Update on Activities of OECD/NEA in the Field of Earthquake Engineering

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ABSTRACT

The Organization for Economic Cooperation and Development (OECD) Nuclear Energy Agency (NEA) established the seismic subgroup discussed in this paper to address high-level seismic safety issues from an international perspective; to provide information to member countries; and to help them in assessing their facilities. The seismic subgroup supports the Working Group on the Integrity and Aging of Components and Structures established under the Committee on the Safety of Nuclear Installations (CSNI) dealing with safety-related research and development aspects. The seismic group makes recommendations with the objective to exchange information to overcome discrepancies and reach international consensus on technical issues. The group usually operates through annual plenary meetings and technical workshops and communicates to member states by issuing state-of-the-art reports and topical opinion papers. Approximately 25 high-level experts and specialists from 15 countries, representing safety authorities, research organizations, electric utilities, and other international organizations (e.g., the International Atomic Energy Agency and the European Union) participate in seismic group activities. Among other items, the recent and planned activities of the group include the following:

- publishing a report prepared on the differences between nuclear and conventional seismic standards
- discussing the worldwide implications on nuclear facilities of the December 2005 Sumatra tsunami
- conducting a workshop on seismic input motions, incorporating recent geological studies, held in November 2004. (This was the third in a series of workshops to characterize the input ground motion used in the design of nuclear facilities and to improve the synergy among earth scientists and earthquake and structural engineers.)
- developing a strategic plan for seismic subgroup activities for the next 5 years
- holding a meeting of specialists on seismic probabilistic safety assessment, organized jointly with the OECD Risk Working Group during November 2006 in Jeju, Korea, with publication of the proceedings
- developing a benchmark, SMART 2008, to be conducted in France, on seismic design and assessment analysis for multistory reinforced concrete buildings subjected to torsion and nonlinear effects

During a yearly plenary session, the group defines its program of work and presents it to the CSNI for approval. As conditions warrant, the CNSI provides top-down direction. The seismic group is recognized as a forum to exchange technical information. It has no budget of its own, and activities are completed solely on a voluntary basis.

As its first task, the seismic group developed strategic recommendations to describe its activities and identified the following topics or issues for the group to address:

- seismic analysis and design of piping
- engineering characterization of seismic input
- aging effects, particularly as it affects seismic design
- validation of analysis methods
- reevaluation of existing facilities and assessment of margins beyond the design basis

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This paper will detail some of the recent activities and products of the seismic group.

INTRODUCTION

The OECD/NEA seismic subgroup was formed about 12 years ago to address the seismic behavior of structures, systems, and components.

MISSION STATEMENT

The seismic subgroup is under the Committee on the Safety of Nuclear Installations (CSNI) Working Group on the Integrity and Aging of Components and Structures (WGIAGE or IAGE) within the Organization for Economic Cooperation and Development (OECD) Nuclear Energy Agency (NEA). The IAGE has a mandate to undertake the following six types of

functions:

1) constitute a forum for the exchange of views, information, and experiences germane to generic technical aspects of the integrity and aging of components and structures
2) review, as appropriate, national and international programs concentrating on research, operational aspects, and regulation
3) stimulate new research in relevant technical areas and recommend potential international cooperative projects
4) develop common technical positions on specific integrity and aging issues of operating and new nuclear power plants (NPPs)
5) identify areas requiring additional research
6) discuss the potential impact of aging and other time-dependent challenges to integrity on the safety, regulation, and operability of NPPs [1]

The seismic subgroup's responsibility under this mandate is to address the effects of vibratory ground motion on nuclear installations.

RECENT ACTIVITIES

Recent activities conducted by the seismic subgroup in carrying out its mission include 1. cosponsoring a workshop on seismic probabilistic safety assessment to update the state of knowledge in this rapidly evolving area that had not been reviewed by CSNI since 1999; 2. preparation of a summary report of three workshops sponsored by the subgroup as part of the subgroups initial mandate; and 3. publication of a number of reports on other subgroup studies. These activities are described below.

Joint Workshop on SPSA in Jeju, Korea

In November 2006, the CSNI seismic subgroup cosponsored a workshop with the Working Group on Risk (WGRisk) on seismic probabilistic safety assessment (SPSA) at Jeju Island, Korea. The International Atomic Energy Agency (IAEA) also cooperated in sponsoring the workshop. Two Korean institutes, the Korea Atomic Energy Research Institute and the Korea Institute of Nuclear Safety, hosted the event. The main objectives were to review recent advances in SPSA methodology, to discuss practical applications, to review the current state of the art, and to identify methodological issues that would benefit from further research. Workshop participants also discussed applications of the seismic margin assessment methodology, a methodology related to SPSA. One specific objective was to compare the situation today with the situation at the time of a previous workshop on this topic held in Japan in 1999 and to develop an updated set of findings and recommendations.

