Non Linear Seismic Soil Structure Interaction Ssi


In the past, facilities considered to be at the end of their useful life were demolished and replaced with new ones that better met the functional requirements of modern society, including new safety standards. Humankind has recently recognised the threats to the environment and to our limited natural resources due to our relentless determination to destroy the old and build anew. With the awareness of these constraints and the emphasis on sustainability, in future the majority of old structures will be retrofitted to extend their service life as long as feasible. In keeping with this new approach, the EU’s Construction Products Regulation 305/2011, which is the basis of the Eurocodes, included the sustainable use of resources as an "Essential Requirement" for construction. So, the forthcoming second generation of EN-Eurocodes will cover not only the design of new structures, but the rehabilitation of existing ones as well. Most of the existing building stock and civil infrastructures are seismically deficient. When the time comes for a decision to prolong their service life with the help of structural and architectural upgrading, seismic retrofitting may be needed. Further, it is often decided to enhance the earthquake resistance of facilities that still meet their functional requirements and fulfill their purpose, if they are not earthquake-safe. In order to decide how badly a structure needs seismic upgrading or to prioritise it in a population of structures, a seismic evaluation is needed, which also serves as a guide for the extent and type of strengthening.

Seismic codes do not sufficiently cover the delicate phase of seismic evaluation nor the many potential technical options for seismic upgrading; therefore research is ongoing and the state-of-the-art is constantly evolving. All the more so as seismic evaluation and rehabilitation demand considerable expertise, to make best use of the available safety margins in the existing structure, to adapt the engineering capabilities and techniques at hand to the particularities of a project, to minimise disruption of use, etc. Further, as old structures are very diverse in terms of their materials and layout, seismic retrofitting does not lend itself to straightforward codified procedures or cook-book approaches. As such, seismic evaluation and rehabilitation need the best that the current state-of-the-art can offer on all aspects of earthquake engineering. This volume serves this need, as it gathers the most recent research of top seismic experts from around the world on seismic evaluation, retrofitting and closely related subjects.

Seismic analysis of nuclear structures is routinely performed using guidance provided in "Seismic Analysis of Safety-Related Nuclear Structures and Commentary (ASCE 4, 1998)." This document, which is currently under revision, provides detailed guidance on linear seismic soil-structure-interaction (SSI) analysis of nuclear structures. To accommodate the linear analysis, soil material properties are typically developed as shear modulus and damping ratio versus cyclic shear strain amplitude. A new Appendix in ASCE 4-2014 (draft) is being added to provide guidance for nonlinear time domain SSI analysis. To accommodate the nonlinear analysis, a more appropriate form of the soil material properties includes shear stress and energy absorbed per cycle versus shear strain. Ideally, nonlinear soil model material properties would be established with soil testing appropriate for the nonlinear constitutive model being used. However, much of the soil testing done for SSI analysis is performed for use with linear analysis techniques. Consequently, a method is described in this paper that uses soil test data intended for linear analysis to develop nonlinear soil material properties. To produce nonlinear material properties that are equivalent to the linear material properties, the linear and nonlinear model hysteresis loops are considered. For equivalent material properties, the shear stress at peak shear strain and energy absorbed per cycle should match when comparing the linear and nonlinear model hysteresis loops. Consequently, nonlinear material properties are selected based on these criteria.

This monograph deals with the problem of dynamic behaviour and seismic response of structures which are designed and
constructed in seismic regions. Extensive attention is given to description of measuring methods, methods of evaluation of results and determination of dynamic properties of structures. The questions of linear and non-linear seismic response are solved taking into account the peculiarities of stiffness and damping and the demands of proper seismic design and the protecting of structures against unfavourable seismic effects. There is detailed analysis of torsional seismic effects on structures with asymmetrical disposition in plan, of the influence of higher axial forces on the seismic response and of the problems of soil-structure interaction. The experimental results are extensively documented, with graphs, tables, photographs and a keyword index. This volume will interest structural engineers, engineers-designers, geophysicists, mechanical and geotechnical engineers. It is intended to serve both readers already acquainted with problems of earthquake engineering and beginners in this field.

