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# General Report — Session 6

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# 6A. SEISMIC ANALYSIS AND DESIGN OF RETAINING AND MARINE STRUCTURES

# and

# 6B. SEISMIC ZONATION, SEISMIC HAZARD ASSESSMENT, SITE CHARACTERIZATION AND GROUND RESPONSE ANALYSIS

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**General Report – Session 6**

## INTRODUCTION

This General Report covers papers submitted to Session 6A on Seismic Analysis and Design of Retaining and Marine Structures, and Session 6B on Seismic Zonation, Seismic Hazard Assessment, Site Characterization and Ground Response Analysis. The Report presents each session separately, and for each session, the Report presents: (1) overview of the topic; (2) review of submitted papers, and (3) final comments on the papers in the session.

## SESSION 6A OVERVIEW – SEISMIC RESPONSE OF RETAINING STRUCTURES

Seismic response of retaining walls is a complex soil-structure interaction problem. The wall movements and pressures depend on the dynamic response and interactions of the wall, foundation strata, and backfill, as well as the characteristics of the input ground motions. Non-linear inelastic behaviour of the soil, and generation and dissipation of pore water pressure in the foundation and backfill during earthquake loading add to the complexity of the problem. Since there are very few well-documented case histories involving field measurements during earthquakes, most of our understanding of the seismic response of retaining structures comes from experimental model tests and numerical analyses. Despite the availability of powerful and advanced computer codes, it is still not possible to accurately model all aspects of the seismic response of retaining walls. Furthermore, current numerical dynamic analysis models are either too complicated or too time consuming that they cannot be adopted in routine practice. As a result, pseudo-static approaches are used in practice for the design of retaining walls. These simplified procedures fall into two basic categories:

- Force-based methods; and
- Displacement-based methods.

In the force-based approach, the loads imposed on the wall during earthquake shaking are determined and wall is designed with appropriate factors of safety, or load and resistance factors, to resist seismic loads. The seismic pressures on the walls are estimated by considering whether the wall will yield or not yield (Kramer 1996). For yielding or flexible walls, the classical Mononobe-Okabe equations (Seed and Whitman, 1970), or its variations, are used to estimate active or passive earth pressures. For non-yielding or rigid walls, the Wood (1973) solutions for linear elastic soil are often used. For more complex ground and site conditions, such as layered soils or non-uniform backslope geometry, limit-equilibrium based slope stability analysis programs are also used to estimate seismic active earth pressures.

In the displacement-based approach, Newmark sliding block type analysis methods, such as that introduced by Richards and Elms (1979), are used in seismic design of retaining walls. The performance based design concept is to allow walls to slide within acceptable limits but not to tilt or rotate, since the latter may lead to wall failures. The displacement–based design approach is widely used in European practice.

More details on the simplified design methods and their limitations for seismic design of various types of retaining walls are given in AASHTO LRFD Bridge Design Specifications (2007) and NCHRP Report 611 (2008).

In the last 10 to 20 years, the use of finite element or finite difference based computer programs to investigate the seismic response of retaining structures is becoming more common. These programs allow consideration of more complicated geometries, time-dependent loads, and soil properties that change with cyclic loading. The numerical methods provide insights into behaviour of the complex soil-structure systems during seismic loading, and allow "calibrations" of the simplified design procedures.

## REVIEW OF PAPERS IN SESSION 6A

Fourteen (14) papers were submitted to Session 6A. The papers are listed in Table 1 in order of their assigned paper numbers, and the types of retaining structures presented in the papers are noted. The papers are briefly summarized and their conclusions discussed, and are presented below under each of the following types of structures:

1) MSW Walls (3 papers);
2) Concrete Cantilever Walls (4 papers);
3) Concrete Rigid Walls (3 papers);
4) Marine Structures (2 papers); and
5) Other Structures (2 papers).

**Table 1. Summary of Papers in Session 6A**

| Paper No. | Authors | Paper Title | MSE Wall | Canti-lever | Rigid Walls | Marine | Others |
|---|---|---|---|---|---|---|---|
| 6.01a | Fransiscus S. Hardianto<br>Kim M. Truong<br>John E. Sankey<br>(USA) | A Review of Seismic LRFD (Load-and-Resistance Factor Design) Method for MSE (Mechanically Stabilized Earth) Walls | X | | | | |
| 6.04a | Kalliopi Kakderi<br>Kyriazis Pitilakis<br>(Greece) | Seismic Analysis and Fragility Curves of Gravity Waterfront Structures | | | | X | |
| 6.05a | Yung-Yen Ko<br>Ho-Hsiung Yang<br>Cheng-Hsing Chen<br>(Taiwan) | Seismic Fragility Analysis of Sheet Pile Wharves – Case Study of the Hualien Harbor in Taiwan | | | | X | |
| 6.06a | Mohammadreza Abbasi Garavand<br>Alireza Saberi<br>Mona Salimi Ghezelbash<br>(Iran) | Seismic Analysis of Retaining Wall Structures | | X | | | |
| 6.07a | Yohsuke Kawamata<br>Scott A. Ashford<br>(USA) | Discussions on Dynamic Interaction Between Piles and Large Particle Rockfill | | | | | X |

