuum surfaces is critical to the performance of a variety of systems including deep foundations, microtunneling technologies, earth retention structures, and grain hoppers. A number of recent laboratory studies have allowed quantification of the stress, strain, and deformation behavior of granular media at interfaces with various materials under loading and are summarized herein. This has been accomplished using various polymer impregnation and image analysis techniques in conjunction with axisymmetric and conventional interface shear tests.

Due to the complexity of many of these interface dependent systems, numerical methods such as finite elements and finite differences are now being implemented to model the system performance. In these models, interface elements that accurately reflect the physical behavior of interfaces must be utilized. Accordingly, the objective of this paper is to highlight the characteristics of the interface that have a first order effect on interface behavior as identified through experimentation in an effort to develop a framework from which a rigorous numerical interface element can be developed.

Mechanical Properties Of Granular Agricultural Materials Considered In Silos Design

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Traditional methods for silos design just took into account some material properties such as the angle of internal friction, the grain to wall friction coefficient and the specific weight. Currently some of these methods are still commonly applied in different international silo design standards. However, with these methods it was not possible to accurately predict dynamic loads in silos. Since numerical methods began to be applied to the design of silos it was possible to better understand the interaction between the grain and the silo walls. With this technique it was necessary to consider additional parameters such as the dilatancy angle, the Poissonís ratio and the modulus of elasticity that describe the behavior of materials usually stored in silos. Because of the lack of existing data within the literature, the goal of this research was to provide values of different material properties considered in either traditional or more recent silo design methods. These values will be used in finite element models recently developed by the authors to study the discharge of silos.

Contact Density - Confining Stress - Energy to Liquefaction Relations

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Soil liquefaction phenomenon involves progressive reorganization of intergrain contacts, frictional loss of energy, and eventual collapse of soil skeleton. Resistance to liquefaction depends on the nature and density of active intergrain contacts. Higher the density of active intergrain contacts (per grain) more resistant is the soil to liquefaction. Higher is the confining stress higher is the energy loss along contacts and higher is the resistance to liquefaction. This paper examines this idea analytically and experimentally. A theoretical framework for estimation of an index of active contact density for granular mix soil is presented. Theoretical expression for internal frictional energy loss W is developed. W agrees well with the measured external energy input. Both theory and experimental data indicate that the energy required to cause liquefaction increases linearly with initial effective confining stress and increases log-linearly with intergrain contact density.

Computational Mechanics of Beams, Plates and Shells
June 4, 2002
14:30
Chair: Ertugrul Tacироglu UCLA

Structural Analysis of Frames with Mixed Variational and Flexibility-based Methods

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The need to accurately compute the nonlinear response of structural frames has sparked an interest in the application of mixed variational and flexibility-based methods to the formulation of beam finite elements. The so-called Nonlinear Flexibility Methods, notwithstanding the fact that they have not been extended for geometrically nonlinear problems, appear to perform well compared to classical stiffness methods for inelastic beams. Although, most of these methods appeal to the variational principles, their exact variational basis has not been made entirely clear. We show that, because the equations of equilibrium and kinematics can be integrated directly, a nonlinear flexibility method, in the spirit of those presented in the literature, can be derived without appealing to variational principles. The method does not involve interpolation of the displacement field and there is no need for mesh refinement to improve the accuracy of the results. The formulation can be implemented as a classical displacement-based finite element method. Furthermore, it can be shown that this method can be interpreted algorithmically, as an optimal two-field (Hellinger-Reissner) variational principle, with minor subtleties.

Realistic Modelling of Composite Floor Slabs under Fire Conditions

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This paper describes two alternative strategies for modelling the response of composite floor slabs under fire conditions. The first strategy is based on a grillage approximation with 1D elasto-plastic elements, whereas the second strategy employs a more realistic representation based on a newly developed 2D flat shell element. In addition to the modelling of geometric and material nonlinearities, the new 2D shell element incorporates an essential capability of representing geometrically orthotropic slabs, achieved through modifying the Reissner-Mindlin hypothesis. Following a description of the aforementioned 1D and 2D element formulations, a comparative study is undertaken on a composite floor slab subject to ambient and fire loading conditions, where consideration is given to different edge restraint conditions. The study shows that grillage modelling can significantly overestimate the resistance of the com-

posite slab in the large displacement range, particularly in the absence of planar edge restraints. It is therefore suggested that realistic modelling of composite floor slabs using the newly developed 2D shell element is a most effective approach for an adequate response assessment under extreme loading conditions, such as due to fire.

Advanced Large Displacement Analysis of Composite Floor Slabs

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This paper presents a new method for the large displacement analysis of floor slabs. The proposed method employs a co-rotational framework, where considerable simplification is achieved in determining the orientation of the local element axes. The method is developed for 4-noded quadrilateral elements, where three translational and two rotational degrees of freedom are considered for each node in the global reference system. In this respect, further method simplification is achieved through the choice of two components of each of the nodal orientation vectors as rotational degrees of freedom. Although the proposed co-rotational method can be applied to a wide range of quadrilateral elements for flat slabs and even for curved shells, its application is illustrated herein with reference to a newly developed 4-noded quadrilateral element for flat composite slabs. Several examples are finally provided which demonstrate the applicability, accuracy and efficiency of the new method for large displacement analysis of floor slabs.

Response of a multi-connected plate to a point force

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The response of a plate to a unit transverse point force is usually referred to as the plate's influence function. This, in turn, is associated with the Green's function (matrix) of a certain boundary value problem for the equation (system) that simulates bending of the plate. As to applications in engineering science, the compactness and computability of Green's functions are certainly defining issues. Of all the existing representations of influence functions for thin Poisson-Kirchhoff plates of uniform flexiral rigidity, only a few are compact enough and directly suitable for immediate computer implementations. Among those is the classical influence function of a clamped circular plate.

A modified version of the eigenfunction expansion method has earlier been proposed in [2] for the construction of Green's functions to some elliptic boundary value problems that occur in applied mechanics. The version appears effective in various areas of continuum mechanics including the plate and shell theory. Based on the version, compact representations of influence functions have later been obtained for the simply and elastically supported circular plate.

To accurately compute the response of a multi-connected Poisson-Kirchhoff plate to a transverse concentrated force, an algorithm is developed, in this study, as based on the classical method of functional equations [1] that in recent publications is often referred to as the method of fundamental solutions [3]. The resolving potential representations are built with the aid of some existing Green's functions of the biharmonic equation for apropriate simply-connected regions. Since the observation and the source points of the resolving potentials occupy different sets, boundary value problems to be considered reduce to some functional (integral) equations with smooth kernels. It is shown that not only the deflection function but also the components of the stress tensor, which are generated by a point force, are accurately computable within this approach.

References:

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Application of Elasto-plastic theories in modeling the behavior of Reinforced Concrete Beams

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In this paper, the load displacement curves of reinforced concrete beams has been obtained using elasto-plastic theories and a finite element program. In the program, the beam is modeled in two different ways: a) By using a combination of separate elements for the concrete and the reinforcement, connected at the respective nodes. The elements are formulated using the plane stress theory for concrete, and one dimensional elements for the reinforcements; and b) By using a layered approach with each layer having it own material properties. The reinforcement is modeled as one of the layers. In order to take into account the effects of shear, the Timoshenko Beam Theory has been utilized in this approach. The results of the model have been compared to experimental results presented by Scordelis & Bresler. The comparison shows a good correlation between the results for a substantial portion of the curves. It is also noticed that the combination approach gives better results compared to the layered approach.

Direct Identification of Damage in Beam Structures Using Dead Load Measurements

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Changes in local flexibility caused by damage in a structure will case the internal forces of the structure to redistribute. A method for damage detection in beam structures is proposed that is based on measuring the change in redundant forces in the system due to dead load. Damage is modeled as a hinge plus a rotational spring that connects two sub-domains of a beam. By solving a nonlinear least squares problem, the damage location and severity can be obtained. Two example problems are presented, first, a single-span beam with partial restraint at each end, and second, a two-span continuous beam that is fixed at each end. Early laboratory tests conducted on a 10-foot aluminum beam show promising results.

Elasticity
June 4, 2002
14:30
Chair: Nimal Rajapakse University of British Columbia

SOME NEW RESULTS IN CONSTRUCTING OF 3-D GREEN'S MATRICES

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This article suggests a new method of constructing of Green's Matrices in 3D elasticity. The method is based on new integral representations for Green's matrices, their kernels being the Green's functions for incompressible influence elements. In general cases, the Green's matrices construction leads to the integral equations. For certain wide classes of mixed problems one theorem is presented, which expressed Green's matrices via integrals containing only Green's functions for Poissonís equation. As examples, two new boundary value problems for the octant and for semi-wedge are solved. The Green's matrices of these problems were obtained in elementary functions, that is very important for their numerical implementations. The method can be developed for regions of any orthogonal curvilinear co-ordinates, both in elastostatics and elastodynamics. As a result, the list of Greenís matrices can be essentially enlarged.

DISPERSIVE BEHAVIOR OF EXTENSIONAL WAVES IN PRE-STRESSED IMPERFECTLY BONDED INCOMPRESSIBLE LAYERED COMPOSITES

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Layered elastic composites are widely used in engineering applications. In general, the interface is assumed to be perfectly bonded for analysis and design. However, since in practice damage may occur due to loading or defects in the manufacturing process, the interface could be considered as imperfectly bonded. In this analysis, the effect of an imperfect interface on harmonic extensional wave propagation in a pre-stressed, symmetric layered composite is considered, where the layers consist of isotropic, incompressible, elastic materials. The shear spring type resistance model employed to simulate the imperfect interface can accommodate the extreme cases of perfect bonding and a sliding interface. The dispersion relation is obtained by formulating the incremental boundary-value problem and the use of the propagator matrix technique. Dispersion curves are presented in non-dimensional form and for the numerical examples where the material has to be prescribed either Mooney-Rivlin material or Varga material is assumed. The effect of the shear spring parameter on the dispersive behavior is clearly indicated.

3-D FRACTURE DYNAMICS WITH ALLOWANCE FOR CRACK EDGE CONTACT INTERACTION

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In this article the problem of the fracture dynamics with allowance for unilateral crack edge contact interaction with friction are presented. A variational formulation of the problem has been given. Boundary variational inequalities and boundary functionals have been derived. The boundary integral equations (BIE) method in frequency domains has been used as a solution for the elastodynamic problem for bodies with cracks. Singularities of the kernels in these integral equations have been studied. Regularization methods for the potentials with weakly singular, singular and hypersingular kernels have been considered. Several algorithms for the solution of the elastodynamic unilateral contact problem for bodies with cracks have been elaborated. The problem has been solved for plane harmonic tension-compression wave propagation in space with penny-shaped, elliptic and rectangular cracks with allowance for unilateral contact interaction of the crack edges. Dependence of the solution accuracy on the approximation of coordinates and time, and also of numbers of terms in the expansion of the stress-strain state components into Fourier series, has been investigated. Numerical results have also been presented.

Health Monitoring
June 4, 2002
16:15
Chair: Mohammad Noori North Carolina State University

Wavelet Transforms For System Identification And Associated Processing Concerns

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The time-frequency character of wavelet transforms allows increased flexibility ñ as both traditional time and frequency domain system identification approaches can be adapted to examine non-linear and non-stationary data. However, a number of additional processing concerns must be understood to fully exploit the power of the multi-resolution, dual-domain transform, particularly for the popular Morlet wavelet. Unfortunately, in prior applications of wavelet transforms for system identification, the implications of the aforementioned concerns were often negligible, as these studies considered mechanical systems characterized by higher frequency signals. It was the subsequent analysis of Civil Engineering structures that highlighted the need to understand more fully these processing concerns in order to insure successful system identification. This study identifies a number of these considerations that are a direct consequence of the waveletís multi-resolution character, including considerations for selection of wavelet central frequencies and strategies to resolve end effects errors. In total, this study serves as an overview of these processing considerations for Civil Engineering structures, helping to lessen the challenges associated with the transition into the time-frequency domain.