W S HALL School of Computing and Mathematics, University of Teesside, Middlesbrough, TS1 3BA UK G OLIVETO Division of Structural Engineering, Department of Civil and Environmental Engineering, University of Catania, Viale A. Doria 6, 95125 Catania, Italy Soil-Structure Interaction is a challenging multidisciplinary subject which covers several areas of Civil Engineering. Virtually every construction is connected to the ground and the interaction between the artefact and the foundation medium may affect considerably both the superstructure and the foundation soil. The Soil-Structure Interaction problem has become an important feature of Structural Engineering with the advent of massive constructions on soft soils such as nuclear power plants, concrete and earth dams. Buildings, bridges, tunnels and underground structures may also require particular attention to be given to the problems of Soil-Structure Interaction. Dynamic Soil-Structure Interaction is prominent in Earthquake Engineering problems. The complexity of the problem, due also to its multidisciplinary nature and to the fact of having to consider bounded and unbounded media of different mechanical characteristics, requires a numerical treatment for any application of engineering significance. The Boundary Element Method appears to be well suited to solve problems of Soil-Structure Interaction through its ability to discretize only the boundaries of complex and often unbounded geometries. Non-linear problems which often arise in Soil-Structure Interaction may also be treated advantageously by a judicious mix of Boundary and Finite Element discretizations.

This book is a printed edition of the Special Issue “ Development and Application of Nonlinear Dissipative Device in Structural Vibration Control” that was published in Applied Sciences

Despite advances in the field of geotechnical earthquake engineering, earthquakes continue to cause loss of life and property in one part of the world or another. The Third International Conference on Soil Dynamics and Earthquake Engineering, Princeton University, Princeton, New Jersey, USA, 22nd to 24th June 1987, provided an opportunity for participants from all over the world to share their expertise to enhance the role of mechanics and other disciplines as they relate to earthquake engineering. The edited proceedings of the conference are published in four volumes. This volume covers: Soil Structure Interaction under Dynamic Loads, Vibration of Machine Foundations, and Base Isolation in Earthquake Engineering. With its companion volumes, it is hoped that it will contribute to the further development of techniques, methods and innovative approaches in soil dynamics and earthquake engineering.

Dynamic Soil-structure interaction is one of the major topics in earthquake engineering and soil dynamics since it is closely related to the safety evaluation of many important engineering projects, such as nuclear power plants, to resist earthquakes. In dealing with the analysis of dynamic soil-structure interactions, one of the most difficult tasks is the modeling of unbounded media. To solve this problem, many numerical methods and techniques have been developed. This book summarizes the most recent developments and applications in the field of dynamic soil-structure interaction, both in China and Switzerland. An excellent book for scientists and engineers in civil engineering, structural engineering, geotechnical engineering and earthquake engineering.

This volume comprises papers presented at the China-US Millennium Symposium on Earthquake Engineering, held in Beijing, China, on November 8-11, 2000. This conference provides a forum for advancing the field of earthquake engineering through multilateral cooperation.

This text details the proceedings of the 11th European Conference on Earthquake Engineering. CD-ROM contains full text of the 650 papers in printed form. This would have been 6 volumes of 1000 pages each. Topics covered are: Engineering seismology; Experimental aspects for soils, rocks and construction material; Computational aspects for materials, structures and soil-structure interaction; Civil engineering projects; Active and passive isolation; Industrial facilities, lifelines and equipment; Vulnerability, seismic risk and strengthening; Site effects and spatial variability of seismic motions; Reliability analyses and probabilistic aspects; Design criteria, codes and standards; Eurocode 8 and national applications; Seismic risk in the Mediterranean basin; Post earthquake investigations;

This book describes the application of nonlinear static and dynamic analysis for the design, maintenance and seismic strengthening of reinforced concrete structures. The latest structural and RC constitutive modelling techniques are described in detail, with particular attention given to multi-dimensional cracking and damage assessment, and their practical applications for performance-based design. Other subjects covered include 2D/3D analysis techniques, bond and tension stiffness, shear transfer, compression and confinement. It can be used in conjunction with WCOMD and COM3 software Nonlinear Mechanics of Reinforced Concrete presents a practical methodology for structural engineers, graduate students and researchers concerned with the design and maintenance of concrete structures.