**Table 1. Summary of Papers in Session 6A (cont'd)**

| Paper No. | Authors | Paper Title | MSE Wall | Canti-lever | Rigid Walls | Marine | Others |
|---|---|---|---|---|---|---|---|
| 6.08a | Francesco Leuzzi<br>Sebastiano Foti<br>Renato Lancellotta<br>(Italy)<br>George Mylonakis<br>(Greece) | Dynamic Response of Cantilever Retaining Walls Considering Soil Non-Linearity | | X | | | |
| 6.09a | Anitha Nelson<br>P.K. Jayasree<br>(India) | Seismic Response of Reinforced Soil Retaining Walls with Block Facings | X | | | | |
| 6.15a | Aditya Parihar<br>Navjeev Saxena<br>D.K. Paul<br>(India) | Effects of Wall-Soil-Interaction on Seismic Response of Retaining Wall | | X | | | |
| 6.16a | J. Matos e Silva<br>(Portugal) | Diaphragm Walls Seismic Design According to the Eurocodes | | | X | | |
| 6.18a | Zhiqiang Li<br>Jinbei Li<br>Yaping Kong<br>(China) | Analysis of Aseismic Reliability Considering the Uncertainties both Structural Parameters and Earthquake Loadings for Gravity type Earth-Retaining Wall | | | X | | |
| 6.20a | Guoxi Wu<br>(Canada) | Seismic Soil Pressures on Rigid Walls with Sloped Backfills | | | X | | |
| 6.22a | Omar Al-Farouk Salem Al-Damluji<br>Akram Younis Thanoon Al-Sa'aty<br>Rafi Mahmoud Sulaiman Al-Nu'aimy<br>(Iran) | Effects of Internal Gas Explosion on an Underwater Tunnel Roof | | | | | X |
| 6.24a | Binod Shrestha<br>Hadi Khabbaz<br>(Australia) | Application of Vertical Reinforcement for Performance Enhancement of Reinforced Soil under Seismic Loading | X | | | | |
| 6.27a | Alberto Pettiti<br>(Italy)<br>Dominic Assimaki<br>(USA)<br>Sebastiano Foti<br>(Italy) | Numerical Simulation of the Performances of Cantilever Walls Subjected to Seismic Loading | | X | | | |

MSE Walls

**Paper No. 6.01a by Hardianto, F.S., Truong, K.M. and Sankey, J.E.** presented a study comparing the seismic design of a typical MSE (mechanical stabilized earth) wall using LRFD (load and resistance factor design) and ASD (allowable stress design) methods. The comparative design followed the displacement-based LRFD method in AASHTO (2007), and the force-based ASD method in AASHTO (1996, 2002). A series of parametric analyses were performed to examine the influence of wall height, reinforcement length, acceleration coefficient, wall displacement, and top of wall geometry (i.e. backfill slope angle). The study found little difference between the two design methods, provided the appropriate amount of tolerable wall deformation is selected. The authors concluded that since MSE walls were designed based on traditional ASD method and have performed well during earthquakes, the new AASHTO LRFD (2007) method for seismic design of MSE wall is conservative.

The authors have provided a nice summary and background of the LRFD and ASD methods for design of MSE walls. However, the paper did not provide details of the analyses performed for the parametric study of the MSE wall.

**Paper No. 6.09a b**y **Nelson, A and Jayasree, P.K.** described the seismic numerical analyses of a 6 m high reinforced soil retaining wall with two alternative types of facing: (1) modular concrete block facings and (2) gabion facings. The finite element program PLAXIS V8 was used to analyze the walls at the end of construction and subjected to seismic loading simulated by means of a variable amplitude harmonic vibration. Water was not considered in this study. The study investigated and compared the response of the two walls in terms of lateral facing deflection, dynamic earth pressure, reinforcement tensile force, acceleration amplification factor, and crest surface settlement subjected to dynamic loading with peak acceleration of 0.2 g. Parametric analyses were also conducted to examine the effects of changes in input loading characteristics, backfill properties and reinforcement parameters. The study found that gabion faced reinforced soil wall performed better than segmental faced wall in terms of lateral deflections, reinforcement tensile forces, acceleration amplifications, and crest settlements. The study also found that dynamic loading frequency, backfill properties and reinforcement length were important parameters affecting the response of the reinforced soil walls.

The authors have presented a methodical approach using finite element analyses to compare the seismic performance of reinforced soil walls with concrete block facings and with gabion facings. The authors' conclusion, that gabion faced walls are more effective than concrete block faced walls in resisting earthquake loading, should be further checked by model tests or field observations of walls subjected to actual earthquakes.

**Paper No. 6.24a b**y **Shrestha, B. and Khabbaz, H.** presented a new concept of using vertical reinforcement to improve the static and seismic performance of conventional reinforced soil walls with horizontal reinforcement. The authors used theoretical models to describe the potential improvement of soil behaviour under static loading against bearing failure, tensile over-stress, and pull-out failure; and under dynamic loading against overturning, and bulging failure modes. Two possible construction methods to insert and stitch two horizontal reinforcing layers together were proposed in the paper.

The authors have presented an interesting concept to increase the seismic performance of reinforced soil walls using vertical reinforcement inclusions. As they acknowledged, this concept is in its initial stages and further research, including numerical modeling and experimental testing, are underway. The practical application and cost effectiveness of this method will also need to be evaluated before it will be adopted in construction.

Concrete Cantilever Walls

**Paper No. 6.06a by Gavarand, M.A., Saberi, A. and Ghezelbash, M.S.** described a 3D dynamic finite element analysis of a concrete cantilever retaining wall carried out using the computer program ANSYS. Recorded earthquake strong motion time histories were used in the analysis. Nonlinear behaviour of the soil, concrete and reinforcement were apparently modeled using the material models available in the ANSYS programs. A transmitting boundary was also apparently used. The paper suggested that their numerical modeling results gave similar damage pattern as observed on a retaining wall in Japan that was damaged by the 1995 Kobe earthquake. The paper also compared the results of the nonlinear dynamic analysis with earth pressures calculated from classical Rankine and Coulomb solutions, which indicated dynamic earth pressures substantially less than active earth pressures from classical theories.

The paper appears to be an exercise in numerical dynamic analysis, with no details presented. It is not clear why a 3D model is needed to model a 2D plane strain problem. The need for nonlinear material models for concrete and reinforcement is also not demonstrated. The authors' conclusion that earth pressures from classical theories for cantilever walls are overly conservative compared to their computed dynamic earth pressures may be misleading. Overall, this paper does not add any contribution to existing knowledge.

