Preface

The book provides an insight on advanced methods and concepts for the design and analysis of structures against earthquake loading. This second volume of the series is a collection of 28 chapters written by leading experts in the field of structural analysis and earthquake engineering. Emphasis is given on the current state-of-the-art methodologies and concepts in computational methods and their application in engineering practice. The book content is suitable for both practicing engineers and academics, covering a wide variety of topics in an effort to assist the timely dissemination of research findings for the mitigation of seismic risk. Due to the devastating and socioeconomic consequences of seismic events, the topic is of great scientific interest and is expected to be of valuable help to scientists and engineers. The chapters of this volume are extended versions of selected papers presented at the COMPDYN 2011 conference, held in the island of Corfu, Greece, under the auspices of the European Community on Computational Methods in Applied Sciences (ECCOMAS).

In the introductory chapter of Mylonakis et al. the seismic response of inhomogeneous soils is explored analytically using one-dimensional viscoelastic wave propagation theory. The authors treat the problem analytically obtaining the exact solution of the Bessel type for the natural frequencies, mode shapes and base-to-surface response transfer function. The model proposed is validated using available theoretical solutions and finite-element analyses. The chapter presents results that demonstrate the effect of salient model parameters such as layer thickness, impedance contrast between surface and base layer, surface-to-base shear wave velocity ratio in the inhomogeneous layer, rate of inhomogeneity and hysteretic damping ratio.

Lekidis et al. study the Evripos bridge, a famous structure in central Greece that connects the island of Evia to the mainland. The bridge is cable stayed and its behavior to seismic excitations has been continuously monitored. The authors investigate the dynamic response of the bridge due to asynchronous base excitations along its supports and make comparisons with the conventional design procedure of assuming a synchronous base excitation at all supports. Valuable conclusions are drawn regarding the impact of spatially variable ground motion on the seismic response of cable-stayed bridges.

In the chapter of Kostic et al., the authors present a novel beam-column element formulation for the inelastic three-dimensional analysis of frames. Beam-column elements with section resultant plasticity for the hysteretic behavior of the end plastic hinges are widely used for numerical simulations in earthquake engineering because they offer a good compromise between accuracy and computational cost. The chapter presents a lumped plasticity beam-column element with significant capabilities for the description of the global and local response of frames under monotonic and cyclic loads. The proposed element accounts for the interaction of the axial force with the bending moments about the principal section axes with suitably defined yield and limit surfaces that permit the description of the gradual yielding and the post-yield hardening behavior of the end sections. Comparisons of the hysteretic response of structural elements and small structural models between the proposed element and the more accurate, but computationally much more intensive fiber section description of the cross section demonstrate the capabilities of the proposed model.

Adam et al. present a methodology for predicting the seismic peak response of vibratory non-structural elements. The non-structural elements may be attached to both elastic and ductile load-bearing frame structures. The proposed methodology is based on modified modal superposition of floor response spectra for single-degree-of-freedom (SDOF) oscillators on SDOF supporting structures. For several example problems, the "exact" results are contrasted with the outcomes of the proposed methodology. The comparison provides evidence that the proposed methodology delivers sufficiently accurate predictions of the seismic peak response.

Lignos et al. discuss the effectiveness of simplified nonlinear models for the seismic assessment of steel moment frames using single and multi-mode nonlinear static methods. It is demonstrated that the nonlinear static procedure (NSP), also known as pushover analysis, has much value in understanding important behavior characteristics that are not being explored in a nonlinear response history analysis (NRHA) in which engineers usually focus on a "blind" demand/capacity assessment rather than interpretation and visualization of the steel frame behavior. It is also shown that NSP procedures have many limitations for quantitative assessment of steel moment frame demands even for low-rise frames. The authors conclude that both NSP and NRHA have intrinsic value and that it is advisable to employ a combination of both to understand seismic performance of steel moment frames and to quantify important engineering demand parameters for these lateral resisting structural systems.