A parametric analysis of typical base isolated bridges was conducted. The bridges were located in different soil types and were subjected to three different earthquakes (recorded on soft and medium soils). The work had two main objectives: to assess the effects of the nonlinear behavior of the isolation pads of the bridges on the seismic responses (accelerations, displacements, and pier seismic forces), and to study combined effects of base isolation and inertial interaction due to the presence of flexible foundations. The analytical models used for the study were selected on the basis of initial evaluation of different models proposed in the literature to
represent a bridge structure and to evaluate the isolation pads' nonlinear behavior. The bridges studied were developed with a three-dimensional model. After completing the studies, 2 degree of freedom models were used to investigate more general trends of the inertial SSI effects for the base isolated bridges. The results of the work show the efficiency of base isolation pads in improving the seismic performance of bridges in most cases. They suggest that the inertial SSI effects will not be generally important for bridge foundations designed with a factor of safety of 3, with more than one line of piles in either direction since they will be very stiff foundations. But they also showed that for slender piers it is important to carefully evaluate the translations on top of the piers due to the rocking effects of the foundation.

In order to describe soil-structure interaction in various situations (nonlinear, static, dynamic, hydro-mechanical couplings), this book gives an overview of the main modeling methods developed in geotechnical engineering. The chapters are centered around: the finite element method (FEM), the finite difference method (FDM), and the discrete element method (DEM). Deterministic Numerical Modeling of Soil–Structure Interaction allows the reader to explore the classical and well-known FEM and FDM, using interface and contact elements available for coupled hydro-mechanical problems. Furthermore, this book provides insight on the DEM, adapted for interaction laws at the grain level. Within a classical finite element framework, the concept of macro-element is introduced, which generalizes constitutive laws of SSI and is particularly straightforward in dynamic situations. Finally, this book presents the SSI, in the case of a group of structures, such as buildings in a town, using the notion of metamaterials and a geophysics approach.

Proceedings of the NATO Advanced Research Workshop on Coupled Site and Soil-Structure Interaction Effects with Application to Seismic Risk Mitigation Borovets, Bulgaria 30 August - 3 September 2008

This volume deals with numerical simulation of coupled problems in soil mechanics and foundations. It contains analysis of both shallow and deep foundations. Several nonlinear problems are considered including, soil plasticity, cracking, reaching the soil bearing capacity, creep, etc. Dynamic analysis together with stability analysis are also included. Several numerical models of dams are considered together with coupled problems in soil mechanics and foundations. It gives wide range of modelling soil in different parts of the world. This volume is part of the proceedings of the 1st GeoMEast International Congress and Exhibition on Sustainable Civil Infrastructures, Egypt 2017.

This volume brings together contributions from world renowned researchers and practitioners in the field of geotechnical engineering. The chapters of this book are based on the keynote and invited lectures delivered at the 7th International Conference on Recent Advances in Geotechnical Earthquake Engineering and Soil Dynamics. The book presents advances in the field of soil dynamics and geotechnical earthquake engineering. A strong emphasis is placed on proving connections between academic research and field practice, with many examples, case studies, best practices, and discussions on performance-based design. This volume will be of interest to research scholars, academicians and industry professionals alike.

The second volume in a projected series on dynamic analysis and earthquake resistant design, this text includes topics such as: dynamic analysis of soil-structure interaction system, rupture of ground due to earthquake and its prediction, basic method response calculations and nonlinear problems.

This report describes correlations between analytical and experimental seismic responses of a model bridge structure which was constructed to have the same features as the typical full-scale high curved highway bridge structure. Modifications of the previously reported mathematical procedures for simulating the nonlinear behavior of expansion joints are presented. These include subdividing the time interval of integration and applying an equilibrium correction at the end of each interval and each subinterval. Correlations of displacement response of the bridge model carried out for three different excitations are described. Parameter studies conducted to assist in the interpretation of correlation results are presented, and the characteristics of the dynamic behavior of the bridge model are discussed. General conclusions are summarized.