Experimental verification of Structured Neural Networks for SystemIdentification and Damage Detection

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Accurate spatial and temporal estimation of wind load on structures plays an important role in design and construction of buildings in coastal regions and open trains. The common approach to this problem is using codes and standards obtained from wind-tunnel tests on isolated structures. The use of artificial neural networks for finding specific patterns in data obtained from different wind-tunnel/filed tests has been reported in the literature. In this study localized radial basis functions neural networks are proposed and successfully used for estimation of wind load on a three-story shear building using state-space model of the structure.

Wavelet-based health monitoring of randomly excited structures

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This paper concerns the wavelet approach for structural health monitoring in which the wavelet transform is used as a detector for the singularities in the structural responses, which are caused by sudden changes in the system parameters. If the system is subject to broadband random excitation like earthquakes, however, the singularities could be caused by the excitation process, too. Therefore, some isolation method is needed to separate the singularities due to the excitation and the singularities due to the system's changes. First, the input-output correlation is investigated in the wavelet domain in order to explain how the singularities in the input propagate through the system and affect the output. The derived equation shows that the wavelet transform of the output at a small scale can be decomposed into a superposition of the wavelet transforms of the input and the components corresponding to the system's changes. A simple numerical example shows, using this equation, the influence of the input's randomness is successfully removed and the spike indicating the time of the system's change is extracted.

Time-varying modal identification by Monte Carlo filter

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In this paper, changing dynamic characteristics of time-varying systems, which are modeled in the form of modal decomposition, are identified using Monte Carlo filters. Extending the ordinary modal decomposition form to the time-varying case, a time-varying MDOF system is represented as a superposition of time-varying SDOF systems, which have time-varying mode shape vectors, time-varying natural frequencies and time-varying damping ratios. The system equations and the non-Gaussian evolution models of modal parameters are merged into an augmented state space model. The resultant state space model is nonlinear and non-Gaussian, so that the state vector needs to be identified using nonlinear non-Gaussian estimators. A Monte Carlo filter is applied, which is one of the most promising approach to the nonlinear non-Gaussian state estimation problems. Numerical simulations for a simple 2-DOF system show that the proposed identification scheme can track the abrupt change of the modal characteristics even in noisy circumstances.

Experimental Analysis - II

June 4, 2002
16:15
Chair: Laurence Jacobs Georgia Institute of Technology

PREMATURE FATIGUE FAILURE OF A HYDRAULIC EXCAVATOR AND THE RESULTING FATIGUE MONITORING SYSTEM

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One of the largest barge mounted hydraulic excavators in the world experienced substantial fatigue cracking during normal operation. Fatigue cracking in a similar, smaller, excavator went undetected long enough for cracks to grow to a critical length resulting in boom fracture. Because of previous cracking problems in the larger excavator, the owner of the excavators sought advice to mitigate the risks associated with the fatigue problem.

To better understand the excavator boom stresses, a visual examination was performed, strain gages were installed at critical locations and strains were measured during static tests and normal dredge operations. The results were used to develop a structural maintenance program, which included a permanent computer monitoring system. The computer system continuously monitored the boom strains and calculated the accumulated fatigue damage at each gage location using an approximation of the reservoir method. The system allowed engineers to determine when to schedule critical inspections and was equipped with an alarm to warn the operator when high stresses occurred during the dredge operation.

EXPERIMENTAL STUDY ON THE PRESSURE OF CEMENT BASED MATERIALS AGAINST FORMWORK

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An experimental study on the pressure of cement paste against formwork is reported. The object of the investigation was to experimentally determine the evolution of pore water and lateral pressures of cement paste until the form is removed. An original experimental device equipped with two special transducers was designed. These transducers make it possible to measure the pressure due to 1 and 0.05 meter depth of cement paste. Tests are carried out with four types of cement pastes, the water/cement (W/C) mass ratio ranging between 0.30 and 0.45. The results show that the kinetics of the pore water pressure and of lateral pressure are strongly affected by the W/C ratio and the level of stress to which the cement based materials is subjected. In all cases, initially we obtain levels of total and interstitial pressures equal to a theoretical hydrostatic pressure exerted by homogeneous fluid having the density of the mixture. Then, they decrease in a perfectly identical way toward zero. We record then interstitial depressions whose maximum value can reach tens of kPa.

CHARACTERIZATION OF INFILTRATION PHENOMENA IN THE VADOSE ZONE

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Dye tracer and visualization techniques have been widely used for describing water flow patterns in soils and particularly, for determining the volumetric water content in one and two dimensional laboratory experiments. The present study describes a three dimensional laboratory experiment (axi-symmetrical condition) using color image analysis for determining the spatial distribution of the water content. The infiltration of a dye (fluorescein) mixed with water is achieved under axi-symmetrical condition in a Plexiglas chamber filled with an initially wet sand. Both infiltration and drainage processes are visualized under blue light filter and recorded on videotape. The image analysis technique used for determining the saturation state is based on the use of a limited color palette which allows us to quantify the evolution of the saturation state in the sand. Simultaneously,nine tensiometers connected to a data acquisition system, are used to determine the negative water pressure in the sand. The measurements of the suction confirm the existence of a second wetting front (after the dye solution flow) due to the initial mobile water content in the sand.

ELASTIC FOUNDATION MODEL-BASED TDCB SPECIMEN FOR MODE-I FRACTURE OF BI-MATERIAL BONDED INTERFACES

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A modified beam theory is developed to predict compliance rate change of Tapered Double Cantilever Beam (TDCB) specimens for Mode-I fracture of hybrid interface bonds. The analytical model treats the uncracked region of TDCB specimen as a tapered beam on generalized elastic foundation, and the effect of crack tip deformation is incorporated in the formulation. A closed-form solution is obtained, in which the compliance and compliance rate change of TDCB specimens can be easily computed. The Tapered Beam on Elastic Foundation (TBEF) model is verified with finite element analyses and experimental calibration data for wood-wood and wood-composite bonded interfaces, and good agreements of compliance and compliance rate change are achieved for a specific range of crack length. The linearity of compliance crack-length relationship of the specimen is further validated and can be used with experimental measured critical fracture loads to determine the respective critical strain energy release rates or fracture toughness of interface bonds. This study indicates that the developed analytical model which accounts for the crack tip deformation can be efficiently and accurately used for compliance and compliance rate change predictions of TDCB specimens and reduce the experimental calibration effort, and the constant compliance rate change for linear-

slope TDCB specimens can be applied with confidence for Mode-I fracture tests of hybrid material interface bonds.

New Methods for Design and Evaluation of Crack Experiment

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In this paper, we propose two methods for experiment study of cracks on the basis of Rice's criterion (Rice, 1992). These methods are from the viewpoints of energy and stress, respectively, and are in good compliance with former theories and experiments. They can be used to design experiment, to interpret and predict experimental results. Analysis exhibits that a pure load mode is unfavorable to dislocation emission and dislocation emits more easily in the presence of other load component. Another finding is that dislocation emission direction is selective, that is, not any specified direction possesses the possibility of dislocation emission by adjusting load direction.

Reliability and Analysis of Stochastic Structural Systems

June 4, 2002
16:15
Chair: Erik Johnson **University of Southern California**

Development of Seismic Fragility Curves for Tall Buildings

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This study focuses on the reliability assessment of tall buildings subjected to earthquake loadings. The vulnerabilities of these tall structures are expressed with the development of fragility curves, which provide the probability of exceeding a prescribed level of damage for a wide range of ground motion intensities. The methodology to develop these curves follows a Monte Carlo simulation approach incorporating uncertainties in ground motion and in structural characteristics. Uncertainty of ground motion is introduced by modeling it as a stochastic process, with a prescribed power spectrum, duration and marginal probability distribution function. The effect of the assumption of Gaussianty and the role of duration of strong ground motion are also evaluated. Deviations from Gaussianity can have significant detrimental effects on the structural response. Duration can also have a significant effect on the response, as a nonlinear model involving stiffness degradation is used. Uncertainty of structural characteristics is introduced by modeling different material properties as random variables at critical locations of the structure.

Reliability Analysis of Multigirder Steel Bridges Designed by LRFD

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The reliability level of steel girder bridges designed by AASHTO LRFD Strength I limit state for flexure is examined. The reliability analysis is based on the stochastic finite element method (SFEM). The bridges are modeled as grillage beam systems. Basic design variables include dead and live loads, as well as sectional and material properties. Steel girder bridges are designed in accordance with AASHTO LRFD Strength I limit state for flexure of AASHTO LRFD Specifications (1998). Bridge span varies from 30 ft (9.14 m) to 120 ft (36.58 m) and girder spacing varies from 4 ft (1.22 m) to 12 ft (3.66 m). The reliability level corresponding to load modifier of 0.90, 0.95, 1.0, 1.05, and 1.1 is investigated using the SFEM. The results obtained in this study indicate that the reliability index is very sensitive to the lateral distribution of live load. Due to overestimating the lateral distribution of live load, the AASHTO LRFD Specifications for Strength I limit state for flexure results in a conservative design of steel girder bridges.

Efficient Reliability Methods for Automotive Structural Systems

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This paper proposes an efficient method for the reliability analysis of a vehicle body-door subsystem with respect to one of the important quality issues -- the door closing energy. The developed method combines optimization-based and simulation-based approaches. The proposed approach consists of two major parts. In the first part, an optimization-based method is used to search for the most probable point (MPP) on the limit state. This is achieved by using an adaptive response surface constructed through an optimal symmetric Latin hypercube design of experiments and a trust region update approach. In the second part, a multi-modal adaptive importance sampling method improves the reliability estimate, using the MPP information from the first part as the starting point. A generalized framework for reliability estimation is then established for problems with a large number of random variables and implicit limit states.

Differential Settlements of Structures Founded on Heterogeneous Soils

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The paper studies the problem of interaction of a structure with spatially varying soil properties. In particular, the problem of the interaction of a two-span continuous beam founded on a heterogeneous soil is solved analytically. The geometrical and stiffness characteristics of the structure interact strongly with the spatial properties of the heterogeneous soil. For a certain value of the correlation distance, a feature of the heterogeneous soil formation, the uncertainty and the risk of high values, not predicted with deterministic models, in estimating differential settlements and forces (bending moments, shear forces, etc.) on the structure becomes maximum. The analytical solution uses a series expansion of the soil properties relative to those of the structure. The error in the solution, due to the truncation of the series expansion, is estimated by relevant numerical results.

Recent Advances in Materials Characterization and Modeling of Pavement Systems IV

June 4, 2002
16:15
Chair: Eyad Masad **Washington State University**
Co-Chair: Thomas Papagiannakis **Washington Statre University**

Microstructural Analysis of the Viscoelastic Behavior of Asphalt Concretes

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Asphalt concretes are composite materials consisting of interspersed aggregates, asphalt binder and air voids. Their constitutive behavior depends largely on the interaction of the aggregates and the binder, which have drastically different stiffnesses. This behavior is further complicated by the non-linear viscoelastic behavior of the binder. The paper at hand presents a fundamental methodology for describing the constitutive behavior of asphalt concretes. It involves three main steps. The first step involves the development of mechanistic binder models from rheological measurements and their implementation into stress-strain relationships suitable for FEM modeling. Binder non-linearity is treated in a piece-wise linear fashion, whereby the binder model constants are assigned as a function of strain level. The second step involves capturing the microstructure of asphalt concretes trough imaging techniques and processing the images to translate them into FEM grids. The third step involves verification of these asphalt concrete models by comparing predictions of shear modulus and phase angle to the properties measured in the laboratory using a Simple Shear Test (SST).