Pardalopoulos et al. propose a new approach for the rapid preliminary assessment of the seismic vulnerability of reinforced concrete buildings. The method determines the columns' limiting shear resistance at the critical story of the structure by applying a strength assessment procedure associated with typical column details representative of the state of practice from the time that the building was constructed. The severity of the seismic displacement demand and the maximum seismic acceleration that the building can sustain is evaluated with the aid of a stiffness index assessment. The presented method requires prior knowledge only of the basic geometric and material properties of the building. The method is verified on two reinforced concrete buildings that failed during the 1999 Athens earthquake, proving that this approach allows engineers to immediately identify the most vulnerable buildings that are likely to collapse in a potentially strong earthquake and also to assist them on setting objectives for the rehabilitation of RC buildings.

Existing structures have lightly reinforced shear walls and in most cases, especially under cycling loading, shear cracks will appear, reducing the shear capacity of the wall. The aim of the work of Panagouli et al. is to estimate the post-cracking strength of shear walls, taking into account the geometry of existing cracks and the mixed friction-plastification mechanisms that develop in the vicinity of a crack. In this chapter, Panagouli et al. examine a typical shear wall of an existing structure where a crack has been formed. The authors propose a new approach for modeling the geometry of the crack, using the notion of fractal geometry. Due to the significance of the crack geometry, a multi-resolution analysis is performed. The materials (steel and concrete) are assumed to have elastic-plastic behavior, while for concrete both cracking and crushing are taken into account in an accurate manner. On the interface unilateral contact and friction conditions are assumed to hold. For every structure resulting for each resolution of the interface, a classical Euclidean problem is solved. The obtained results lead to valuable conclusions concerning the post-cracking strength of lightly reinforced shear walls.

Mergos and Kappos investigate the seismic behavior of existing RC buildings designed and constructed in accordance with standards that do not meet current seismic code requirements. In these structures, not only flexure, but also shear and bond-slip deformation mechanisms need to be considered, both separately and in combination. The authors have developed a novel finite-element model for the inelastic seismic analysis of planar RC frames. The proposed model is able to capture the gradual spread of inelastic flexural and shear deformations as well as their interaction at the end regions of RC members. Additionally, it is capable of predicting shear failures caused by degradation of shear strength in the plastic hinges of RC elements, as well as pullout failures caused by inadequate anchorage of the reinforcement in the joint regions. The proposed element is verified against experimental results involving individual column and plane frame specimens with non-ductile detailing, showing that satisfactory correlation is established between the model predictions and the experimental evidence.

Taiebat et al. investigate the seismic response and design of basement walls. The authors examine the current state of practice that is based on the Mononobe-Okabe (M-O) method and perform a series of dynamic numerical analyses on a typical basement wall designed with the M-O earth pressures. The wall is subjected to three ground motions spectrally matched to the Uniform Hazard Spectrum prescribed by the NBCC2010 guidelines and the seismic performance of the wall under this level of demand is discussed. The authors give emphasis on peak ground acceleration (PGA) levels appropriate for the design of such structures, since the provisions of current standards tend to overestimate the demand. Particular attention is also given to the resulting drift ratio in the walls.

In the chapter of Asteris et al., the authors discuss the seismic modeling of infilled framed structures. The feasibility of possible immediate implementation for practical design of some recent developments both in analysis and design of infilled frames is first investigated. Moreover, contemporary seismic design codes and guidelines introduce provisions for the calculation of the stiffness of solid infilled frames mainly through modeling the infill walls as “diagonal struts.” However, the case of infilled frames with openings is still an open issue. This chapter uses available finite-element results to propose an analytical equation in order to obtain a reduction factor for the case of frames with openings against solid frames. The validity of the methodology is demonstrated by comparing the results of the proposed equation with the results of various researchers in the literature.