**Paper No. 6.08a by Leuzzi, F., Foti, S., Lancellotta, R. and Mylonakis, G.** presented results of a systematic parametric study conducted using the finite difference code FLAC to investigate the effects of various factors affecting the dynamic soil-structure interaction of cantilever retaining walls. Starting from simple cases involving the elastic response of a homogeneous soil and moving gradually towards more realistic conditions involving nonlinear-hysteretic response of inhomogeneous soil under a range of dynamic loadings, the salient features of the dynamic soil-structure interaction problem were addressed. The factors examined included soil inhomogeneity, nonlinear-hysteric behaviour of soil, level of excitation, and ratio of excitation frequency and fundamental frequency of backfill soils. In addition, the effects of flexibility of the wall and rotational restraint at the base of the wall were also examined. The results were presented in non-dimensional parameters that removed the effect of magnitude of various parameters and helped to illustrate effects of flexibility of the wall relative to backfill. The consideration of soil inhomogeneity for rigid walls under elastic condition was shown to reduce the internal forces in the structure, and also the tensile stresses near the top of the wall for large flexible wall. The elastic-plastic analyses for flexible walls illustrated that the dynamic amplification was important for excitation frequency between one and two times the fundamental frequency of the backfill, and the consideration of soil non-linearity was shown to elongate the resonant period of the soil layer, which may reduce potentially adverse amplification effects.

The analyses and results presented in the paper are methodical and provide nice insights into various aspects of dynamic soil-structure interaction. Most of the results have previously been addressed in the literature. As noted by the authors, further analysis of case histories and model experiments using real earthquake records and comparisons of analytical results are needed. The FLAC tool with its strain based built-in hysteretic model, which the authors used for the dynamic analysis, appears promising. However, its use for routine analysis in practice is questionable.

**Paper No. 6.15a by Parihar, A., Saxena, N. and Paul, D.K.** presented results from analyses conducted to study the effect of potential separation and slip between a concrete cantilever wall and the backfill under static and earthquake loading conditions. 2D finite element analyses were conducted with and without interface elements using the computer program ANSYS. The study showed the effect of potential separation and slip near the top of the wall, which resulted in reduction in earth pressures under static conditions. Free vibration analysis results indicated that the wall-soil interaction models were more flexible (i.e. larger fundamental periods of vibration) than the wall itself fixed at the base. Results suggested maximum dynamic earth pressures 1 to 1.7 times higher than static earth pressures.

No details of the constitutive models for the soil and wall are given in the paper. Results are shown without explanation of the trends. How the addition of interface elements alters the dynamic characteristics of the wall and backfill under earthquake loading would have been useful, but is not demonstrated in the paper.

**Paper No. 27a by Pettiti, A., Assimaki, D. and Foti, S.** presented results from a carefully conducted numerical analysis of a flexible cantilever retaining wall subjected to earthquake loading using the finite element computer program DYNAFLOW. A multi-yield plasticity constitutive model with Mohr-Coulomb yield functions and a kinematic hardening rule was used for the soil, and the concrete diaphragm wall was treated as linear elastic material. The analyses were conducted in steps. An initial static analysis was conducted to establish the in-situ stress state due to gradual excavation, and it was continued by dynamic analysis. A suite of seven earthquake records were used in the dynamic analysis. Results were presented showing wall bending moment, displacement and acceleration profiles from the seven input earthquake records scaled to 0.25g and 0.35g. Comparison of bending moment profiles predicted using a simplified pseudo-static approach and the dynamic analysis showed that the estimates using the pseudo-static approach were conservative.

The authors have presented interesting results from their numerical simulation of a flexible cantilever concrete diaphragm wall at the end of excavation and during earthquake loading. As they indicated, more parametric analyses with different input loading and further validation of predictions using model test results are needed.

<u>Concrete Rigid Walls</u>

**Paper No. 6.16a by Matos e Silva, J.** described the estimation of seismic earth pressures on anchored diaphragm wall based on Eurocode 8 and Portuguese Standard ENV 1998-1-1. Eurocode 8 uses the Mononobe-Okabe equation for estimation of active and dynamic earth pressures and Portuguese ENV provides seismic zonal accelerations for Portugal. The paper indicated that applying this procedure to diaphragm walls in a stadium in Coimbra, Portugal resulted in 40% increase in anchor forces due to seismic loading and resultant deepening of the walls. Unfortunately, the paper did not provide any details of the seismic analysis or design of the stadium diaphragm walls.

**Paper No. 6.18a by Li, Z., Li, J. and Kong, Y.** proposed a method for evaluating the seismic response and reliability of gravity retaining walls considering uncertainties in soil and wall parameters and earthquake loading. The reliability analysis was incorporated into a finite element modeling of a concrete gravity wall. The results of the dynamic reliability analysis were compared to Richard-Elms displacement method analysis of the same wall, and to field performance of a collapsed wall due to the 1994 Northridge earthquake. The paper also highlighted the importance of including the nonlinear behaviour of the soils. Unfortunately, the paper is difficult to follow due to poor English and presentation.

**Paper No. 6.20a by Wu, G.** described parametric analyses using the 2D finite element computer program VERSAT-2D to estimate soil pressures on rigid walls with horizontal and sloping backfills. Nonlinear time history analyses were conducted using a hyperbolic stress–strain model to simulate the hysteresis response of soil under irregular earthquake loads. A suite of eight recorded earthquake time histories scaled to three levels of ground motions were used in the analyses of a 5 m high rigid wall for three cases of backfill conditions: horizontal backfill consisting of loose sand, 2H:1V sloping backfill of loose sand, and 2H:1V sloping backfill of dense sand. The rigid wall and dry backfills were modelled on a rigid base. A soil pressure coefficient, $K_{0E}$, was introduced to represent the total static plus the average of the seismic pressures from the eight earthquake records. The results showed that the 2H:1V slope resulted in total soil pressures twice as high as those with horizontal backfill, and an increase of 10%-15% in the height to the point of thrust for sloping backfill compared to the horizontal backfill. The results also indicated seismic soil pressures from dense backfill were acting higher above the base of wall than those from loose backfill, due to the decrease in depth of passive failure zone in dense sand compared to loose sand.

The author has presented a methodical parametric study that clearly demonstrates the effect of sloping backfills on rigid wall seismic pressures and the capabilities of VERSAT-2D as a tool to capture the behaviour. The paper also illustrates the necessity of using a large suite of earthquake time histories, instead of a single record, to remove uncertainties in the input ground motions. Note that the analyses presented in the paper are confined to a 5 m high model wall with idealized dry sand backfills. Thus, as the author indicated, the purpose of the paper is to illustrate a method of analysis and not to produce design charts on seismic pressures acting on rigid retaining walls.