Participants at the specialist meeting agreed that the nuclear power industry, operating NPPs, various national regulatory agencies, and designers of new NPPs all use SPSA and that SPSA can systematically contribute to accomplishing the following very important objectives:

- understanding the seismic risk arising from NPPs, as well as, understanding the seismic hazard contribution to risk to NPPs
- understanding the safety significance of seismic design shortfalls
- prioritizing seismic safety improvements
- evaluating and improving seismic regulations
- modifying the seismic regulatory/licensing basis of an individual NPP

Presenters at the Jeju meeting discussed the following significant developments/implementations in SPSA use since the 1999 workshop:

- the use of SPSA in the design of new advanced reactors, in the technical studies supporting revised regulation, in the analysis of seismic risk for multiplant sites, and in other applications
- a major expansion of SPSA use by national regulatory agencies (e.g., in several countries regulatory agencies are requiring the use of probabilistic criteria in determining the design-basis earthquake)
- the use of SPSA to evaluate the effectiveness of proposed modifications and improvements to NPPs before implementation
- the application of probabilistic seismic hazard analysis (PSHA) and performance-based guidance in specific licensing actions (e.g., for an early site permit in the United States)
- a reevaluation of seismic capacity/margins via the application of a full-scale PSHA for all NPPs in Switzerland under the program name, PEGASOS

The participants identified the following areas in which SPSA and PSHA could be strengthened:

- PSHAs must be performed in a realistic manner to produce realistic results that include the same level of uncertainty and variability observed in nature. The results should be compared to all available field observations, such as those associated with recurrence records.

- Uncertainty in the area of quantifying human reliability responses in operating personnel and emergency organizations continues to be an issue. The issue is generic to all human reliability analysis and involves the uncertainty in data and the lack of data.
- The analysis of correlations among various components of similar function and construction is another continuing issue, specifically the quantification of the correlation of failure of similar equipment or structures because of an earthquake.

Because of the specific issues identified during the PEGASOS program in Switzerland, the workshop participants identified as an urgent need the comparison of PSHA results from an area of low to moderate seismicity with areas of high seismicity. Some participants and other practitioners have identified an issue or at least a perceived issue associated with a difference between some PSHA results and the observed seismicity. The workshop participants identified the seismic subgroup as the logical sponsoring organization to fulfill this need. [2] (See the section below on Current Activities.)

Three Seismic Subgroup Workshops

In addition to the workshop activities described above, the seismic subgroup sponsored three international workshops between November 1999 and November 2004. These workshops focused on the progress in the fields of (1) seismic input characterization, (2) the relationship between recent seismological data and seismic engineering, and (3) the enhancement of seismic motions used in nuclear design based on the findings of several recent geological studies. The primary goal of the three workshops is to extract the seismic information most relevant to current nuclear practice and thereby relevant to the positions held by a national regulatory body, such as the U. S. Nuclear Regulatory Commission (NRC). The information was chosen for (1) its potential to challenge the current practice and understanding of the earthquake input side of the safety equation and (2) its possible contribution towards the refinement of nuclear codes and practices.

The three workshops brought together seismologists and earthquake engineers and launched an extensive discussion of all the components having an impact on the seismic safety of nuclear facilities, including seismology, site effects, and structural response. Advances in (1) the characterization of faults through geological studies and the fitting of data from existing databases into refined models, (2) detailed geophysical/geotechnical analyses of sites in conjunction with earthquake monitoring and tests, and (3) significant improvements in modeling and simulation of structural response as well as large-scale tests have all highlighted the need to reexamine accepted seismic design practice and to implement ways to improve safety. The three workshops identified the potential regulatory improvements from the recent developments in the various components of seismic safety (e.g., seismic input, probabilistic approaches) along with the current status and trends of the different regulators regarding the implementation of new findings through the safety guidelines.