Continuum Damage Model for Permanent Deformation of Asphalt Mixes

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Permanent deformation is one of the most significant distresses that cause severe damage in asphalt pavements. It is caused by high traffic loads associated with high field temperatures. It is believed that permanent deformation develops at small rate and accelerates with the initiation of microcracks in asphalt pavements. A viscoplastic continuum damage model is developed to describe the

permanent deformation of asphalt pavements. The model is based on Perzyna's formulation with Ducker-Prager yield function modified to account for the material inherent and induced anisotropy. The material anisotropy parameter is measured through microstructural analysis of two-dimensional sections of asphalt mixes. The change in the material anisotropy parameter during loading is shown to be a function of aggregate properties. A damage parameter is included in the model in order to quantify the development of microcracks. Experimental procedures are outlined to determine the model's parameters. The model is used to predict the creep response of several mixes subjected to uniaxial loading.

A Porous Elastoplastic Compaction Model for Asphalt Mixtures with Parameter Estimation Algorithm

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Estimation of compaction energy to reach a certain field density is essential when predicting construction costs for asphalt concrete pavements. A compaction model can be used to predict the required compaction energy and optimize the design requirements for field conditions. A mechanical model is developed to simulate laboratory compaction of asphalt mixture specimens. Gurson-Tvergaard porous material model with elastoplastic matrix is assumed to describe compaction of an uniaxial cylindrical specimen under a prescribed compaction pressure and cyclic shear strain induced by the Superpave Gyratory Compactor. Plastic strains are integrated from an incremental elastoplastic constitutive equation. Three model constants are estimated to determine measured deflections by means of Levenberg-Marquardt parameter estimation algorithm. Statistical correlations are constructed to evaluate effects of mixture properties on the estimated model constants. The proposed constitutive model accurately predicts the volume change of specimens undergoing continuous gyratory compaction. Estimated model constants proved strong correlations with mixture volumetric properties.

Viscoplasticity Modeling of Asphalt Concrete

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A constitutive model based on an extended form of the Schapery continuum damage formulation (Ha and Schapery, 1998; Schapery, 1999) is currently being evaluated and developed as a comprehensive material model for asphalt concrete. This model considers the viscoelastic, damage, and viscoplastic components of asphalt concrete behavior over the full range conditions of interest for the mechanistic prediction of flexible pavement distresses. The focus of the present paper is limited to the viscoplastic response component at intermediate and high temperatures. The results confirm earlier findings (Schwartz et al., 2002) that asphalt concrete in compression is a thermorheologically simple material well into the large strain viscoplastic regime at elevated temperature. The study demonstrates that the proposed viscoplastic model component provides a good representation of the viscoplastic response of asphalt concrete in uniaxial unconfined compression. Given the validity of time-temperature superposition for viscoplastic response, the viscoplastic material parameters can be calibrated from a limited number of uniform time and uniform load creep and recovery tests. Typical viscoplastic material parameters are derived for a representative asphalt concrete mixture.

Multi-Scale Modeling of Materials - II
June 4, 2002
16:15
Chair: George Voyiadjis Louisiana State University
Co-Chair: Rami Haj-Ali Georgia Institute of Technology

THE INFLUENCE OF POROSITY ON FRACTURE CHARACTERICTICS IN MORTAR STRUCTURES.

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The purpose of this paper is to quantify the influence of microstructural degradations, namely a variation of porosity on the mechanical properties of heterogeneous quasi-brittle materials (mortar, concrete). The study deals with this problem on a model mortar material. The porosity is controlled by the introduction of inclusions of weak mechanical characteristics (polystyrene) in a matrix having a reduced porosity. Mass densities ranging from 2.3 to 1.4 can be achieved with a good spatial distribution of the inclusions. Experimental investigation on this material in compression, bending, emission acoustic measurements and their analysis are detailed. The experiments show that the elastic modulus, the compressive strength and the tensile strength decrease with the mass density. The brittleness of the structures as well as the fracture energy (obtained by applying Bazant's size effect law) are decreased too. Comparaison with leached mortar beams are also presented

EFFECT OF MORPHOLOGY ON THE MECHANICAL BEHAVIOR OF HETEROGENEOUS NONISOTROPIC MICROBEAMS

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In many microstructures, the size of the subelement (grain, chain bundles, fillers), is not negligible as compared to the overall scale (thickness, length) and the random morphology is expected to cause an inherent statistical dispersion of the structural response, and even affect the average structural behavior. These features have a direct influence on both the design and reliability of microsystem performance. In this work, we study analytically the effects of various microstructure morphology characteristics like grain size, shape, location, module and statistical correlations on the generalized displacements of statically determinate beams. The analysis includes shear deformation effects, nonisotropic material tension-shear coupling, and their relation to structural coupling, like tensile-bending-torsion deformations. Generalizing previous studies of isotropic heterogeneity, the beams in this analysis are made of random nonisotropic elastic elements, including heterogeneity inside the cross section. Although the beams are externally determinate, the nonisotropic behavior imposes additional internal compatibility (indeterminacy) degrees of freedom, which cannot be neglected.

HOMOGENEOUS OPTIMAL DESIGN OF A FINITE ELASTIC STRIP SUBJECTED TO TRANSIENT LOADING

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We investigate wave propagation in a finite elastic strip subjected to free-fixed boundary conditions. Our goal is to find a design of functionally graded materials (FGMs) that provides the smallest amplitude of stress during the wave propagation along the strip. We are able to show that within a class of FGMs, the homogeneous design provides the smallest stress amplitude. In the special case of two layers, we identify the class of all optimal designs and the time intervals when the stress reaches its peak values. The benefit of this work is that it provides general practical observations for manufacturing of multilayered lightweight armor. The results obtained here are used to validate a purely numerical scheme using finite elements.

DETAILED 3D SIMULATION OF BOLTED PULTRUDED COMPOSITE CONNECTIONS

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Rami Haj-Ali *Georgia Institute of Technology*

An experimental and analyitical study is carried out to investigate the response of bolted pultruded composite connections using nonlinear material and detailed 3D structural finite element (FE) models. A new 3D micromechanical model for the fiber reinforced plastic (FRP) pultruded composite material is used to generate the effective nonlinear response at each Gaussian material point within the 3D FE model. The constitutive model is calibrated by specifying the fiber and matrix elastic and nonlinear parameters. The fiber material is linear isotropic while the matrix is nonlinear plastic. The material parameters are determined from coupons taken from the pultruded beams. The effect of slip between the components and the bolts on the overall response of the connection is included by explicitly recognizing contact and friction between all the components. Pull tests are also performed in order to compare the prediction ability of the overall combined material and structural framework.

MICRO-MECHANICS IN SOILS AND SHEAR BANDS

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Shear bands cause localized large shear strains. At such strains, the strain rate in the shear band is much higher than that outside the band. This unique phenomenon brings out some uncommon micro-mechanical behaviors of the material. They are mainly rate dependency, rotation of grains, grain interaction, and soil-pore fluid interaction. These micro-mechanical behaviors are typically considered separately. However, the real behavior of the natural soil is a kind of mixed and coupled output of all those factors. This study presents the coupled micro-mechanical behavior of soils considering all four factors for the geo-materials. Rate dependency is incor-

porated through visco-plascicticity, rotation of grains is incorporated through the plastic spin, grain interaction is incorporated by the use of the gradient theory, and soil-pore fluid interaction is incorporated by the coupled theory of mixtures.

A Micromechanical Framework for Nonlinear Viscoelastic Analysis of Pultruded Composites

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This study introduces a new three-dimensional (3D) micromechanical modeling approach for the nonlinear viscoelastic response of pultruded composites. The pultruded fiber reinforced plastic (FRP) composites under consideration include combinations of roving and continuous filament mat (CFM) reinforcements. The proposed framework can be easily integrated with a finite element (FE) software for the analysis of pultruded structures. The proposed 3D framework consists of three nested and independent models for the roving layers, CFM layers, and a sublaminate model used to generate the overall 3D effective continuum response. The roving layer consists of unidirectional fibers embedded in the matrix; it is idealized as doubly periodic array of fiber with rectangular cross sections. The CFM layer consists of long, swirl, and in-plane randomly oriented filaments. This system is idealized using the average response of two alternating layers with limiting fiber orientations. A 3D nonlinear multi-axial viscoelastic constitutive behavior is formulated using Schapery's integral form. This model is implemented only for the isotropic matrix at the lower level of the nested modeling framework. The fiber medium is considered as transversely isotropic and linear elastic. Stress-update algorithms are needed at all levels of the framework in order to satisfy the nonlinear constitutive and micromechanical relations between the average stresses and strains in the subcells. New iterative numerical algorithms with predictor-corrector type steps are derived to achieve the correct stress and strain states. Experimental tests are performed to calibrate and predict the nonlinear viscoelastic response. These tests include creep and recovery at different loading levels.

Fluids - Modeling of Natural Hazards

June 4, 2002
16:15
Chair: Michelle Teng University of Hawaii at Manoa
Co-Chair: Hayley Shen Clarkson University

Pollutant dispersion near a low hill under a turbulent wind

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A methodology is developed to study the pollutant concentration distribution in a turbulent shear flow over a two dimensional hill with small slope. As in a typical boundary layer problem, the flow domain is divided into an inner and an outer region. With the velocities obtained from the Navier-Stokes and continuity equations, the diffusion equation for the pollutant concentration is readily solved. A variational method with adjustments to the streamline coordinate system is used in order to obtain an accurate solution of the concentration in the downwind region. Closed form analytical solutions of the pollutant dispersion patterns and concentration distributions are determined. It is shown that when there is an upwind source located in the outer region, the concentrations decrease with distance along the upwind side of the hill and tend to be a constant rapidly near the hilltop. This diffusion model can be applied to any realistic flow field once the streamlines can be specified through the velocities.

Multiple Solutions Of Smoke Layers In Building Fires And Natural Ventilation

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This paper studies the buoyancy-driven flow in a building with three displaced openings for building fires and natural ventilation. These solutions are used to analyze the effect of the vertical location and the area of middle opening upon the thickness of smoke layer (stratification level) and the performance of natural ventilation. Three possible flow patterns in the building and two possible flow directions at the middle opening are first identified for all possible conditions in the building and the analysis is based on each condition. This paper focuses on the analysis of the smoke layer height in building fires. The performance of buoyancy-driven natural ventilation is also investigated. Interestingly, multiple solutions of the heights of smoke layers and the ventilation flow rates are found for a certain range of geometry parameters.

A Model For Urban Flood Disaster Prevention

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We present a model that can predict flood wave propagation on city streets with enough resolution that individual buildings can be resolved in the computational grid. Storm sewers are incorporated as

distributed point sinks. Basement flooding is also included as in-line storage. Automobiles are handled as prolate spheroids and are allowed to move and rotate according to the local flow field. The mathematical basis for the simulation is based on a two-dimensional shallow-water scheme capable of handling wet and dry cells and arbitrary topography. Debris transport is accomplished by a Lagrangian technique and post-processing of the velocity and vorticity fields after each time step. The shallow-water equations are solved by a finite-volume scheme while the debris stransport is carried out by solution of a large system of ordinary differential equations.

CONTAMINANT TRANSPORT IN THE SUBSURFACE AT THE PORE-MICROPORE INTERFACE

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The field of contaminant transport and remediation has achieved a great deal of advancements in recent years. However, practice has shown that remediation efforts are often plagued by extremely long breakthrough curve tails, an indication of almost infinite time requirements for the remediation efforts to bring the level of contaminants below the regulatory standards. It has been postulated that this is due to the effect of micropores. This paper proposes a method to forecast effects of micropores on contaminant transport at both macroscopic and microscopic levels and to establish a link between the two different approaches.