<u>Marine Structures</u>

**Paper No. 6.04a by Kakderi, K. and Pitilakis, K.** proposed fragility curves for water front/retaining gravity structures for ground shaking without the presence of liquefaction. They used the computer program PLAXIS to perform 2D finite element analyses of concrete gravity quay walls typically found in Greece and Europe. Parametric analyses were performed with four different wall heights and two width-to-height ratios, four different ground conditions, and five earthquake records from Europe scaled to five levels of peak ground accelerations. Displacement time histories were used as input in the finite element models, and a total of 800 analyses were carried out. The authors checked the reasonableness of the results by comparing the computed residual horizontal displacements at top of wall with observed damages of quay walls from earthquakes and with experimental data. They then used the results of the numerical analyses to derive fragility curves, which describe the probability of reaching or exceeding defined damage states for a given level of peak ground acceleration, for gravity quay structures.

The paper presents a methodical approach using numerical modeling to derive fragility curves for waterfront gravity quay structures and idealized ground conditions typical in Europe. The fragility curves can be useful for seismic assessment of port facilities subjected to earthquake shaking in the absence of liquefaction. The reliability of these curves should be checked as more field data from damaged quay structures become available.

**Paper 6.05a by Ko, Y.Y., Yang, H.H. and Chen, C.H.** performed seismic fragility analyses for the sheet pile wharves at Hualien Harbor in Taiwan. The finite element software PLAXIS was used for the 2D dynamic nonlinear analyses. Initially, analyses were conducted on two types of anchored sheet pile walls subjected to two levels of earthquake ground motions, corresponding to return periods of 75 and 475 years. The input earthquake was a time history record from the 2002 Hualien offshore earthquake. The seismic responses of the two wharves appeared reasonable when compared to industry guidelines on expected damage states of sheet pile wharves (PIANC, 2001). Subsequently, dynamic analyses of the two wharves were conducted with a suite of 12 selected earthquake records from Taiwan, in both horizontal components, and scaled to 12 peak ground acceleration levels ranging from 0.1g to 1.0g (i.e. 288 input time histories). The computed maximum residual displacements at the top of the sheet pile walls were lognormally distributed to obtain the fragility curves for the two wharves. The fragility curves define the conditional probabilities that the structural damage meets or exceeds specified damage states under various levels of peak ground accelerations.

The authors have presented a systematic study using numerical analyses to determine seismic fragility curves for two typical sheet wall wharves at Hualien Harbor. The fragility curves can be used for earthquake loss estimation of the harbor facilities. As the authors alluded, the numerically determined fragility curves should ideally be verified or checked against field data of earthquake-damaged sheet pile wharves.

<u>Other Structures</u>

**Paper No. 6.07a by Kawamata, Y. and Ashford, S.A.** dealt with the cyclic response of concrete piles embedded in large particle rockfill. Full scale lateral load pile tests were conducted on five instrumented prestressed concrete piles embedded in rockfill at the University of California, San Diego in 2007 to improve understanding of the seismic performance of wharf-pile-rockfill dike system. The piles were instrumented with tiltmeters and strain gauges, and cyclic loads were applied at the pile heads using a hydraulic actuator. In the first part of the paper, a brief description of the test setup, experiments, and some examples of the test results (i.e. pile top load-displacement curves, and pile rotation profiles from tiltmeters) were presented. Based on the test results and observations during the tests, some possible mechanisms affecting soil-pile interaction under dynamic cyclic loading conditions were discussed in the second part. The paper also compared the field test data with numerical results based on current practice, which indicated that p-y curves from current design practice resulted in much lower lateral resistance of the soil-pile system.

The paper presents some interesting insights into the cyclic response of piles embedded in rockfill. The authors suggest that a stress-independent particle compression of rockfill under dynamic lateral loading increases the soil reaction, and that this should be taken into account to come up stiffer p-y curves for design. This hypothesis will require more fundamental and thorough analysis before it can be adopted in seismic design practice.

**Paper No. 6.22a by Al-Damluji, O.A.S., Al-Sa'aty, A.Y.T. and Al-Nu'aimy, R.M.S.** presented analytical formulations for finite element modeling of an underground reinforced concrete tunnel roof subjected to internal gas explosion. Coupled and uncoupled solutions to the soil-pore fluid-structure interaction problem were presented. Three load cases, namely, gravity dead load, uniformly distributed overburden load (sand and water), and dynamic load from internal gas explosion, were considered. Linear and non-linear constitutive relationships for reinforced concrete materials were also considered. A computer code was developed for predicting the behaviour of tunnel roof due to an internal gas explosion in the tunnel. No verification of the analytical model with experimental test or field performance was conducted.

Although effect of gas explosion in a tunnel is an interesting civil engineering issue, this paper does not fit within the topic of Session 6A.

## FINAL COMMENTS ON SESSION 6A

The 14 papers submitted to Session 6A cover a wide variety of earth retaining structures used in transportation corridors and marine structures. Of the 14 papers, 10 papers employed numerical analyses to study the seismic response of retaining walls. Most of the analyses assumed 2D or plane strain, which is appropriate for most retaining wall problems, and were based on either finite element or finite difference methods. The following commercially available computer programs were used (together with the paper numbers in parenthesis):

- PLAXIS (6.04a, 6.05a and 6.09a)
- ANSYS (6.06a and 6.15a)
- FLAC (6.08a)
- VERSAT (6.20a)
- DYANFLOW (6.27a)

Dynamic soil-structure interaction behaviour of retaining structures is one of the most complex problems in geotechnical earthquake engineering. Capturing nonlinear hysteretic behaviour of soil and ductile behaviour of the reinforced concrete are becoming important aspects, particularly since the state-of-practice is moving towards adopting performance based approach. Effect of pore pressures during seismic loading is another important factor, particularly for marine structures.