Dasiou et al. deal with the topic of seismic efficiency of restored ancient colonnades using fragments of architectural members. As a common practice, restoration projects of ancient colonnades have to deal with joining together fragments of architectural members using threaded titanium bars (as reinforcement) fixed into place with cement mortar. The basic criterion for the design of such connections is that, in case of a seismic event, the reinforcement should absorb the seismic energy and fail before the marble suffers any damage. The efficiency of the reinforcement of the connection calculated with this methodology is investigated, while two case studies with different geometries: a column of the Parthenon Pronaos and the Southern colonnade of the Ancient Agora of Kos in Greece, are examined. The induced forces were calculated using the distinct element method.

Dimitrakopoulos and DeJong investigate the seismic response of rocking structures and discuss their retrofit with external viscous dampers. Stand-alone rocking structures have been thoroughly investigated, but there are relatively few theoretical studies on the response of retrofitted rocking structures. In this chapter emphasis is given in optimizing the rocking behavior, instead of preventing it, with the aid of viscous dampers. A single rocking block analytical model is utilized to determine the optimal viscous damping characteristics which exploit the beneficial aspects of rocking motion while dissipating energy and preventing overturning collapse. To clarify the benefits of damping, overturning envelopes for the damped rocking block are presented and compared with the pertinent envelopes of the free rocking block. Preliminary experimental work to verify analytical modeling is also presented. In the end of the chapter, the principles of controlling rocking behavior with damping are extended to a particular class of rocking problems, the dynamics of masonry arches. A pilot application of the proposed approach to masonry arches is also presented.

Perus et al. present a web-based methodology for the prediction of approximate IDA curves. The proposed methodology consists of two independent processes. The first process results to a response database of the single-degree-of-freedom model, whereas the second process involves the prediction of approximate IDA curves from the response database by using n-dimensional linear interpolation. The web application utilizes a response database of IDA curves, which was calculated for thirty ground motion records and the discrete values of the six parameters, which describe the period, damping and the force-displacement relationship of a building’s pushover curve. The web application enables quadrilinear idealization of the pushover curve, including strength degradation. Structural collapse capacity can therefore also be estimated. A very good agreement between the computed and the approximated IDA curves is observed, demonstrating that this tool can be a valuable aid for earthquake engineering practice in the future.

De Luca et al. discuss the issue of bilinear fitting of static pushover curves. The authors propose an improvement of codes' bilinear fit for static pushover curves aimed at decreasing the error introduced in the conventional pushover analysis by the piecewise linear fitting of the capacity curve. The error introduced by the bilinear fit of the force-deformation relationship is quantified by studying it at the single-degree-of-freedom (SDOF) system level. Incremental Dynamic Analysis (IDA) is employed to enable a direct comparison of the actual curved backbones versus their piecewise linear approximations. A near-optimal elastic-plastic bilinear fit can be an enhanced solution to decrease systematically the error introduced in pushover analysis, compared to the fit approaches provided by most codes. The main differences are (a) closely fitting the initial stiffness of the capacity curve and (b) matching the maximum strength value, rather than disregarding them in favor of balancing areas or energies. The proposed approach is shown to reduce the conservative bias observed for systems with highly curved force-deformation backbones.

Gkimousis and Koumousis investigate the inelastic behavior of reinforced concrete structures subjected to a number of strong ground motions of escalated Intensity Measure, by monitoring the characteristic Engineering Demand Parameters (EDPs). This provides the necessary data to estimate the overall performance of a structure at a particular site of specified seismic hazard within the framework of Incremental Dynamic Analysis. A series of plane frames of different number of spans and stories is investigated. Moreover, the authors examine also the effect of some general design code provisions on the collapse capacity of the frames studied, such as stiffness distribution along the building height and the strong column-weak beam design principle.

Borzi et al. study the seismic risk assessment of Italian school buildings. The work is based on the idea of defining a methodology that implements an analysis in successive steps with an increasing level of detail in an attempt to identify the most seismically vulnerable school buildings in Italy. The school building location, the exposure data and the seismic input information are implemented in a WebGIS platform through interactive maps and tabs. By means of the developed WebGIS tools, the seismic risk analyses of the school buildings are performed and the obtained results are presented in terms of maps and tables.