NUMERICAL SIMULATION OF STORM SURGE GENERATED BY HURRICANE IWA IN HAWAII

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The ADCIRC finite element model was applied to solve the depth-averaged shallow water equations to simulate storm surge generated by the 1982 Hurricane Iwa in Hawaii. This study is a follow-up to the recent study by Gica et al. (2001) where the storm surge generated by the 1992 Hurricane Iniki in Hawaii was simulated. The objective of the present study is to further investigate the effects of barometric pressure and wind stress in generating storm surge in the Pacific insular environment in the absence of continental shelves. Our simulated results were compared with the surge height recorded by a tidal gage in Nawiliwili Bay of Kaua'i Island in Hawaii. The results agreed well with the recorded data and this verifies our simulation. In addition, our results further confirmed that, for the Hawaiian coastal waters where water depth increases rapidly offshore, the barometric pressure was the dominant forcing in generating storm surge while the effect of wind stress was negligible.

Computational Mechanics - Computational Dynamics

June 4, 2002
16:15
Chair: Si-Hwan Park University of Hawaii at Manoa

THE USE OF RITZ VECTORS IN A COMPARATIVE STUDY FOR VIBRATORY ANALYSIS OF DAM-FOUNDATION SYSTEMS

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Finite element modelling of complex systems for the purpose of studying the effects of soil structure interaction usually lead to a large number of degrees of freedom. The change of basis from the physical coordinates of the finite element model to a generalized coordinate system may thus become unavoidable. The present paper is concerned with a numerical investigation of free vibration behaviour of soil-dam systems using two generalized coordinate reduction procedures. Two soil-dam dynamic interaction models and two criteria for the evaluation of the rate of convergence of the coordinate reduction procedures are used for that purpose. The results obtained show clearly that the load dependent Ritz vectors provide a more performing mathematical basis than that of the exact eigenvectors in terms of accuracy and convergence. Furthermore, an empirical rule is proposed in order to accurately estimate the number of the first P eigenmodes of the complete system.

A DISCONTINUOUS GALERKIN METHOD FOR MODELING TRANSIENT WAVE PROPAGATION IN UNBOUNDED LAYERED MEDIA

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An absorbing boundary condition based on the discontinuous Galerkin method is applied to transient analysis of elastic wave propagation in unbounded layered media. The boundary condition is exact in the finite-element sense, and the associated computational cost is an order of magnitude lower than for conditions based on Green functions. Furthermore, an implicit time-stepping scheme in conjunction with this boundary condition appears to lead to an unconditionally stable transient analysis procedure. Problems of foundation dynamics involving horizontally layered media are considered to demonstrate the performance of the condition.

Dynamic Response Of A Long, Discretely Supported Beam

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This paper describes a computational model of a long beam resting on discretely-located flexible supports. The model is suitable for assessing certain types of vibrations in building floors, and for various aerospace and other applications. The model is efficient and yields a numerically exact solution when the joist spacing is small (i.e., continuous). The beam configuration is completely described using a fundamental frequency, a characteristic length, and the distribution of the joist stiffnesses, as well as two damping ratios and a dimensionless rotatory inertia parameter. The model is applied to vibration serviceability behavior of floors. When a floor plate is geometrically regular and supported by identical, equally spaced joists or beams, vibration can propagate in the direction transverse to the joists. Such "vibration transmission" can lead to the perception of poor behavior. Two response regimes are identified for the floor system, determined by a characteristic length and the relative distribution of joist stiffnesses. The practice of varying the stiffness distribution of the supporting joists as a vibration mitigation strategy is also assessed.

Time-continuous cohesive interface finite elements in explicit dynamics

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Cohesive zone modeling is one of the most widely used techniques for modeling fracture of brittle and quasibrittle materials. It is predicated on the fact that in quasibrittle fracture, a process zone forms ahead of the crack front, in which material softening or decohesion takes place. Cohesive zone modeling idealizes the process zone with a weak interface of thickness zero.

Decohesion is usually modeled by a relationship between the traction across the interface and the relative displacement between the two faces of the interface pointwise. We identify two pathologies with initially rigid traction-displacement cohesive relationships used in explicit dynamics in the previous literature, namely, division by zero and nonconvergence in time. These problems arise partly from the attempt to extend uniaxial traction-displacement relationships to multiaxial loading. We also argue that any attempt to fix these pathologies in a functional traction-displacement setting leads to two new pathologies, namely, encoding and traction locking. We exhibit an example of a law that fixes division by zero and time discontinuity but still suffers from encoding and traction locking.

Wednesday - June 5th, 2002
Session Abstracts

Nonlinear Dynamics
June 5, 2002
9:45
Chair: Ahsan Kareem University of Notre Dame

Study of the Joint Opening Effects on Dynamic Response Properties of an Existing Arch Dam

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This paper presents the experimental and finite element studies on the effect of discontinuous behavior at the vertical contraction joints on the dynamic response of the existing arch dam. The variation of the resonant frequencies as a function of the reservoir water level is investigated. The measured dynamic properties are compared to predictions from finite element models, for which the nonlinear behavior due to the discontinuities of the vertical contraction joints are both included and neglected. Based on both test and computed results, it is found that the arch action due to higher hydrostatic pressure under almost full reservoir condition, tighten the contraction joints, and caused the overall dam body to behave more like as a continuous structure. According to the computed results, it is concluded that the contraction joints open and close during the shaking, under less than 75 per cent of the full reservoir condition, and such a varying tightness of the contraction joints really did affect the resonant frequencies of the fundamental vibrational mode.

An Improvement in Nonlinear Analysis

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When studying the nonlinear behavior of engineering structures, incremental iterative analysis is indispensable. According to the nature of iterative computations their results can never be exact. To control the additional errors, using nonlinearity tolerances is essential. However, because of the limited computers' capabilities small tolerances can not always be applied. Hence almost in all of the well-known analysis softwares, the maximum number of iterations is bounded to an additional parameter. This parameter is generally selected merely by computational practice, and thus may lead to low accuracy if the selected values are very small, or divergence of iterations if the selected values are high. To overcome this problem, a technique for automatically controlling the number of iterations is presented in this paper. Based on the number of significant digits that can be considered by computers, this technique not only omits one of the analysis parameters, but also ensures that if computer capabilities allow, nonlinearity residual errors would be as small as requested. The improvement is verified by applying the suggested technique to a nonlinear dynamic problem.

A Phenomenological Model of a Bolted Joint

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Mechanical joints can have a significant effect upon structural response, causing localized nonlinear stiffness and damping changes. As many structures are assemblies, incorporating the effects of joints is necessary to produce predictive finite element models. In this paper, we present an adjusted Iwan beam element (AIBE) for non-linear dynamic response analysis of beam structures containing joints. The adjusted Iwan model consists of a combination of springs and frictional sliders that exhibits nonlinear, hysteretic behavior due to the stick-slip behavior of the sliders. The beam element consists of two adjusted Iwan models arranged to correspond to the usual arrangement of degrees-of-freedom, transverse displacement and rotation at each of the two nodes. The resulting element requires six parameters, which need to be initially determined. The parameter identification constitutes an inverse problem that will be discussed in a later paper. By using AIBE, a nonlinear dynamic response analysis is implemented for a beam structure with a bolted joint. The effectiveness of AIBE is assessed by comparing the numerical solution with experimental measurement.

Characterization of an Essentially Nonlinear 2-DOF Vibration Test Apparatus

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As part of a study of energy pumping in nonlinear multi-degree-of-freedom systems, a 2-DOF test rig comprising a linear, SDOF primary system weakly coupled to a nonlinear energy sink (NES) has been built to operate on an existing bench-top air track. The static and dynamic behavior of the various components and of the system as a whole has been measured to facilitate comparison of experimental and simulated responses. Several of the subsystems are linear and have been characterized by conventional modal analysis, for example by hammer tests, but the proper functioning of the NES depends upon the generation of an essentially nonlinear restoring force; the design and calibration of the cubic-hardening

nonlinear spring used for this purpose are discussed in detail. This paper presents the nominal and measured values of all the system parameters.

Experimental Verification of the Performance of a Nonlinear Energy Sink

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The phenomenon of energy pumping, in which vibratory energy is transferred irreversibly within a nonlinear, multi-degree-of-freedom system with the goal of reducing the transient response of the primary substructure, has recently been investigated analytically and through numerical simulations. This paper describes the first efforts to demonstrate energy pumping in the laboratory, using a 2-DOF test rig comprising a linear, SDOF primary system weakly coupled to a nonlinear energy sink (NES). Following a brief review of the parameters of the apparatus, we focus on the simulated and measured responses of the primary and sink subsystems.

Symposium on Computational Inelasticity - Soil-Structure Interaction

June 5, 2002
9:45
Chair: Majid Manzari The George Washington University

Examination of models for time dependent behavior of soils

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Various constitutive relations have been proposed to represent time-dependent deformation behavior of soils. They can be divided into (1) Empirical models (2) Rheological models and (3) General stress-strain time models. In this paper special emphasis is placed on elasto-viscoplastic models that combine inviscid elastic and time dependent plastic behavior. Elasto-viscoplastic models belong to the category General stress-strain-time models and they can mainly be divided into (1) Models based on the concept of overstress and (2) Models based on the concept of non-stationary flow surface theory. A short presentation of the theories is given. Furthermore, the structure of the theories is described and compared. Finally, it is concluded that existing models in principle are able to model clay, whereas time effects for sand cannot be described by means of existing models.

Observed Time Dependent Behavior Of Soils

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Time-dependent behavior of soils has been investigated extensively through one-dimensional and triaxial test conditions. The phenomena associated with time effects in soils are creep, relaxation, strain rate effects and accumulated effects. Most of the observations presented in the literature have focused on the determination of time-dependent behavior of clayey soils, whereas the reported experimental studies of granular materials are few. Nevertheless, time effects in granular materials such as sand are not negligible. This paper presents a concise review of results from triaxial tests on sand and clay. The purpose of the tests was to examine strain rate effects and accumulated effects. From the tests it can be concluded that clay to some extent shows isotach behavior whereas sand exhibits non-isotach behavior. This fact has major importance in connection with modeling of sand and clayey soils.

NONLINEAR DYNAMIC SINGLE PILE-SOIL INTERACTION ANALYSIS

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Nonlinearities due to both strain-induced and pore water pressure induced softening are important aspects in dynamic pile-soil interaction. While the model of beam on Winkler foundation is widely used for its analysis, the above nonlinearities have not yet been satisfactorily represented in such models. This paper presents a method to take into account of these effects, in which the soil response is expressed in terms of multiple steady state modal shape functions. By using adequate number of these steady-state shape functions, the time-domain response is captured. The soil (i.e., exterior) domain is divided into a number of sub regions in performing the integrations involved in evaluating the stiffness and damping matrices, thereby, accounting for the spatial variation of these properties. An approximate pore water pressure model is developed and used in calculating the cyclic pore water pressure.

DETAILED MODELING OF FACING FOR REINFORCED SOIL WALLS

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Traditionally, the construction of mechanically reinforced soil structures has involved the use of free-draining granular backfill soil. In recent years, financial considerations have led to an increased interest in using cohesive backfill soil. The numerical simulation of reinforced soil structures with cohesive backfill is complicated by the fact that now not only the reinforcement, but also the backfill soil exhibits time-dependent response.

Recently, a laboratory instrumented geosynthetically reinforced wall with cohesive backfill (Wu, 1992) was modeled numerically and analyzed using the finite element method (Dechasakulsom, 2000). A series of parametric studies was performed that showed the importance of properly accounting for the time-dependent response of the backfill soil.

The mathematical models created for the aforementioned studies combined several robust methodologies. In particular, the cohesive backfill soil was characterized using the elastoplastic-viscoplastic bounding surface constitutive model (Kaliakin and Dafalias, 1990). The soil-reinforcement and soil-facing interfaces were modeled using a kinematically consistent zero-thickness interface element (Kaliakin and Li, 1995) that has been shown to overcome the deficiencies of other elements of the same type. Finally, the response of the reinforcement was represented by constitutive models of varying complexity, ranging from time-independent elastoplastic ones to a simple model that accounts for both creep and relaxation of the reinforcement. The latter model was calibrated using the results of previous creep and relaxation experiments (Leshchinsky et al., 1997).