## SESSION 6B OVERVIEW – SEISMIC ZONATION AND SEISMIC HAZARD ASSESSMENT

Earthquakes can cause damage to structures, or even collapse. The extent of damage depends on seismic response of the structure and foundation support, as well as the magnitude and characteristics of the ground motions. The consequence of damage or failure dictates the acceptable level of ground motion for design, which is usually expressed in terms of the probability of exceedance, or return period, of certain level of ground motion. In practice, the design ground motion is usually determined by conducting a probabilistic seismic hazard assessment, either for building code purposes or for a specific site.

Probabilistic seismic hazard assessment (PSHA) is usually carried out using the well-known Cornell-McGuire method, which has been the basis for seismic hazard provisions of building codes in US, Canada and elsewhere. The four steps in a typical PSHA consist of definition of seismic sources as either areal or line (fault) sources, definition of earthquake frequency within each source zone, definition of ground motion prediction equation for earthquakes in each source, and, finally, numerical summation of hazard contribution to the site from all earthquake magnitudes at all distances from each source. Commercial computer programs are available to perform the calculations in the last step.

Characterization of earthquake sources, development of source zone models and model parameters, and selection of ground motion prediction equations (GMPE) are the key elements in a PSHA. Seismological and geological data are traditionally used in the characterization of sources. However, the use of geodetic data is becoming increasingly popular with the availability of GPS and other remote sensing data, especially in regions that are capable of producing large earthquakes.

The accumulation of ground motion data from recent earthquakes and extensive research effort in the past two decades have led to development of more accurate GMPEs. One such notable set of equations is the product of the New Generation Attenuation Models Project (NGA), which was sponsored by Earthquake Engineering Research Institute to develop equations for shallow crustal earthquakes in Western North America. These equations were immediately adopted by US Geological Survey to develop seismic hazard maps for Western US. The newer GMPEs consider many factors explicitly, including the site conditions and type of fault, and use the distance term in the equations more objectively. The newer GMPEs for both crustal and subduction earthquakes can be used to generate not only the peak ground accelerations, but also the complete response spectra. Thus, these newer GMPEs facilitate the development of Uniform Hazard Response Spectra (UHRS) from PSHA for a particular reference site condition.

Uncertainties in the seismic hazard assessment should be considered and addressed quantitatively to obtain reliable estimate of ground motions. Recent seismic codes emphasize the need for treatment of uncertainties in the estimation of seismic hazard. Two types of uncertainties are normally considered in PSHA, namely the aleatory uncertainty and the epistemic uncertainty. Aleatory uncertainty is readily incorporated within the Cornell-McGuire analysis frame work by integrating over the statistical distribution in the ground motion relations and by considering the randomness in earthquake location. The epistemic uncertainty, which is due to incomplete understanding of the physical models governing earthquake occurrence and ground motion generation, is usually treated following a logic or event tree approach. In a logic tree, uncertainties such as the different choices for source zones models, GMPEs, model parameters such as the recurrence rate, maximum magnitude, depth, etc. are considered and weighed subjectively. The logic tree approach allows the determination of ground motions at the desired confidence level, e.g. mean, median (50$^{th}$) or 84$^{th}$ percentiles. The choice of confidence levels is also specified by some seismic codes. For example, in Canada, median values are recommended for buildings, while mean values are used for dams.

Seismic hazard assessment is a rapidly evolving field with emerging new technologies to characterize sources, advances in GMPEs, and methods to address uncertainties in a PSHA. These advances together with new earthquake and geological data have prompted many countries to update their seismic hazard maps regularly. The regulatory bodies also emphasize the need for a site specific seismic hazard assessment for critical structures such as dams, and they often call for a detailed PSHA. However, the level of effort put into a PSHA starting from the characterization of source zones to estimation of ground motions can vary considerably. The level of effort is usually dictated by how much we know about the tectonic setting of the site and the nearby faults, how much data we have to calibrate our models, and how good our choice of GMPEs are. A simple PSHA for a complex site can result in an unreliable estimate of ground motions. In some aspects of PSHA, experts also may not necessarily agree, primarily due to lack of research in these areas. For example, whether the ground motions in a PSHA should be truncated at three epsilons or not remains a contentious issue. Thus, a process called Senior Seismic Hazard Analysis Committee (SSHAC) has been adopted for major infrastructure projects. The SSHAC process divides the hazard assessment into four levels depending on the complexity of the problem, risk and perception. A level 1 assessment may be suitable for a relatively easy site while a level 3 is warranted for a complex site or sites. Level 3 assessment involves gathering data from available resources, seeking opinions from experts in various fields, developing a fairly comprehensive model and assessment process, and having all of these reviewed by a panel of peer reviewers. One such effort in currently underway by BC Hydro to develop ground motions for their 41 dams located in British Columbia, Canada (McCann et al. 2009).

There have been significant advances in various aspects of PSHA which addressed many issues associated with the process and improved the method as whole. As a result, some of the road blocks for the use of PSHA in routine practice have been removed, and more and more people are using it. However, more research is clearly warranted, as the results of PSHA have important design and cost implications.

## REVIEW OF PAPERS IN SESSION 6B

Fifteen (15) papers were submitted to Session 6B. The papers are listed in Table 2 in order of their assigned paper numbers, and the types of seismic analyses or applications presented in the papers are noted. The papers are briefly summarized and their conclusions discussed, and are presented below under the following headings:

1) Seismic Hazard Analyses (7 papers);
2) Site Characterization (3 papers);
3) Ground Response Analyses (3 papers); and
4) GIS Microzonation (2 papers).