For large relatively stiff structures, soil structure interaction (SSI) plays a major role in dictating the overall seismic response. In light of recent strong seismic excitation affecting such structures, three-dimensional response as well as nonlinear soil behavior are among the areas of increased interest. As such, a series of numerical studies are conducted to shed more light on the involved SSI mechanisms. Amongst those studies is a comparison of the equivalent linear and nonlinear soil formulations in evaluating the seismic response of large embedded structures. Depending on the level of attained nonlinear response, influence of the following modeling considerations is discussed: i) employing the nonlinear versus linear soil formulation, ii) initial own-weight lateral earth pressure stress-state, and iii) the soil-structure interface characteristics. Both formulations generally resulted in remarkably close estimates of structural response. An opportunity to investigate the SSI mechanisms of large embedded structures due to low amplitude shaking was permitted by the availability of seismic data from an instrumented test site at Higashi-dori, Japan. The compiled data set includes the recorded accelerations, for two downhole arrays, and the response of a 1/10th scale twin reactor. The extracted site properties are shown to provide a reasonable match to the recorded data. Using these properties parametric computational studies are conducted to illustrate salient mechanisms associated with the seismic response of such large embedded structural systems. Furthermore, an opportunity to investigate the seismic response of the Fukushima nuclear reactors due to strong shaking was facilitated by data recorded during the magnitude 9.1 Tohoku earthquake. Linear and nonlinear response of the ground was evaluated using system identification techniques. During the strong shaking, a clear and significant reduction in stiffness was observed within the upper soil strata. Of special interest was the response of Unit 6, which was the most heavily instrumented of the reactors. Response at the base of Unit 6 was compared to that of the nearby downhole array. Amplification of motion along the height of Unit 6 was evaluated, exhibiting the primary role of rocking response.
With construction techniques becoming ever more complex, and population pressure leading to the development of increasingly problematic sites, expertise in the area of soil structure interaction is crucial to architectural and construction industries worldwide. This book contains the proceedings of the ISSMGE Technical Committee 207 International Conference on Geotechnical Engineering - Soil Structure Interaction and Retaining Walls - held in St Petersburg, Russia, in June 2014. The conference was dedicated to the memory of the outstanding geotechnical expert Gregory Porphyryevich Tschetubaitoff. Topics covered at the conference included: soil structure interaction, underground structures and retaining walls, site investigation as a source of input parameters for soil structure interaction, and interaction between structures and frozen soils. The papers included here are the English language papers. Papers presented by the authors in Russian are published by the Georeconstruction Institute of St. Petersburg.

Effort is geared towards development of large-scale nonlinear ground-structure seismic response simulations. Mechanisms to allow for modeling of transmitting boundaries are incorporated, mainly relying on the Domain Reduction Method (DRM) approach. Parallel computing is employed to permit the execution of these large-scale simulations. A range of geometric configurations are addressed in order to explore various aspects of the involved seismic response characteristics. The OpenSees computational platform is employed throughout. To accommodate nonlinear response and soil/structure element stiffness considerations, an implicit time integration scheme is adopted. This scheme poses severe limitations on the number of parallel computing processors that can be used with reasonable efficiency (due to the required taxing communications between the different processors). Within the available constraints on time and computing resources, and the necessary additional OpenSees parallel-implementation machine-specific adaptations, the conducted DRM investigations mostly employed a soil domain 3D 8-node brick element of a 20 m side length (with about 150,000 such elements in the mesh). Consequently, severe limitations are imposed on the frequency content of the propagated seismic waves and the resulting system response. Future extensions in this direction of research can build solidly on the developments in this report and provide more accurate higher frequency system response. Significant attention is given to the simulation of a large-scale highway interchange system under seismic loading. A three-dimensional (3D) Finite Element model of an existing bridge interchange at the intersection of Interstate 10 and 215 (San Bernardino, CA) is developed. This interchange consists of three connectors at different bridge superstructure elevations. Initial focus is placed on modeling the three bridges, evaluation of vibration properties, and validation of one of the bridge models (North-West connector, NW) based on available earlier recorded earthquake response. A strategy to incorporate the above bridge structural models into a bridge-foundation-ground system (BFGS) is implemented based on the Domain Reduction Method (DRM) as developed by Bielak and his co-workers. A numerical implementation of this DRM by Petropolous and Fenves is employed and adapted as the soil domain. In this implementation, seismic waves are propagated from a realistic fault rupture scenario in southern California. As such, the BFGS can include the three-bridge interchange subjected to a 3D seismic excitation scenario. Within this numerical analysis framework, the effect of foundation soils of different stiffness and strength are investigated. The results are compared to the more conventional bridge model response under uniform as well as multi-support base excitation. In addition to this DRM-based implementation, a nonlinear ground-bridge model based on the actual local soil conditions at the interchange is investigated (with the NW only as the super-structure). Efforts include implementation and validation of a classical transmitting boundary at the base of the soil domain. Using this formulation, the BFGS response is compared and validated with earthquake recorded response at the bridge and local site. Under a potential site specific strong ground motion, computed force demands from the employed linear column models are compared to the strength as defined by a representative nonlinear column formulation. Finally, the seismic response of a large rigid structure with different embedment depths is assessed. Dynamic interaction between the structure and the surrounding soil is studied based on changes in soil elastic properties, depth of embedment, and characteristics of input excitation.