One of the areas identified as requiring further study was the simulation of the wall facing. In particular, it was unclear how important the detailed modeling of the structural elements comprising the facing was to the performance of the mathematical models of the reinforced wall under consideration. The proposed paper will describe the results of subsequent analyses in which the wall facing was modeled with varying degrees of complexity.

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Aerospace General Topics
June 5, 2002
9:45
Chair: Ramesh Malla University of Connecticut
Co-Chair: Gautam Dasgupta Columbia University

Probabilistic Creep-Fatigue Life Prediction of Aircraft Engine Blades

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Fatigue and creep are two major failure mechanisms for aircraft engine structures operating at high temperature. Fatigue is one of the principal failure mechanisms of structures under cyclic loading. Cyclic loading causes fatigue damage in an accumulative manner that may lead to fracture. Creep is another major failure mechanism for structures operating at high temperature under sustained load. The interaction between different fatigue loading levels may have large impact on the fatigue life. Also, the interaction between creep and fatigue has been found to have significant effect on the creep-fatigue life prediction.

Different models have been developed in the past for creep and fatigue damage evaluation and life prediction. The damage is assumed to be irreversible, and continuum damage mechanics is used to evaluate the damage evolution in the materials under fatigue and creep loading. Crack is assumed to initiate when the accumulated damage reaches the critical value. Most of these models are deterministic and do not include the interaction effect between creep and fatigue during the procedure of damage evaluation. Some probabilistic models used creep life under constant stress level and fatigue life under constant stress amplitude as random variables. However, these are secondary variables. It is preferable that the basic uncertainties in material and load be addressed directly in life prediction and reliability analysis.

This paper develops a probabilistic approach to incorporate the basic source of uncertainties in creep-fatigue life prediction. Stress histories are simulated to include the uncertainties in loading to model the varying stress levels in practical problems. Uncertainties in material properties are introduced in the fatigue life calculation for each stress level and propagated through the procedure of damage evaluation. These uncertainties are propagated through a continuum damage mechanics model to simulate the uncertainty in creep-fatigue life. The interaction effect on fatigue between different loading levels, and the interaction effect between creep and fatigue are included. Creep and fatigue damage are evaluated simultaneously according to the simulated loading histories. This also helps to consider the loading sequence effect. Different mean stress correction methods are investigated. The effect of mean stress on the creep-fatigue life is studied with numerical examples.

Life prediction of a generic engine blade is illustrated with proposed method. The varying stress cycles due to pilot maneuvers produce fatigue damage, and the holding times cause creep damage in the component. Due to the uncertainties in loading and material properties, predicted crack initiation occurs at different times. The corresponding creep-fatigue life is a random variable. The PDF of crack initiation life is computed using the proposed method. There exists scatter in the predicted fatigue life due to the uncertainties in the material properties and loading. The predicted fatigue life appears to follow a lognormal distribution.

Three Node Curved Finite Elements

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Finite element discretization of an arbitrary two-dimensional region with curved boundary segments is considered. The interior is covered with convex polygons of n-sides, vide ref.[1]. In thermo-mechanical problems, the finite element shape functions for the interior elements should be able to reproduce the constant temperature and strain fields exactly in regions with piecewise linear boundary segments, i.e., each such element must pass the patch test.

In order to attain higher precision, the curved boundary is not approximated with piecewise linear segments. When the interior is covered with Wachspress polygonal elements, curved elements are merely "glued" only on the boundary of convex n-gons. Such curved elements (since they are restricted only to the boundary) do not enter in any arbitrary patch hence are exempt from the reproduction of linear displacement fields associated with constant strains.

[1] Wachspress, E. L.: A Rational Finite Element Basis, Academic Press, NY, 1975.

Performance of the Carbon Fiber Reinforced Polymer (CFRP) Bonded to Concrete

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Linear elastic stress analysis was used to investigate the state of stress in double lap-strap test (DLST) specimens. The DLST specimens are constructed by bonding carbon fiber reinforced polymer (CFRP) to concrete prisms with epoxy adhesive. FEM was performed to investigate the effects of the CFRP thickness, overlap length, and temperature on the performance of the graphite/epoxy composite/concrete interface. Results indicate that the shear modulus has the greatest influence on the overall behavior of the double lap-strap specimen. Analysis of the CFRP to concrete interface showed that the resulting stress distribution is dependent on CFRP stiffness and CFRP thickness. Temperature dependent Critical Strain Energy Release Rate Gcr of the interface is obtained using crack closer model of the delaminating composite and experimental results.

Four-noded Triangular Finite Elements

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The limits and extents of the isoparametric formulation for a four-noded finite element are derived by transforming the parametrized shape function from eta-zeta to x-y coordinates. This analytic inversion results in a quadratic equation. The coefficients of this equation dictate whether the form of the shape function is a polynomial, a rational polynomial or an expression containing a square root. Furthermore, in x-y coordinates the C0 shape function for a triangular element with a mid-side node can be derived. Consequently, this study extends the class of elements for which closed form shape functions can be constructed. In 1975 E. L. Wachspress introduced a rational polynomial formulation for finite elements which applies consistently to any convex n-sided polygon; it does not apply to elements with a mid-side node. Combining these results, convergent shape functions and consistent strain matrices can be formulated for all non-concave quadrilaterals. The associated energy density function can be integrated exactly using the divergence theorem.

Experimental And Analytical Studies Of Full-scale Amberlite Water De-ionizing Bed For Space Applications

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A critical component in the oxygen generation assembly for long term human habitation system in space is the de-ionizing (DI) bed - a packed bed of ion-exchange resin beads - that purifies water by removing ions (dissolved salts and organic impurities) from reclaimed water. The DI bed shrinks during the course of its operation. For the bed to work satisfactorily in microgravity environment, it is required that the bed is kept compressed and this is done with the aid of a compressed spring mechanism placed at one end. The objective of this current research work is to study the behavior of the full-scale DI bed experimentally in order to gain an understanding of how a force applied at one end is transmitted along the length of the bed and to determine an analytical model that fits experimentally obtained data. A series of experimental investigations was carried out in several lengths of full-scale DI bed made of Amberlite IRN-78 ion exchange resin to determine load- deflection characteristics of the bed, including the friction force characteristics between the resin bed and the inner wall of the housing cylinder. Stress behaviors (creep and stress relaxation), possibly through particle rearrangement, were observed in the DI bed. It was also observed that the friction between the DI medium and the wall of housing cylinder plays crucial role in the transmission of load from one end of the DI bed to the other. An analytical model similar to that used for determining stresses in silos, incorporating deformation effects and density changes, was developed and found to fit experimental data reasonably well. An equation normally used for stress relaxation in soils was found to fit the stress relaxation curves that were obtained experimentally.

Experimental Analysis III
June 5, 2002
9:45
Chair: Laurence Jacobs **Georgia Institute of Technology**

Investigation On Ice Forces On Fixed Platform Structure: From The In-situ Measured Data On JZ20-2-1 Platform In China Bohai Sea

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The design ice force formulas are assessed and dynamic ice force modes are identified by in-situ measured data on the JZ20-2-1 platform located in Liaodong Bay of the China Bohai Sea. Two commonly used methods for determining design ice forces, namely the Korzhavin-Afanasev and Schawz formulas, are analyzed and compared to the measured ice forces data on the leg of the platform. These two formulas may underestimate design ice force for ice thickness below 20 cm, while giving reasonable predictions for 20-30 cm ice thickness. The modified Schawz formula for the Bohai structures produces reasonable results for thin ice and may largely overestimates forces for thick ice. The dynamic ice force modes and ice failure patterns are identified. Self-excited ice forces are found happen to this structure by investigating the characteristics of ice force in frequency domain. The frequency of occurrence of each ice force mode and ice failure pattern are roughly estimated. For this structure, the dominant ice force mode is forced mode, and the main failure pattern of ice is crushing.

Experimental Technique And Theoretical Modeling To Study Of Contact Load Ratio - Friction Function

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This paper considers the mechanical interaction due to surface roughness and examines the surface theories using the classical definition of coefficient of friction: the tangential-to-normal load ratio. The aforementioned postulation for maximum static friction is used to experimentally evaluate the contact models. For this purpose a pin-on-disk test apparatus is employed with the capability of measuring tangential and normal forces for a frictional contact. The tests involve pairs of disk and specimen, i.e. Steel-on-Steel and Aluminum-on-Aluminum contacts. In each case profilometer measurements are performed on the disk and the Greenwood and Williamson parameters are determined. Using the parameters the theoretical estimates of normal and tangential loads are obtained. The theoretical values of tangential-to-normal contact force ratios are compared with those obtained from measurements for various applied normal loads. The tests utilizing a pin-on-disk apparatus showed that reasonable agreements between experimentally obtained load ratios and those predicted using the theoretical elastic

and elastic-plastic contact. The agreement was found to be most favorable in the case of elastic-plastic model.

DYNAMIC LOAD SIMULATOR (DLS): STRATEGIES AND APPLICATIONS

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This paper describes the development of a new type of testing facility for simulating dynamic loads referred to as Dynamic Load Simulator (DLS). The DLS uses multiple actuators to simulate dynamic loading conditions and can be used as an alternative to conventional facilities such as wind tunnels, wave tanks and shaking tables for special applications. The system is envisioned as a low-cost dynamic testing simulator, which can be readily assembled using existing equipment in typical structural dynamics laboratories.

Control of multiple-actuators is difficult due to the inherent problem of cross-coupling, which implies that each actuator affects the dynamics of other outputs. In order to compensate for these interactions, a new type of coupled control system using the nonlinear control system toolbox in MATLAB has been developed in this study. This technique solves the time-domain control parameter-tuning problem as a constrained optimization problem. A suite of loading protocols which include sinusoidal, wind loading with high and low correlation, earthquake loading and Non-Gaussian type loading are simulated and verified experimentally on the DLS system.

Optical Diagnostics for Soil and Structures

June 5, 2002
9:45
Chair: Masoud Ghandehari **Polytechnic University**
Co-Chair: Amy Rechenmacher **Johns Hopkins University**

DISPLACEMENT FIELD MEASUREMENT IN TRANSPARENT SOILS

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Model tests to measure 3D deformations within a soil mass are limited by soil sensors not providing a continuous image of the measured continuum. Additionally, soil sensors exhibit static and dynamic characteristics, which are different from those of the surrounding soils, and therefore can change the response of the measured continuum. The fundamental premise of this research is that transparent synthetic soil surrogates can be used to overcome these difficulties using optical techniques. A system consisting of a laser source and a line-generating lens was used to optically slice transparent synthetic soil models. A digital camera was used to capture speckle images of the laser slices before and after deformation. Next, digital image correlation (DIC) was performed by comparing the two images to obtain the displacement field in the transparent soil model. The accuracy of DIC was evaluated. An example model consisting of a strip footing on transparent amorphous silica gel is presented, where deformations in the model were measured using the proposed methodology and compared to finite element analysis.

FRACTURE PROCESSES IN CONCRETE STUDIED WITH SUBREGION-SCANNING COMPUTERVISION

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An understanding of the fracture process of concrete and other cementitious materials is necessary for thier design and utilization since cracking characterizes their failure. Subregion Scanning Computer Vision (SSCV) is an effective tool for observing this process in an experimental setting. SSCV, based on Digital Image Correlation (DIC), is a full-field technique for quantitatively examining the development of cracks, with 0.5 micron resolution. DIC utilizes a cross-correlation alogrithm to measure sub-pixel displacement in a sequence of digital images captured of a specimen undergoing failure. Using this technique, the complete behavior of specimens with multiple cracks at incremented levels of fracture can be investigated. SSCV improves on single-image DIC by dividing the specimen into 56 smaller subregions, each of which is imaged separately and so much improves measurement resolution. Examples of the results obtained in studies of crack growth in a model concrete under compressive loading and in a fiber-reinforced mortar under tensile loading are discussed.