**Table 2. Summary of Papers in Session 6B**

| Paper No. | Authors | Paper Title | Seismic Hazard Analysis | Site Character-ization | Ground Response Analysis | GIS Micro-zonation |
|---|---|---|---|---|---|---|
| 6.02b | Kaveh Andisheh<br>Seydeh Sara Hossini<br>Motaza Taghizadeh<br>(Iran) | Preparation the Site Specific Spectrum for Civil Regions of Zagross Mountains | X | | | |
| 6.03b | Kaveh Andisheh<br>Gholamreza Ghodrati Amiri<br>Motaza Taghizadeh<br>(Iran) | Evaluating Seismicity Parameters of Sanandaj, Iran based on Instrumental Earthquake | X | | | |
| 6.04b | Kaveh Andisheh<br>Gholamreza Ghodrati Amiri<br>Seyed Ali Razavyain Amrei<br>(Iran) | Uniform Seismic Hazard Spectra of Sanandaj, Iran | X | | | |
| 6.05b | Llambro Duni<br>Luljeta Bozo<br>Neki Kuka<br>Enkela Begu<br>(Albania) | An Upgrade of the Microzonation Study of the Centre of Tirana City | X | | | |
| 6.06b | Ivanka Paskaleva<br>Mihaela Kouteva<br>(Bulgaria)<br>Franco Vaccari<br>Giuliano F. Panza<br>(Italy) | Characterization of the Elastic Displacement Demand: Case Study - Sofia City | X | | | |
| 6.07b | Hing-Ho Tsang<br>(Hong Kong)<br>Saman Yaghmaei Sabegh<br>(Iran)<br>P. Anbazhagan<br>(India)<br>M. Neaz Sheikh<br>(Australia)<br>T. G. Sitharam<br>(India)<br>J. S. Vinod<br>(Australia) | An Alternative Method for Probabilistic Seismic-Hazard Assessment: A Case Study of Three Cities | X | | | |
| 6.09b | Simone Barani<br>Roberto De Ferrari<br>Gabriele Ferretti<br>Daniele Spallarossa<br>(Italy) | Calibration of Soil Amplification Factors for Real Time Ground Motion Scenarios in Italy | | | X | |

**Table 2. Summary of Papers in Session 6B (cont'd)**

| Paper No. | Authors | Paper Title | Seismic Hazard Analysis | Site Character-ization | Ground Response Analysis | GIS Micro-zonation |
|---|---|---|---|---|---|---|
| 6.10b | Luis Osorio Flores<br>Juan M. Mayoral Villa<br>Miguel P. Romo<br>(Mexico) | Seismic Microzonation of the Texcoco Lake Area, Mexico | | | X | |
| 6.12b | Arif Mert Eker<br>Haluk Akgün<br>Mustafa Kerem Koçkar<br>(Turkey) | A Comparison of Local Site Conditions with Passive and Active Surface Wave Methods | | X | | |
| 6.13b | Piera Paola Capilleri<br>Michele Maugeri<br>Erminia Raciti<br>(Italy) | Geotechnical and Seismic Risk Evaluation in Urban Areas | | | | X |
| 6.14b | Jan Willem Roelof Brouwer<br>Torild Van Eck<br>Femke Goutbeek<br>A.C.W.M. Vrouwenvelder<br>(Netherlands) | The Meaning of Eurocode 8 and Induced Seismicity for Earthquake Engineering in the Netherlands | X | | | |
| 6.16b | Gloria Estrada<br>(Colombia) | Analysis of Earthquake Site Response and Site Classification for Seismic Design Practices | | | X | |
| 6.17b | Syed M. Ali Jawaid<br>(India) | Comparison of Liquefaction Potential Evaluation based on Different Field Tests | | X | | |
| 6.20b | Vera Pessina<br>Emilia Fiorini<br>Roberto Paolucci<br>(Italy) | GIS-based Identification of Topographic Sites in Italy with Significant Ground Motion Amplification Effects | | | | X |
| 6.23b | Chavdar V. Kolev<br>Martina G. Perikliyska<br>(Bulgaria) | Geotechnical Preconditions for Skyscrapers Construction in Bulgaria and Seismic Risk Aspect | | X | | |

Seismic Hazard Analyses

**Paper No. 6.02b by Andisheh, K., Hossini, S.S. and Taghizadeh, M.** summarized the probabilistic seismic hazard assessment study of five cities in Kurdistan province of Iran. Kijko method was adopted to calculate seismic parameters with consideration of incomplete earthquake catalogue and uncertainty in magnitude. A logic tree approach with five attenuation relationships was used in the computer program SEISRISK-III to calculate peak horizontal ground acceleration (PGA) on bedrock at four hazard levels for the five cities. The "average" bedrock PGAs were then used to estimate smooth response spectra of each city for both rock and soil sites and for 50%, 20%, 10% and 2% probability of being exceeded in 50 years, based on Newmark-Hall method. The Newmark-Hall derived spectra were compared with design spectra specified in the Iranian code of practice for seismic resistant design of buildings.

This paper could be improved by comparing the Iranian seismic design code requirement with modern seismic hazard assessment methodology, using updated research findings including new ground motion prediction equations. Unfortunately, the outdated methodology adopted in this study severely limits its usefulness to the earthquake engineering community. As well, this paper is English-challenged and contains little details of the analyses or explanations of the findings.

**Paper No. 6.03b by Andisheh, K., Ghodrati Amiri, G. and Taghizadeh, M.** presented an evaluation of seismic parameters of five earthquake recurrence models for Sanandaj, Iran. The five models are: Gutenberg-Richter model, Kijko-Sellevoll method, Gumbel Distribution Functions Type I, Type III and Type S. The database consisted of earthquakes recorded from 1900 to 2006 within 200 km of Sanandaj city. The temporal variations of seismicity were also evaluated for the instrumental earthquake records.

This paper is a fundamental element for subsequent seismic hazard assessments for this region of Iran, and could be an important contribution to the local Iranian community. However, in-depth analysis and discussion of results are lacking, so that no useful finding can be concluded from this study.

**Paper No. 6.04b by Andisheh, K., Ghodrati Amiri, G. and Razavian Amrei, S.A.** presented the results of a probabilistic seismic hazard assessment (PSHA) study of Sanandaj, Iran. Earthquakes within 200 km radius of Sanandaj city, together with a European-based attenuation relationship, were used to compute uniform hazard response spectra (UHRS) for rock, stiff soil or soft soil sites. The maximum, mean and minimum UHRS calculated for the three site classes were presented for 10% and 2% probability of being exceeded in 50 years. The paper concluded that proposed spectral accelerations in the Iranian Code of Practice are conservative when compared to the UHRS in this study.

Similar to Papers 6.02b and 6.03b, the authors have not provided details of their analyses or explanations of their findings.