Vassilopoulou and Gantes investigate the geometric nonlinear dynamic response of saddle-shaped cable nets subjected to uniform harmonic loads using an equivalent SDOF model. The transformation from the MDOF cable net to the SDOF system is obtained with the aid of similarity relationships. The comparison between the two models by means of the steady-state amplitude of the central node demonstrates that the behavior of the SDOF model describes satisfactorily the response of the MDOF, predicting the dominant nonlinear phenomena.

Naprstek et al. present a work on the nonlinear dynamic behavior of a ball vibration absorber, modeled as a holonomous system. Using Lagrange equations of the second type, the governing nonlinear differential system is derived. The solution procedure combines analytical and numerical processes, where the 2nd Lyapunov method is used as the main tool for the dynamic stability investigation. The function and effectiveness of an absorber identical to those installed at the existing TV towers was examined in the laboratory of the Institute of Theoretical and Applied Mechanics. The response spectrum demonstrates a strongly nonlinear character of the absorber.

Casarotti et al. attempt to evaluate the response of an isolated system based on double curved surface sliders. The objective is to study the response of a particular installation system for Double Curved Surface Sliders for buildings with large plan development in case of construction defects related to the non-perfect co-planarity of the devices. A case study is presented, in which the effects of randomly simulated construction defects are analyzed. Preliminary results showed that the simulated construction defects have only limited influence on the global hysteretic behavior of the system and that the simultaneous loss of contact may occur only for a limited number of devices.

During strong earthquakes, structural poundings may occur between adjacent buildings due to deformations of their stories. In the case of seismically isolated buildings, pounding may occur with the surrounding moat wall due to the insufficient seismic gap at the base of the building. Polycarpou and Komodromos investigate numerically the effectiveness of rubber shock-absorbers as a mitigation measure for earthquake-induced structural poundings. The study presents a methodology that can be used to numerically simulate the use of rubber layers between neighboring structures with relatively narrow seismic gaps in order to act as collision bumpers and mitigate the detrimental effects of earthquake-induced poundings. The efficiency of this potential impact mitigation measure is parametrically investigated considering both cases of conventionally fixed-supported and seismically isolated buildings subjected to various earthquake excitations.

Lavan and Daniel present a methodology for sizing, tuning and allocating multiple tuned-mass dampers in 3D irregular structures. The methodology is based on a two-step iterative analysis/redesign algorithm, which allows obtaining a very efficient amount of added dampers' mass while converging to an allowable response of the structure. This performance-based design methodology is simple, relies on analysis tools only, and is fast converging and thus its use is attractive for the engineering practice. The proposed method allows reducing absolute accelerations to a desirable level following the performance-based design principles. This is achieved using several TMDs located at different places and tuned to several frequencies. The methodology is general in scope and suitable for all types of structures, regardless of the amount of irregularity.

Melkumyan presents three remarkable projects on retrofitting buildings using base isolation. The first is about retrofitting of a five-story stone apartment building without resettlement of the occupants. The second involves the retrofitting of a 60-year-old, three-story stone historical school building and the third project is about the development of the design on retrofitting by base isolation of a 180-year-old historical building. The retrofitting scheme is described and detailed results of the earthquake response analysis for two cases, i.e. when the building is base isolated and when it has a fixed base, are given. For all three buildings comparative analyses of the cost of innovative base isolation retrofitting technology versus the costs of the different methods of conventional retrofitting are presented.

Manos and Mitoulis present an expert system developed for the preliminary design of the seismic isolation of bridges, assumed to respond as a SDOF system. The expert system and the developed software include a series of checks of Eurocode 8-2, in order to ensure the satisfactory seismic "optimum" performance of the selected isolation scheme. In doing so, the software accesses a specially created database of the geometrical and the mechanical characteristics of commercially available cylindrical or prismatic elastomeric bearings, than can be easily enriched by relevant data from laboratory tests on isolation devices. The proposed methodology is validated through rigorous 2D and 3D MDOF parametric numerical analyses and with the case study of a real bridge.