While numerous books have been written on earthquakes, earthquake resistance design, and seismic analysis and design of structures, none have been tailored for advanced students and practitioners, and those who would like to have most of the important aspects of seismic analysis in one place. With this book, readers will gain proficiencies in the following: fundamentals of seismology that all structural engineers must know; various forms of seismic inputs; different types of seismic analysis like, time and frequency domain analyses, spectral analysis of structures for random ground motion, response spectrum method of analysis; equivalent lateral load analysis as given in earthquake codes; inelastic response analysis and the concept of ductility; ground response analysis and seismic soil structure interaction; seismic reliability analysis of structures; and control of seismic response of structures. Provides comprehensive coverage, from seismology to seismic control Contains useful empirical equations often required in the seismic analysis of structures Outlines explicit steps for seismic analysis of MDOF systems with multi support excitations Works through solved problems to illustrate different concepts Makes use of MATLAB, SAP2000 and ABAQUAS in solving example problems of the book Provides numerous exercise problems to aid understanding of the subject As one of the first books to present such a comprehensive treatment of the topic, Seismic Analysis of Structures is ideal for postgraduates and researchers in Earthquake Engineering, Structural Dynamics, and Geotechnical Earthquake Engineering. Developed for classroom use, the book can also be used for advanced undergraduate students planning for a career or further study in the subject area. The book will also better equip structural engineering consultants and practicing engineers in the use of standard software for seismic analysis of buildings, bridges, dams, and towers. Lecture materials for instructors available at www.wiley.com/go/dastesismic
Earthquake Geotechnical Engineering for Protection and Development of Environment and Constructions contains invited, keynote, and theme lectures and regular papers presented at the 7th International Conference on Earthquake Geotechnical Engineering (Rome, Italy, 17-20 June 2019). The contributions deal with recent developments and advancements as well as case histories, field monitoring, experimental characterization, physical and analytical modelling, and applications related to the variety of environmental phenomena induced by earthquakes in soils and their effects on engineered systems interacting with them. The book is divided into the sections below: Invited papers Keynote papers Theme lectures Special Session on Large Scale Testing Special Session on Liquefact Projects Special Session on Lessons learned from recent earthquakes Special Session on the Central Italy earthquake Regular papers Earthquake Geotechnical Engineering for Protection and Development of Environment and Constructions provides a significant up-to-date collection of recent experiences and developments, and aims at engineers, geologists and seismologists, consultants, public and private contractors, local national and international authorities, and to all those involved in research and practice related to Earthquake Geotechnical Engineering.