**Paper No. 6.05b by Duni, L., Bozo, L., Kuka, N. and Begu, E.** presented the results of a probabilistic seismic hazard assessment (PSHA) study for Tirana city, Albania, using the spatially smoothed seismicity approach. Peak ground acceleration (PGA) values and uniform hazard response spectra (UHRS) were computed for firm rock site condition (corresponding to site class A specified in Eurocode 8) and for return periods of 95, 475, 975 and 2475 years. Deaggregation of the seismic hazard, based on PGA at the 475-yr return period, was then conducted and used to develop a suite of acceleration time histories representing rock motions for ground response analysis. Two synthetic times histories were generated using stochastic simulations of the seismological model, and three regionally recorded earthquake time histories were selected. The five acceleration time histories were scaled to the 475-yr PGA and used in 1D level ground response analysis of five representative idealized soil profiles in Tirana to calculate the peak acceleration profiles of the soil models and response spectra. Finally, the calculated surface response spectra were compared with the corresponding spectral shapes codified in Eurocode 8.

This study should be useful for upgrading the seismic code design requirement of Tirana city. The authors have adopted modern basic methodology for the study, considering the seismotectonic environment and the available data of the region. Additional details of the authors' treatment of uncertainties in the PSHA and the soil modelling in the ground response analyses would make his paper more valuable to the profession.

**Paper No. 6.06b by Paskaleva, I., Kouteva, M., Vaccari, F. and Panza, G.F.** presented the results of a deterministic seismic hazard assessment study used to generate synthetic ground motion database for Sophia city, Bulgaria. The synthetic waveforms were generated for four earthquake scenarios using a hybrid approach that combined the modal summation technique and the finite difference method. Displacement response spectra calculated from the synthetic time histories for three geological models in Sophia city were compared with the design spectra recommended in Eurocode 8. Subsequently, the response spectra in standard acceleration/displacement versus period format were converted to acceleration versus displacement ($S_a$-$S_d$) format. The authors indicated that the earthquake source mechanism, magnitude and source-to-site distance and the local geological conditions significantly influenced the spectrum characteristics and the associated displacement demand. The authors claimed that the new procedure is particularly suitable for regions of high seismicity while lacking instrumental earthquake records.

The new procedure proposed in this paper could be useful in the development of ground motion modeling and seismic hazard assessment. Unfortunately, the figures in the paper are difficult to decipher and details of the analyses are lacking.

**Paper No. 6.07b by Tsang, H.H., Yaghmaei-Sabegh, S., Anbazhagan, P., Sheikh, M.N., Sitharam, T.G. and Vinod, J.S.** presented a case study of probabilistic seismic hazard assessment (PSHA) for Hong Kong (China), Tehran (Iran), and Bangalore (India) using a newly-proposed method. The new method, named Direct Amplitude Based (DAB) approach, uses historical earthquake data and a closed-form equation to calculate seismic hazard at a site. The authors indicated that the advantages of the proposed method include: (i) it is not necessary to characterize seismic sources; and (ii) site-specific and event-specific characteristics that influence ground motions can be incorporated in the early stage of the computational procedure.

The results computed using the proposed DAB method for the three cities were compared with previous results computed by conventional source-based method. Several issues or findings were discussed, such as the assumption of uniform seismicity in a previous study in Tehran, the importance of the completeness of earthquake catalog, the extents of area from which earthquake records are compiled, as well as the use of reliable ground motion prediction equations.

The proposed DAB procedure could serve as a useful tool for checking the credibility of the results obtained from other currently-used methods of PSHA. Because the new procedure does not explicitly consider the local tectonic setting or fault data, its reliability for high seismic areas with short historical earthquake database and for hazard at very low probability level needs further investigation.

**Paper No. 6.14b by Brouwer, J.W.R., Van Eck, T., Goutbeek, F.H. and Vrouwenvelder, A.C.W.M.** presented an investigation of the implications of induced seismicity and the feasibility of adopting Eurocode 8 in the Netherlands. Although Netherlands has a low earthquake activity rate and buildings are not required to design for earthquake loadings, the induced seismicity due to the exploitation of natural gas has been observed in the northern part of the Netherlands, which have led to recorded peak ground accelerations of up to 0.3g, albeit of short duration. The key objective of this study was to investigate the suitability and the appropriate approach of adopting Eurocode 8 seismic provisions for Dutch conditions, considering both tectonic and induced seismicity. Other issues discussed include the consistency of seismic zonation for areas in Netherlands bordering Belgium and Germany, and use of cone penetration test that is widely used in local geotechnical practice.

The authors have presented a nice discussion of induced seismicity that has been observed in northern Netherlands. This paper serves as a good basis for future codification or for preparing a national annex to Eurocode 8, relevant to seismic assessment and design in the Netherlands and with the consideration of both tectonic and induced seismicity.

Site Characterization

**Paper No. 6.12b by Eker, A.M., Akgün, H. and Koçkar, M.K.** described a study to compare shear wave velocities measured via passive and active surface wave techniques. The passive technique was the Microtremor Array Method (MAM) and the active technique was the Multichannel Analysis of Surface Wave Method (MASW). Shear wave velocity profiles were apparently measured at 41 sites within the Cubuk district, north of Ankara, Turkey. The authors found that for 33 of the 41 sites, the two methods produced Vs30 values within 10% of each other. The other 8 sites were within 20% of each other. The authors then developed a regional Vs30 map of the study area and discussed the Vs30 distributions within the two main Quaternary geologic units in the study area.

The comparison between the passive and active surface wave techniques is somewhat superficial. It would have been nice to compare full shear wave velocity profiles rather than just Vs30 values.

**Paper No. 6.17b by Ali Jawaid, S.M.** compared the liquefaction evaluations by the Seed simplified method of three sites in the lowlands of India. Two commonly-used methods for estimating the liquefaction resistance, namely, standard penetration test (SPT) and cone penetration test (CPT) were used to calculate the factor of safety against liquefaction at the three sites. It was found that the results by the two methods were significantly different and that a key uncertainty was the unknown energy correction for SPT systems used in India. As a result, the author concluded that CPT is more reliable for liquefaction potential evaluation in India.