Detection of Closed Delamination in Composites with Fiber Optic Sensors

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Delamination is a common mode of failure in laminated composites and it is often difficult to detect. This paper presents a simple fiber optics based technique for the detection of delamination location and size. The integrated strain along a fiber that is embedded or surface-attached to the composite is measured as a function of load position. By comparing the integrated strain vs load position curve, or its second derivative, for undamaged and delaminated members, the delamination location and size can be determined. In this paper, both theoretical and experimental results will be presented to demonstrate the feasibility of the proposed technique to detect delaminations that may close under the applied load. Finite element analysis incorporating contact between the delaminated surfaces is performed to identify the trend of strain perturbation for delaminated members under different support conditions. Experiments are then carried out for composite specimens with different delamination locations and sizes. The results show that relatively small delaminations can be detected with this technique.

Observing the Multiple Cracking of FRC Composites by Electronic Speckle Pattern Interferometry

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Electronic Speckle Pattern Interferometry technique is used to record the location of crack initiation, sequence of the multiple cracking and recording the cracking stresses of the fiber reinforced cement composites. Microstructural parameters at each crack location are quantified by statistical methods. The size of the fiber free areas are measured and percantage of fiber clumping are calculated at the crack surfaces. Relation between the microstructural parameters and mechanical performance is invesigated. It is found that increase in the size of the fiber free areas in the composite decreases the cracking stresses. It is shown that the toughness of the composite depends on the fiber clumping at the first crack cross-section.

Application Of ESPI-technique For The Assessment Of Mineral Building Materials

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Most of the mineral building materials are quasi-brittle. In deformation controlled axial tensile tests of e.g. concrete prisms, one observes a gradual softening after reaching the maximum load. The reason for this softening is primarily caused by the heterogenity of concrete. In contrast to linear elastic fracture mechanics, the tensile fracture of concrete is not combined with a discrete crack but with a fracture process zone (FPZ), a densely microcracked volume. If one is interested in debonding of CFK-lamellas or sheets, the heterogenity of concrete makes the analytical assessment of the debonding very complicated. Therefore experimental work is necessary.

In the paper, the recording of the deformation and post-peak strain distributions of plain concrete are carried out by means of the high sensitive laser speckle interferometry. The Electronic Speckle Pattern Interferometry (ESPI) is a contactless, continuous and repercussionless whole-field measurement technique with a high resolution. The in-plane displacement components of the specimen's surface are measured and are transformed into isostrain-fields. The width of the FPZ in the post-peak tensile response of concrete is determined from these strain fields. ESPI is also used to measure debonding lengths of concrete elements on which CFK-lamellas have been glued.

Besides the presentation of the optical facility and the test set-ups, the results of flexural tests conducted on single-edge-notched flexural concrete specimen at early ages (2d, 7d and 28d) will be shown as well as results of debonding experiments conducted on externaly reinforced concrete prisms. First results of experiments conducted on small masonry samples will be presented.

Digital Image Correlation (DIC) To Evaluate Progression And Uniformity Of Shear Bands In Dilative Sands

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Digital Image Correlation (DIC) has been used to measure local deformations in dense sands to evaluate deformation patterns associated with shear band formation and the uniformity of deformation within persistent shear bands. Displacement vectors and contours of specimen behavior were produced and quantitatively illustrate the patterns of deformation associated with the evolution of displacement from uniform to localized. Results indicate a consistent pattern of uniform deformation, followed by shearing along conjugate planes which eventually yield to one persistent shear band. The wealth of displacement data produced by a typical DIC allowed analysis of strain uniformity along the length of a shear band. Results indicate erratic volumetric behavior along the length of the shear band prior to critical state, and fairly uniform deformation during and after critical state is achieved.

Fiber Optic Chemo-sensing For Civil Infrastructure

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Fiber optic pH sensors based on the evanescent field spectroscopic technique are studied. Portions of poly-methyl methacrylate (PMMA) cladding of polymer clad silica (PCS) optical fibers are replaced with new cladding composed of PMMA doped with a pH sensitive chromophore. Methyl Red, Thymol Blue, Thymolphtalein are used for sensing pH at the acid, neutral and base levels, respectively. Changes in the pH of the sensing environment are detected by measuring the absorption spectrum of the new cladding in the sensing region of the optical fiber.

Environmental Fluid Mechanics

June 5, 2002
9:45
Chair: Vincent Chu McGill University

Large-Eddy Simulation of Wind Flow And Pollutant Dispersion in an Urban Street Canyon

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The local wind climate and the mode of pollutant dispersion in an urban district are highly dependent on the structural and geometric configuration of street canyons. The atmospheric flows within the canopies and above roof level differ significantly as the relative height and width of canopies varies. The inflow condition can also have a significant role to play in the development of recirculating flow within the canyon.

A 2-D finite difference model based on the Marker and Cell (MAC) method using techniques of Large Eddy Simulations (LES) has been developed to study the different flow regimes and pollutant dispersion characteristics within an urban street canyon. The system contains two sub-models: the flow-distribution model based on the steady Reynolds averaged Navier-Stokes Equations (RANS), and the concentration diffusion model. The flow distribution within the street canyon is first developed and the concentration distribution is then solved using the flow information obtained. The code is developed with the method of composite domain with uneven staggered grid in an object-oriented sense for future development in parallel processing. A 3rd order upwind scheme is added into the calculation to ensure numerical stability. The main focus of the study is to investigate the relationship between the different flow regimes and the pollutant dispersion characteristics generated under different canyon height and width.

It is concluded that the pollutant concentrations have higher magnitudes on the leeward side than the windward side, which agrees with findings in the literatures. It is also found that when the canyon height and width varies, different pollutant dispersion mode is exhibited in the form of ‘isolated roughness flow’, ‘skimming flow’ and ‘wake interference flow’ regimes as in the flow pattern. The results obtained can provide useful guidelines on dispersion patterns for future development.

Entrainment Modelling of Plane Surface Jet in Weak Co-Current

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The entrainment characteristics of plane surface jets on the free surface of an irrotational co-current in a channel are studied experimentally and modeled analytically. The entrainment data were extracted from LDV measurements of longitudinal mean jet velocities obtained under different ambient current conditions. Two entrainment models were examined. The first model applied the entrainment coefficient, as defined by Morton, Taylor and Turner (1956) and the second model applied the entrainment coefficient, as defined by Townsend (1956). The results have indicated that Morton et al's coefficient decreased with distance along the jet, while Townsend's coeffcient was constant.

Simulation of Horizontal Turbulence in Shallow Recirculating Flows

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The Large Eddy Simulation method is employed in this study to compute shallow recirculating flows in an open channel. The depth-averaged equations are solved to calculate the large-scale horizontal turbulence. Sub-depth-scale viscosity and sub-grid-scale viscosity are determined by a modified Smagorinsky model. The computations were conducted for a range of friction effect from deep to shallow water depth. Flow parameters, such as the length of the main recirculating zone, the length of the secondary recirculation area, the wake width, the recirculation flow rate, the Reynolds stresses, the mean and fluctuations of a tracer concentration, are computed and are compared with the experimental data. The simulations are in agreement with the experimental data when optimal value of the Smagorinsky coefficient, Cs, is selected for the simulations. The optimal value of this coefficient is not constant but depends on the bed-friction number effect. It decreases rapidly from Cs = 0.26 to 0.14 as the bed-friction number increases from S = 0.027 to 0.25, respectively.

Heated Circular Cylinder In Cross Flow Using Several Finite-difference Schemes

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Vincent Chu ***McGill University***

A simulation of the heat transfer from a cross flow over a heated circular cylinder was conducted using three advection-diffusion schemes: (1) central differencing, (2) power-law, (3) QUICK. The calculations were performed for a range of Reynolds numbers significantly higher than those previously performed on the same flow configuration. All three schemes provided correct boundary-layer separation and accurate heat flux through the front and back surfaces of the cylinder. The far-field vorticity and temperature distributions varied with respect to the selection of the scheme. The QUICK scheme appears to give the optimum compromise between the numerical instabilities of the central-differencing scheme and the false numerical diffusion of the power-law scheme.

Gravity Stratified Flows by Lagrangian Block Method

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In Large Eddy Simulations (LES) of turbulent flows, the required viscosity for energy dissipation at the sub-grid scales is quite small. The sub-grid viscosity is comparable in order of magnitude to the numerical viscosity produced by most of the numerical computational schemes. The need for numerical accuracy is even more important when the buoyancy force is involved in the numerical simulation. Buoyancy is carried by the velocity of the turbulence motion that in turn is driven by the force of the buoyancy. Accurate simulation of the turbulent stratified flows is entirely dependent on the ability of numerical scheme to simulate the chaotic advection of the buoyancy. Because the process is advection dominated, the numerical method must be relatively free of the problems of the numerical diffusion and the unphysical oscillations that many conventional computational schemes have been affected. In this paper, the turbulent plume is simulated by a highly accurate advection scheme known as the Lagrangian Block Method (LBM).

Deterministic and Probabilistic Approaches to Stability Design
June 5, 2002
9:45
Chair: Hayder Rasheed **Kansas State University**
Co-Chair: Ben Schafer **Johns Hopkins Univ.**

Stability of Column Supporting Flat Slab Without Beam Grid

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Column stability of braced and unbraced building framing systems have been widely studied and very well established. But, stability of column supporting two-way flat slab without beam grid is still rather sparse. It is the intention of this study to carry out a detailed study of stability of column, which support reinforced concrete flat slab building system. Computer-aided analysis based on three-dimensional finite element model consisting of columns and two-way flat slab to be used for carrying out stability studies.

The buckling analysis of braced and unbraced column supporting flat-slab building may be generalized to a similar framing building in which portion of flat-slab stiffness is replaced by the stiffness of horizontal beam. It requires analytical analysis in order to decide which portion of flat slab can be counted to substitute for the stiffness of replaced beam grid. The purpose of this study is to carry out detailed analysis in an attempt to formulate a practical process for the buckling strength of columns supporting flat slab building system.

FEM Implementation of Koiter's Asymptotic Post-Buckling Prediction with Application to Stochastic Post-Buckling Analysis

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In proper structural design it is critical to consider not only the elastic buckling behavior, but also the postbuckling response. Koiter showed the importance of postbuckling response parameters for better understanding strength and imperfection sensitivity of structures. Koiter's perturbation method provides an efficient prediction of the postbuckling path for elastic structures. More recent work has focused on a finite element implementation of Koiter's method that is more convenient for typical computational structural analyses. When considering the effects of inherent randomness in the structural parameters on the postbuckling path of a structure, this convenience and efficiency is particularly critical. In this work, Monte Carlo simulation techniques are used to study the effects of random elastic moduli on the postbuckling response of some simple frame structures. This analysis provides a deeper understanding of the variability in anticipated postbuckling response that could provide highly valuable design considerations. A first-order analytical approximation to the mean and variance of the postbuckling behavior is proposed as a means of curtailing the need for a high number of sample simulations.

The Problems of Probability Approaches to Structural Stability

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In this paper the contemporary problems of linking between structural stability analysis and design code procedures are discussed especially from the point of view of the probabilistic approaches that in general are assigning for resulting specified level of structure reliability. From results of probabilistic parametric study presented in this paper some general conclusions can be drawn, namely: For variable ratio of permanent and variable action of compression steel member the reliability is not steady and well-balanced; the difference in the value of reliability index can for certain arrangement of partial safety factors in the design criterion reach the range of $\Delta 1 = 0.7$. Among various arrangements of design criteria the difference can be up to $\Delta 2 = 0.6$. The selection of the basic design criterion can discriminate or prefer constructional systems with predominant permanent or variable type of loading actions. Thus the reliability calibration of design criteria needs permanent and stronger attention.

Issues related to the probabilistic safety assessment of Steel Structures in the Stability domain.