Soil-structure interaction (SSI) effects are relevant for the seismic analysis of tall buildings on shallow foundations since the dynamic behavior of structures is highly affected by the interaction between the superstructure and supporting soils. As part of earthquake-resistant designs of buildings, considering SSI effects in the analysis provides more realistic estimates of its performance during a seismic event, particularly when both the structure and soil undergo large demands that can compromise serviceability. Oversimplifications of structural or soil modeling in the analysis introduces variability and biases in the computed seismic response.

ICSSD 2002 is the second in the series of International Conferences on Structural Stability and Dynamics, which provides a forum for the exchange of ideas and experiences in structural stability and dynamics among academics, engineers, scientists and applied mathematicians. Held in the modern and vibrant city of Singapore, ICSSD 2002 provides a peak at the areas which experts on structural stability and dynamics will be occupied with in the near future. From the technical sessions, it is evident that well-known structural stability and dynamic theories and the computational tools have evolved to an even more advanced stage. Many delegates from diverse lands have contributed to the ICSSD 2002 proceedings, along with the participation of colleagues from the First Asian Workshop on Meshfree Methods and the International Workshop on Recent Advances in Experiments and Computations on Modeling of Heterogeneous Systems. Forming a valuable source for future reference, the proceedings contain 153 papers — including 3 keynote papers and 23 invited papers — contributed by authors from all over the world who are working in advanced multi-disciplinary areas of research in engineering. All these papers are peer-reviewed, with excellent quality, and cover the topics of structural stability, structural dynamics, computational methods, wave propagation, nonlinear analysis, failure analysis, inverse problems, non-destructive evaluation, smart materials and structures, vibration control and seismic responses. The major features of the book are summarized as follows: a total of 153 papers are included with many of them presenting fresh ideas and new areas of research; all papers have been peer-reviewed and are grouped into sections for easy reference; wide coverage of research areas is provided and yet there is good linkage with the central topic of structural stability and dynamics; the methods discussed include those that are theoretical, analytical, computational, artificial, evolitional and experimental; the applications range from civil to mechanical to geo-mechanical engineering, and even to bioengineering.

The consequences of a large dam failing can be disastrous. However, predicting the performance of concrete dams during earthquakes is one of the most complex and challenging problems in structural dynamics. Based on a nonlinear approach, "Seismic Safety Evaluation of Concrete Dams" allows engineers to build models that account for nonlinear phenomena such as vertical joint slippage, cracks, and cavitation. This yields more accurate estimates. Advanced but readable, this book is the culmination of the work carried out by Tsinghua University Research Group on Earthquake Resistance on Dams over the last two decades. Nonlinearity characteristics of high concrete dams, seismic analysis methods, evaluation models A systematic approach to nonlinear analysis and seismic safety evaluation of concrete dams Includes nonlinear fracture of dam-water-foundation interaction system, dynamic fluid-structure and Covers soil-structure interactions, and meso-scale mechanical behavior of concrete are all international front issues of the field.

Risk calculations should focus on providing best estimate results, and associated insights, for evaluation and decision-making. Specifically, seismic probabilistic risk assessments (SPRAs) are intended to provide best estimates of the various combinations of structural and equipment failures that can lead to a seismic induced core damage event. However, in general this approach has been conservative, and potentially masks other important events (for instance, it was not the seismic motions that caused the Fukushima core melt events, but the tsunami ingress into the facility). SPRAs are performed by convolving the seismic hazard (the frequency of certain magnitude events) with the seismic fragility (the conditional probability of failure of a structure, system, or component given the occurrence of earthquake ground motion). In this calculation, there are three main pieces to seismic risk quantification, 1) seismic hazard and nuclear power plants (NPPs) response to the hazard, fragility or capacity of structures, systems and components (SSC), and systems analysis. Figure 1 provides a high level overview of the risk quantification process. The focus of this research is on understanding and removing conservatism (when possible) in the quantification of seismic risk at NPPs.

Frontiers in Offshore Geotechnics II comprises the Proceedings of the Second International Symposium on Frontiers in Offshore Geotechnics (ISFOG), organised by the Centre for Offshore Foundation Systems (COFS) and held at the University of Western Australia (UWA), Perth from 8-10 November 2010. The volume addresses current and emerging challenges.