Burczyński et al. investigate new soft-computing techniques in structural dynamics where one tries to study, model, analyze and optimize very complex phenomena, for which more precise scientific tools of the past were not able to give low-cost and complete solutions. The paper deals with various applications on optimization problems of bio-inspired methods, such as evolutionary algorithms (EA), artificial immune systems (AIS) and particle swarm optimizers (PSO). Structures considered in this work are analyzed using the finite-element method (FEM) and the boundary element method (BEM). The bio-inspired methods are applied to optimize shape, topology and the material properties of 3D structures modeled by the FEM and to optimize location of stiffeners in 2D reinforced plates modeled by the coupled BEM/FEM. The structures are optimized using criteria that depend on frequency, displacements or stresses. Numerical examples demonstrate that methods based on soft-computing can be very effective for solving optimal design problems.

Gencturk and Hossain study the optimal design of RC frames, a widely used structural type around the world, considering both the initial cost and structural performance as problem objectives. Initial cost comprises the total cost of materials and workmanship for structural components, while structural performance is measured by a two-level approach. First, each design is checked for acceptability according to existing codes, and next performance is quantified in terms of maximum interstory drift obtained from nonlinear inelastic dynamic analysis. This multi-objective, multi-level approach allows one to investigate the implications of the selection of design parameters on the seismic performance while minimizing the initial cost and satisfying the design criteria. The results suggest that structural performance varies significantly within the acceptable limits of design codes and lower initial cost could be achieved for similar structural performance.

Moutsopoulou et al. present their work on nonsmooth and nonconvex optimization for the design and the order reduction of robust controllers used in smart structures. H-infinity controller design for linear systems is a difficult, nonconvex typically nonsmooth optimization problem when the controller is fixed to be of order less than the one of the open-loop plant, an important requirement in embedded smart systems. A new optimization package is used, aiming at solving fixed-order stabilization and local optimization problems, based on a new hybrid solution algorithm. The problem is to reduce the vibration of the smart system using H-infinity control and nonsmooth and nonconvex optimization.

Decision-making for infrastructure systems is a difficult task to perform because of the complexity and the variety of the types of risks that may occur in the different phases of the life-cycle of an infrastructure system. In their chapter Xenidis and Angelides propose a new methodology for risk-based decision making for planning and operating infrastructure systems. The methodology integrates the variability of impact upon risk occurrence, the available risk-response strategies, and the preference of the decision maker over these strategies with regard to the criticality of the various impacts upon risk occurrence. It considers four risk-response strategies, namely: acceptance, mitigation, transfer, and avoidance. Three approaches are applied, in order to determine the preference margins between these strategies: Compliance with regulations and specifications, determination based on data elaboration, and subjective judgment. Once the expected value of the impact upon risk occurrence is estimated, the decision maker is able to decide for the respective risk-response.

In the last chapter, Soroushian et al. investigate the practical performance of a recent technique for more efficient dynamic analysis of bridge structures with direct time integration. A typical multi-span concrete bridge is considered, in two structural cases (original and upgraded with nonlinear elements), and subjected to four major earthquakes. The analyses are carried out with the Newmark average acceleration method, and the modified Newton Raphson method for nonlinearity iterations, once conventionally (not implementing the recently proposed technique), and then again with implementing the technique proposed. Having implemented the proposes technique in time integration analysis, the responses obtained are very close to the responses of the conventional analyses, while the computational cost is considerably reduced.

The aforementioned collection of chapters provides an overview of the present thinking and state-of-the-art developments on the computational techniques in the framework of structural dynamics and earthquake engineering. The book is targeted primarily to researchers, postgraduate students and engineers working in this scientific field. It is hoped that this collection of chapters in a single book will be found a useful tool for both researchers and practicing engineers.

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