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The safety assessment of a steel frame containing leaning columns is indicated using a probabilistic simulation-based reliability assessment method SBRA. Special attention is given to the loading effects resulting from the second order theory analysis of the system, and to the application of APT (arbitrary-point-in-time) and MLE (maximum load effects) approaches to the load effect combination analysis of a system exposed to earthquake. The combination of earthquake effects and of all remaining loads is performed. The assessment procedure consisting of steps ìassignment - identification of the frame - specification of loads - specification of all input variables - selection of the transformation model based on the second order theory - analysis of the safety function containing all variables using direct Monte Carlo simulation - application of the safety criterion Pf < Pdì is demonstrated on the pilot example. In order to prove the safety, the obtained probabilities of failure Pf of the investigated cross-section (exposed to axial force and bending moment) are compared with the target probabilities Pd.

DENTIFICATION OF FACTORS OF INSTABILITIES AND THEIR INTEGRATION IN A MODEL OF RUPTURE : AN METHOD OF EVALUATION OF SAFETY COEFFICIENT

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Carlier Erick *Professor*

SEDKI Samia *PhD Student*

In the study of stability of natural or road slopes, the safety coefficient Fs assessment depends on several parameters. The precision in the choice of these parameters thus constitutes a major stake. This study constituted one of the research orientations which is applied to the north Moroccans slopes. This search is undertaken in collaboration with the General Direction of Hydraulic (Morocco), and is based on a multidisciplinary approach involving simultaneously geotechnics, geology and hydrogeology. The principal aim is to define the causes and the mechanisms which generate the deep landslides in order to better evaluate in the risks in this area. The analysis of instability factors allowed to identify those which have an effect on release of the phenomenon and their associated mechanisms. For example, the underground flows strongly take part in the destabilization of natural slopes. Their correlation to the deep plane landslides of the area reveals the same direction and strong hydraulic gradients (apart from the littoral zone). With that add fluctuations of the deep water table. Indeed, two hydrogeologic fields are distinguished between upstream and downstream. Several flows equations are defined. Those depend on the distance, on the time and especially on the hydrodynamic parameters. The evaluation of safety coefficients is developed by using MatLab’s program (according to a model of design at failure by sections and slope at given height), enables to integrate as variables the various factors identified during the analytical phase. Thus, 2d and 3d simulations were carried out by taking account of mechanical parameters which vary according to geological and hydrogeological conditions, of natural slopes and substrate slope, of water levels in particular by intermediary of the defined flows equations... Much informations are drawn from this modelling which enables us either to confirm our previous conclusions or to supplement them. Finally, a card of risks based directly on the evaluation of Fs and inspired by the model tested, is under development. In addition to traditional evaluation of risks, simulations according to rainy seasons at origin of the fluctuations of the deep water table are possible.

Probabilistic Methods - III
June 5, 2002
11:30
Chair: George Deodatis Columbia University

VARIABILITY RESPONSE FUNCTION FOR THE BEAMS WITH RANDOM ELASTICITY AND RANDOM CROSS SECTION

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The concept of variability response function based on the weighted integral method and the local average method is extended to the beam bending problem with random elasticity and random cross section of the beam. The elastic modulus and the height of the beam are considered to be one-dimensional, homogenous, non-correlated, stochastic fields. The stochastic stiffness matrix is calculated by using standard cubic finite element. The stochastic element stiffness matrix is represented as linear combination of deterministic element stiffness matrix and 3 random variables (weighted integrals) with zero-mean property.

The concept of the variability response function is used to compute upper bounds of the response variability. The first and second moment of the stochastic elastic modulus and the stochastic height of the beam are taken as input quanitities for description of the random variables. The response variability is calculated using the first-order Taylor expansion approximation of the variability response function.

The use of variability response function based on the weighted integral method is compared with the use of variability response function based on the local average method in the sense to show the influence of reducing the computational effort on the loss of accuracy. The use of local average method gives approximation with small loss of accuracy with only one random variable per each finite element. Numerical examples are provided for both methods and for different boundary and loading conditions, different wave numbers, different number of the finite elements and different relation between variation of the elastic modulus and variation of the height of the beam. It has been shown that variation of the response deflection could be much larger than variation of the each input quantity.

SERVICEABILITY CRITERIA FOR DESIGN OF REINFORCED CONCRETE STRUCTURES

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Improved analysis procedures and the use of high strength materials have resulted in structural members that are more slender and lighter than in the past. This has resulted in a need to pay closer attention to design for serviceability including design for deflection control. Current design criteria for serviceability are essentially empirical in nature and there is a need to base serviceability design on a more rational foundation. This paper addresses the issue by applying concepts of utility theory and structural reliability to the problem of deflection control in reinforced concrete structures. A

framework for applying such concepts is developed and simple examples are used to demonstrate the application of the proposed procedures in structural design. The incorporation of such an approach in design codes is discussed in concept.

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Hydrologic Inversion Using Marching-Jury Backward Beam Equation and Quasi-Reversibility Methods

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In this paper, a comparison between the Marching-Jury Backward Beam Equation (MJBBE) and the Quasi-Reversibility (QR) methods to perform hydrologic inversion and, more specifically, to reconstruct conservative contaminant plume spatial distributions is presented. Spatially uncorrelated and correlated, non-stationary, heterogeneous dispersion coefficient fields were generated using the Bayesian Nearest Neighbor Method (B-NNM). The MJBBE is found to be robust enough to handle highly heterogeneous parameters and is able to preserve the salient features of the initial input data. On the other hand, the QR method is superior in handling cases with homogeneous parameters and with initial data that are plagued by uncertainty but it performs very poorly in cases with heterogeneous media.

Design Details On Integral Bridges

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Integral bridges have been found to outperform jointed bridges, decreasing maintenance costs, and enhancing the life expectancy of the superstructures. However, a standard design method for integral bridges does not exist. Several factors must still be investigated to gain a better understanding of the behavior of integral abutments, and the factors that influence their analysis, design, detailing, and construction. In this paper, we will be investigating the deck-stringer-abutment continuity details.

Most connections are designed as rigid by using adequate reinforcement detailing between the slab, girders and abutment. However, 1) cracking on the deck has been observed, 2) the detailing may vary as a function of structure geometry. In this work, we are evaluating design details that have been standardized for a variety of applications, and we are suggesting the next step in research that will result in final design specifications for integral abutments.

Symposium on Computational Inelasticity - Theory and Implementation
June 5, 2002
11:30
Chair: Victor Kaliakin University of Delaware
Co-Chair: Boris Jeremic University of California

A Nonlinear Fully Coupled Electro-thermo-mechanical Analysis of Piezoelectric Materials involving Domain Switching

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Coupling of electrical, mechanical and thermal effects is a natural outcome of the general formulation of the response of piezoelectric materials to mechanical loading, electrical fields, or thermal gradients. The presence of polarization vector in the equations for balance of linear momentum makes them inherently nonlinear. Moreover, domain switching is the cause of significant nonlinearity in the response of piezoelectric materials to mechanical and electrical effects. In this paper, the response of piezoelectric solid is formulated by coupling thermal, electrical, and mechanical effects. The constitutive equations are nonlinear. The resulting governing equations become highly nonlinear. The corresponding nonlinear finite element equations are derived and solved by using an incremental technique. The developed formulation is first verified against some benchmark problems for which a closed-form solution exists. Next, a cantilever beam made of PZT-4 is studied to evaluate the effect of domain switching on the overall force-displacement response of the beam. A number of interesting observations are made with respect to the extent of nonlinearity and its progressive spread as the load on the beam increases.

Three dimensional strain localization in pressure-sensitive materials

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A three-dimensional finite element implementation of a simple non-associative Drucker-Prager plasticity model with strong discontinuity mode of localized deformation is formulated for small deformations. A strong discontinuity mode of localized deformation represents slip along a surface of zero measure, whereas a weak discontinuity mode of localized deformation represents shear within a band of finite thickness. A numerical algorithm that detects onset of localization for three-dimensional stress states and the possible normals to slip planes within a three-dimensional finite element is demonstrated. An enhanced strain hexahedral finite element accounting for the various slip-plane cutting conditions is described. This model and finite element lead to mesh-independent solutions

with regard to mesh refinement and mesh alignment. A simple three dimensional numerical example demonstrates the numerical algorithm for determining onset of localization.

Post Localization Analysis of Soil Slopes

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Analysis of soil slopes is of great importance to geotechnical engineers and is often achieved by using simplified techniques such as those based on limit equilibrium method. The classical finite element method has also been used with varying degree of success. But a major difficulty facing the classical continuum approach is the loss of the well posedness of the boundary value problem due to the onset of localization in the underlying elastoplastic constitutive model that generally follows a non-associative flow rule. In the past few years, different regularization techniques have been proposed to remedy the problems associated with the post localization analysis of elastoplastic solids. Here we discuss the application of one of these regularization techniques, i.e. the weak discontinuity approach. It is shown that the slope stability analysis can be carried out far enough, so that the effect of soil volume change on stability can be carefully examined. It is further confirmed that such volume change effects could be quite significant and omission of these effects would lead to unsafe design of soil embankments and slopes.

Dynamics - Isolation and Dissipation Systems
June 5, 2002
11:30
Chair: Nicos Makris U.C. Berkeley

Dual Mode Vibration Isolation Based on Nonlinear Mode Localization

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We study a nonlinear vibration isolation system capable of, (a) isolating its upper part (the 'machine') from periodic disturbances generated at its base; and (b) simultaneously isolating its base from periodic disturbances generated at the level of the machine. By making use of essentially nonlinear (e.g. nonlinearizable) stiffness elements we completely eliminate resonances close to linearized modes, thus achieving vibration isolation over an extended frequency range. Instead, we prove the existence of branches of localized steady state motions in the frequency domain. Indeed, these localized forced motions are principally responsible for fulfilling the dual mode vibration isolation objective of this work.

A Parametric Analysis of a Novel Shock Isolation System

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A new kind of seismic isolation system incorporating energy localization and a nonlinear restoring mechanism in one unit has been described in recent papers. Parametric studies have been carried out to examine the behavior of the primary structure (i.e., the structure being isolated) and the auxiliary mass of the proposed shock isolator. The simulated responses of the structure with and without the isolator to ground motions are examined in this paper. The energy spectral response of the SDOF structure is also described. It is concluded that this nonlinear passive control system induces a strongly localized nonlinear normal mode that is partially confined to the secondary substructure. It performance is found to be effective in limiting structural response.

Non-linear behaviour and dynamic stability of a vibration spherical absorber

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Wind excited vibrations can be reduced using passive or active vibration absorbers. If there is available only a limited vertical space to install such a device, a spherical absorber can be recommended. It is a semi-spherical horizontal dish in which a sphere of a smaller diameter is rolling. Theoretical modeling, laboratory experiments and experimental measurement in situ are presented. Using Lagrange equations, governing strongly nonlinear differential system is derived. The solution procedure combines analytical and numerical processes. Analytical methods are focussed to investigation of qualitative properties of the system. Numerical processes (MATHEMATICA) are used for evaluation of particular cases. The function and effectiveness of the absorber was examined in the laboratory. The dimensions were identical with those of spherical absorbers installed at the existing TV towers. Exciting harmonic forces were supplied using one or two MTS hydraulic actuators. The response spectrum demonstrates a strongly non-linear character of the absorber. An absorber installed at the TV tower reduced response amplitudes to 15-40% of its original values.

Analytical And Experimental Study Of Vibration Behavior Of Frp Composite I-beams

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Advanced and innovative materials and structures are increasingly used in civil infrastructure applications, and by combining the advantages of composites and smart sensors and actuators, adaptive or smart composite structures can be created and be efficiently adopted in practical structural applications. In this paper, a combined analytical and experimental characterization of vibration behavior of a cantilever FRP I-beam is presented. The FRP I-beams are made of E-glass fibers and polyester resins, and the smart sensors and actuators used are piezoelectric ceramic patches. Both theoretical and numerical (finite element modeling) modal analyses are conducted to reveal the fundamental modal frequencies and shapes of FRP I-beams. Based on a Vlasov-type linear hypothesis, beam stiffness coefficients, which account for the material anisotropy of the section as well as the geometrical shape of the structure, are obtained; an explicit formula of beam modal frequencies based on the Hamilton principle is provided. The results based on the theoretical prediction and numerical simulation compare with the data obtained from experimental modal testing using piezoelectric sensors, and a good correlation is obtained. The presented modal analyses, which mainly concern the eigen-vibration properties of FRP I-beams, can play a major role in the active dynamic control.