This study reveals the need to develop a standardized energy correction factor for SPT hammers in India. Although not mentioned in the paper, other factors that could affect SPT N-values should be addressed. In addition, recent research into improving the SPT and CPT liquefaction curves should also be considered.

**Paper No. 6.23b by Kolev, C.V. and Perikliyska, M.G.** described the seismic risk associated with tall building construction in four of the big and fast developing cities in Bulgaria, namely, Sofia, Plovdiv, Varna and Bourgas. As apart of the assessment, historical seismicity, regional geology, general soil conditions, and liquefaction susceptibility of soils in these four cities were discussed, including general foundation solutions.

The paper presents a very general overview of seismicity and seismic foundation issues in the four cities in Bulgaria. Unfortunately, the paper does not provide detailed information, and the English is poor.

Ground Response Analyses

**Paper No. 6.09b by Barani, S., De Ferrari, R., Ferretti, G. and Spallarossa, G.** described a statistical study to develop predictive models for site amplification factors in four selected regions of Italy. Eighty input ground motions, with intensities ranging from 0.015 g to 0.58 g, were propagated through 100 soil columns using the equivalent-linear approach. The sites analyzed were 4 to 48 m thick (only 10% were deeper than 30 m) and had Vs30 values between 370 and 1230 m/s (most were above 350 m/s). The average Vs within the soil deposits ranged between 200 and 796 m/s. Amplification factors were computed for various spectral intensity parameters, as well as spectral acceleration at different periods, for each analysis.

Regression analysis was performed to develop predictive models for the various amplification factors. The authors found that the best predictions of amplification factor included both Vs30 and the natural frequency of the soil deposit ($f_o$). They found that the amplification of spectral intensity parameters was more accurately modeled than the amplification of period-dependent spectral accelerations. The resulting amplification factors were used to develop shaking maps for 2009 L'Aquila Earthquake in Italy that took into account site specific soil conditions.

This paper presents an interesting study of the amplification of shallow soil sites and the predictive ability of Vs30. Because of the shallow nature of the sites analyzed (most sites were less than 30 m thick), the models may have been more successful if the average Vs within the soil deposit was used instead of Vs30.

**Paper No. 6.10b by Osorio Flores, L., Mayoral Villa, J.M. and Romo, M.P.** described research work related to the seismic microzonation of the Texcoco Lake region of Mexico City, an area that consists of very soft soils. Boring and sampling, SPT, and CPT were performed at four strong motion station sites within the study region. Shear wave velocity profiles were estimated from empirical correlations with SPT blowcount and CPT tip resistance. Laboratory resonant column and cyclic triaxial tests were performed to measure nonlinear dynamic soil properties, and these data were fit with a Masing-type model.

Equivalent-linear stochastic site response analyses were performed for the four sites using randomized velocity profiles to account for uncertainties in the shear wave velocity profile. The computed surface response spectra were compared with recorded surface response spectra from the four seismological stations. Together, these data were used to recommend design response spectra for the four sites.

This paper presents a thorough description of the characterization and analysis used to develop design response spectra for the deep soft soil deposits within the Texcoco Lake region of Mexico City. Because of the soil soils in this area and the significant ground motion amplifications observed here during the 1985 Michoacan earthquake, this information is important for microzonation of this area.

**Paper No. 6.16b by Estrada, G.** compared site response estimates from different site classification systems that are currently in use in seismic design codes across the globe. The seismic codes considered are Eurocode, IBC, German code, and Japanese code. Nine soil profiles from literature, based on well-characterized and studied sites around the world, were selected, and the "transfer function derived from site specific analysis" at each site was compared to period-dependent amplification factors derived from the various seismic codes. The apparent differences in comparison of site specific transfer functions with seismic code provisions led the author to conclude that site specific ground response analysis is needed for seismic design.

Some of the curves in Figures 10 to 18, comparing amplification spectra recommended by different seismic codes with those derived by the author from site specific analysis, do not appear reasonable. The paper did not provide details of how these amplification curves were derived. Also, Table 2 is missing in the paper.

GIS Microzonation

**Paper No. 6.13b by Capilleri, P.P., Maugeri, M. and Raciti, E.** described an approach to detect geotechnical hazard factors and vulnerability elements of urban areas. A penalty form was described that assigns numerical penalty factors based on various geotechnical hazard parameters, such as slope angle, water table depth, shear wave velocity. These penalties are summed to represent a Geotechnical Hazard Index ($I_{GH}$), and different ranges of $I_{GH}$ represent different hazard levels. A thorough process for collecting information of the vulnerability of infrastructure using a Geotechnical hazard form was described. A GIS geodatabase for the hazard and vulnerability data was proposed, and applied to three municipalities in Sicily, Italy.

The presented GIS approach will be potentially useful to municipalities attempting to quantify their geotechnical and seismic risk.

**Paper No. 6.20b by Pessina, V., Fiorini, E. and Paolucci, R.** described a GIS-based procedure to evaluate topographic effects that lead to seismic ground motion amplification. The procedure analyzes high-resolution Digital Elevation Model (DEM) to identify critical topographic sites, using factors such as slope angle, presence of ridge, and ridge height, which are subsequently presented in the form of microzonation maps using Geographic Information System (GIS). The procedure is implemented at two levels: Level 0 (regional/national scale) for screening and identifying critical localities; and Level 1 (local/provincial scale) for classifying these localities with refined ground motion amplification factors. The technique was applied to the Marche and Calabria regions in Italy.

The proposed GIS based procedure provides practical microzonation maps that will be useful for urban planners in regions of high seismicity in Italy. Moreover, the method proposed in this paper could potentially be applicable in other parts of the world.

FINAL COMMENTS ON SESSION 6B

The 15 papers submitted to Session 6B cover applications of seismic microzonation, seismic hazard analysis, site characterization and site response analysis to sites around the world. Of the 7 papers dealing with seismic hazard analyses, the probabilistic approach is used in all except for one paper that used the deterministic approach. Shear wave velocity is widely adopted for site classifications for seismic building code purposes worldwide or for microzonation studies. The equivalent linear dynamic analysis approach is still the most popular method for 1D ground response analysis.

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