Spectral Finite Element Modeling Of A Wave Propagation In Sandwich Plate Rows With Periodic Honeycomb Core

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The wave propagation of sandwich plates with cellular core is analysed and controlled. Honeycomb core materials of different geometry placed periodically along the structure introduce the proper impedance mismatch necessary to obstruct the propagation of waves over specified frequency bands (stop bands). The location and the extension of the stop bands can be optimised by proper selection of the geometrical and physical properties of the core. An optimal configuration of the core can be identified to design passive sandwich structures, which are stable and quiet over desired frequency bands. A Spectral Finite Element Model (SFEM) describes the wave propagation in a three-layered sandwich plate simply supported along the longitudinal edges. The method uses dynamic shape functions derived from the solution of the distributed parameter model and allows for predicting the behaviour of the structure with a reduced number of elements. The numerical model is used to formulate the transfer matrix of the considered structure and to predict its dynamical response. The transfer matrix allows for identifying the stop bands for various core configurations. The influence of the core periodic properties on the stop bands and on the plate vibration is assessed through a series of simulations. The results demonstrate the simplicity and the effectiveness of the proposed treatment whereby the transmission of waves and the vibration over specified frequency bands can be significantly reduced without requiring additional passive or active control devices. The unique characteristic of cellular solids therefore can be used to design light-weight composite panels that behave as mechanical filters. The filtering capabilities of such passive composite panels may be easily changed and optimised to reduce their transmissibility over a desired frequency range without compromising the size and the weight of the structure.

Inelastic Behavior of Soils and Soil-Structure Interaction
June 5, 2002
11:30
Chair: A. (Rajah) Anandarajah Johns Hopkins University

Dynamic Finite Element Analysis of Pile-Porous Media Interaction.

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The dynamic response of saturated soil deposits is governed by the effective stres state of the soil skeleton as it interacts with the pore fluid (porous soil mixture) and the structural elements. The phenomenon, known as "set-up" or "freeze" develops as pore pressures generated during driving of piles into these types of soil deposits begin to dissipate, hence allowing the effective stress to increase. From the modern porous media theories, the governing equations of soil mixture are described from the general context of finite deformations, where effective stresses evolve from the thermodynamic restrictions on soil mixture, resulting in the derivation of the couple field equations for the soil. The elasto-plastic bounding surface constitutive model with a generalized form of damage evolution, on the cohesive properties of the soils, is described as an incremental relation between the changes of effective stress and strain of the soil. Finite element spatial discretization follows a hybrid updated lagrangian formulation to allow for changes in volume (void ratio) with time. The dynamic response of piles driven into saturated clayey deposits are analyzed and simulated based on findings of full-scale field studies. The numerical simulations are compared with the field data.

Identification Of The Dynamic Response Of Soil Systems

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Massive geotechnical systems exhibit a broad range of complex response patterns under seismic excitations. A thorough monitoring of the whole response of such systems may not be technically possible, and would generally be prohibitively expensive. A sparse monitoring of distributed soil systems generally does not provide enough information to uniquely and accurately identify local response mechanisms based on boundary value problem analyses. This paper presents an effective point-wise identification technique to locally analyze the constitutive response of soil systems using acceleration records. The identification algorithm consists of: (1)~evaluation of strain time histories from the motions recorded by a multi-dimensional array of closely spaced accelerometers, (2)~estimation of stress tensors corresponding to the evaluated strains, (3)~computation of accelerations associated with the estimated stresses, and (4)~evaluation and calibration of an optimal model of soil response by minimizing discrepancies between the recorded and computed accelerations. Computer simulations and experimental data analyses showed that the proposed technique provides an effective tool to identify local soil characteristics and properties.

Nonlinear Earthquake Response Analysis Of 2-D Underground Structures With Soil-structure Interaction Including Separation And Sliding At Soil-structure Interface

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The paper presents an effective analytical method for SSI systems which can have separation or sliding at the soil-structure interface. The method is based on a hybrid approach which combines a linear SSI code KIESSI-2D in frequency domain with a commercial finite element package ANSYS to obtain nonlinear dynamic responses in time domain. The method is applied to a 2-D underground box structure which experiences separation and sliding at the soil-structure interface. Material nonlinearity of the concrete structure is also included in the analysis. Effects of the interface conditions are examined and some critical factors affecting the seismic performance of underground structures are identified.

Poromechanics

June 5, 2002
11:30
Chair: Alexander Cheng University of Mississippi
Co-Chair: Ahmad Ghassemi University of North Dakota

Vertical Vibrations of A Rigid Circular Disk on A Multi-Layered Poroelastic Medium

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This paper considers the time-harmonic vertical vibrations of a rigid circular disk resting on the surface of a multi-layered poroelastic half space. The half space under consideration consists of a number of layers with different thickness and material properties. The interaction problem is analyzed by dividing the contact surface between the disk and the layered half space into a number of concentric annular rings with uniform traction distribution. Nodal points are selected at the center of each annular element. A flexibility equation system is established to determine the intensity of contract tractions at different nodal locations by imposing the appropriate rigid body displacement boundary conditions. The influence functions required to establish the flexibility equation system correspond to the displacement Green's functions of a multi-layered poroelastic half space based on Biot's elastodynamic theory for porous media. Selected numerical results for vertical compliance of a rigid disk on different poroelastic media are presented to portray the influence of poroelastic effects on the interaction problem.

Anisotropic Chemo-poroelasticity with Ion Transfer

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This paper presents a linear chemo-poroelastic model for predicting shale deformation in transversely isotropic media. The theory incorporates the stresses and pore pressure with four coupled transport processes of fluid and solute: hydraulic conduction, chemical osmosis, chemical solute diffusion, and pressure solute diffusion. The fluid is considered compressible and consisting of a binary electrolyte solution (solute and diluent). The total stresses and variation of fluid content are linearly related to the strains, pore pressure, and solute mass fraction through anisotropic material coefficients. The derived Navier-type equations couple the elastic strains to the pore pressure and the solute mass fraction. The other field equations express the couplings of the fluid and solute diffusions with the elastic strains. To show the impact of the physicochemical processes on the pore pressure and stress fields around a wellbore, an example of a vertical well drilled in an isotropic shale formation is presented. Results indicate that although the osmotically-induced reduction in the pore pressure tends to stabilize the borehole, ion diffusion into the formation can cause the formation to fail in tension.

Variational Formulation of Fluid Infiltrated Porous Material in Thermal and Mechanical Equilibrium

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The mechanics of fluid infiltrated porous bodies is investigated using variational principles. The energy statement is constructed using macroscopic state parameters obtained from microscopic averaging. As a first step, we restrict the investigation to static, reversible processes without external field. Using a quadratic energy form, which implies linear behavior of phase materials, the deformation of porous medium is shown to be nonlinear due to geometric nonlinearity in porosity deformation. The theory can be fully linearized, which is then found to be consistent with the well-known Biot model.nd to be consistent with the well-known Biot model.

Turbulence
June 5, 2002
11:30
Chair: Ching-Jen Chen Florida State University - Florida A&M University

Sensitivity Study Of A 2nd Order Turbulence Model In A Stratified Tidal River

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Eddy viscosity calculated from the turbulent model has significant effects on vertical stratification. In this study, a 2nd order turbulence model was applied to a strongly stratified tidal river. Using the default turbulent model parameters model predictions overestimate current and salinity stratification. In order to improve the performance of the turbulent model, a correction factor of eddy viscosity was proposed to allow the slight adjustment of the turbulent eddy viscosity that is very sensitive to the calculation of the vertical stratification. Sensitivity study was conducted determine the optimal correction factor within the range between 1.0 to 1.2. Results show that the increase of the turbulent eddy viscosity to a 1.12 factor results in the best agreement between model predictions and observations. Using the proposed correction factor of the eddy viscosity will provide a useful approach for modelers to turbulent model performance in predicting turbulent mixing in the stratified flow.

Effects Of Differential Diffusion On Mixing Efficiency In A Diffusively-stable, Turbulent Flow

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Laboratory experiments are used to evaluate the conditions under which differential diffusion exists and its effect on the mixing efficiency. Experiments are conducted using a linearly stratified system, which is stably stratified with both heat and salt to ensure equal Richardson numbers and Reynolds numbers are seen for both scalars as the system is stirred using horizontally oscillating vertical rods. Both the work done on the system and the potential energy change of the system are directly measured to compute the mixing efficiency?defined as the ratio of the potential energy change to the work done. The eddy diffusivities of heat and salt are presented as a function of turbulence intensity (defined using an oceanographic turbulence intensity parameter). The results of this study suggest that differential diffusion exists for turbulence intensities below 300 and above a turbulent Richardson number of 0.1. These experiments also verify that the density ratio can have as large an influence on the mixing efficiency as the stratification strength and the process generating the turbulence.

Turbulent Energy Budget of Wave Interactions with a Rectangular Barge

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This study presents an experimental study on wave interactions with a rectangular barge in a beam sea condition. Regular waves with a wave period the same as the natural frequency of the barge were used in the experiments due to the fact that the barge is prone to capsize under such waves. The barge was fixed on the free surface and no wave overtopping was assumed. Particle Image Velocimetry (PIV) was employed to measure the full-field two-dimensional flow velocity. The phase-averaging method was used to extract the mean flow and turbulence properties. The mean velocity and vorticity and turbulent property were analyzed to quantify the mechanism of the interactions. The advection, transport, production, and dissipation terms in the transport equation for turbulent kinetic energy budget were obtained from the experiments.

The Velocity Field of a Duckbill Valve (DBV) Jet in Coflow

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A systematic three-dimensional numerical study using k-e model and laboratory measurement by laser-doppler anemometry (LDA) on a duckbill valve (DBV) jet with varying large aspect ratios in coflow is presented. The turbulence model parameters are calibrated against detailed experimental data (Sfeir 1978). The DBV jet is taken as a rectangular jet with the same aspect ratio and valve opening area; an assumed small inward lateral (z-) velocity (varying from 0.1 Uj at the edge to zero at the centerline) is adopted in inlet boundary for simulation of the secondary flow caused by DBV. The numerical computations and LDA measurements show that: i) the jet spreading in the major and minor axes are distinctly different in the near-field; a strong “axis-switching” firstly appears in this region at X/D ª 1.5-2; ii) the velocity distribution in the major and minor axis planes can be well-approximated by a Gaussian distribution for X/D > 4; iii) the cross-sectional turbulent intensity distribution is double-peak shaped in the near field with maximum value of around 0.23.

MEASUREMENT OF SOAP FILM FLOWS USING COLOR PIV

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Color Particle Image Velocimetry (CPIV) is applied to measure a variety of flows in a continuous flowing vertical soap film channel. The channel width is typically 5 to 10 cm in laboratory experiments and its height is 3 m. The soap film is between 2 to 6 thick and travels between 0.5 and 4 m/s, depending on the fluid injection rate. The CPIV method invokes color CCD camera to record different color, multi-exposure particle images on a single frame. The time interval between exposures can be specified as required. A multicolor particle image can be easily separated into unique color, sequential images. Both the magnitude and direction of the velocity vectors can be determined from the unique color, sequential particle images using cross correlation analysis. A series of flow past circular cylinder, such as flow past double circular cylinders, flow past circular cylinder in confined channel flows, etc., were investigated. Very detailed velocity and pressure distributions for these ideal two-dimensional fluid motions were obtained.

Author Index

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