The first of three workshops, hosted by the NRC at Brookhaven National Laboratory in 1999, focused on the engineering characterization of the seismic input, specifically on the aspects that influence the establishment of an appropriate seismic input at a given site. These aspects include (1) an understanding of the seismological parameters associated with a site or a region, including elements of PSHA as well as the applicability and maturity of numerical techniques that help bridge the gap in regions of limited data or low seismicity, (2) the dominant effect of the local site conditions on the determination of the seismic input, specifically the correlation between the site effects for rock sites or regions to those for soil sites, and (3) the characterization of the seismic input at a site from both deterministic and probabilistic standpoints, including attempts to validate the assumptions used to characterize seismic inputs through simulation of observations on actual structures. A key element of this first workshop was the regulatory perspective on the enhanced understanding of these three areas and the way this will, or should, influence the revision of standards.

The second workshop, hosted by the Turkish Atomic Energy Agency in 2002 in Istanbul, Turkey, focused on the links among seismic data, earthquake engineering, and analysis procedures used to evaluate the response of nuclear structures. Two key elements of the proceedings included the delineation of recorded data with the help of seismologists and the extraction of the dominant features that will feed/support the engineering analysis of a local site that includes a nuclear structure of interest. The workshop gave special attention to near-field earthquakes (NFEs) of moderate magnitude, a class of earthquakes that continues to puzzle the earthquake community for its widely variable ability to damage structures. The workshop participants considered this topic important and recommended further study in this area. They also emphasized the applicability or direct use of seismic motions generated by the seismological side of the equation in estimating structural damage as well as the potential for incorporating such an approach into regulatory safety guides, e.g., the use of the history analysis technique.

The Japanese National Research Institute for Earth Sciences and Disaster Prevention (NIED) hosted the third workshop in 2004 in Tsukuba, Japan. Although this workshop covered the topics of interest from the two previous workshops, it specifically focused on the most recent deep geological studies on source characterization, fault structure, and fault capability and the way these findings influence the definition of seismic input. The workshop participants paid particular attention to the characterization of asperities and to ways of establishing the link between asperities and strong motions. They emphasized the need for deep borehole research, including the development of technical guidelines for optimizing such an undertaking. To address the current state of nuclear engineering practice and its emphasis on facility seismic reevaluation,

the workshop also focused on the regulatory aspects (i.e., how the scientific observations could be used improve nuclear regulation) of the most recent developments in geophysical research, including elements of PSHA and treatment of uncertainties. It explored recent advances in earthquake engineering analysis of structures, both experimental and numerical, and the potential for adopting nonlinear considerations in the future design.

A comprehensive review of the issues discussed during these workshops and of the recommendations offered by the three involved groups (seismologists, earthquake engineers, and regulators) to resolve outstanding seismic questions has led to the following recommendations.

NFE effects as well as the connection of vertical motions with structural damage need further examination. Since its introduction at the first workshop, this issue has prompted a flurry of activity to reevaluate the damage potential of low-magnitude (<5.5 M) NFEs. Further examination into this type of earthquake revealed that it may not be the magnitude alone that defines its damage potential but its directivity accompanied by the presence of a dominant, low-frequency pulse in the velocity trace of the motion. Experiments on structures using NFE-type inputs (e.g., see the CAMUS shaking table test performed by the Commissariat à l'Énergie Atomique (CEA) described in the References) attempted to assess the ability of these earthquakes to cause damage and compare them to damage caused by their far-field counterparts that are used in the seismic design guidelines. The consensus of several analyses, attempting to draw conclusions from the experiment while simulating the effects of additional near-field records on the structure, is that NFEs have a lesser damage potential. More research that looks into the response of other types of structures to NFEs is needed.

The role of vertical motions on structures needs further examination. A closer look at damage caused by recent catastrophic earthquakes and of the delineation between horizontal and vertical (H/V) motion contributions is paramount. Several field studies based on extensive down-hole arrays are focusing on the H/V ratios. The findings of these field studies are essential to the development of widely accepted vertical site response methodologies (acceptability that is still missing to date). Field studies presented at the workshops underscored that equivalent linear models, an approach that has been used extensively, may not apply. Implementation of purely nonlinear models with nonlinear properties deduced from laboratory experiments is needed. In addition, three-dimensional models are the only reliable way to proceed. The currently available computing capacity can make that possible.

Risk-informed or performance-based design approaches warrant further attention and consideration as they are implemented into upcoming revisions of regulatory guidelines. The conventional structures sector has been more active in including design bases into the safety philosophy of its guidelines.

Seismologists and earthquake engineers both need to continue to improve their dialogues. The three workshops proved that philosophical differences still exist between the two camps in the way each approaches the seismic questions that are linked to the safety of nuclear facilities. The primary philosophical difference is associated with the use of probabilistic approaches. Probabilistic models of earthquake occurrence and the derivation of input motions provide appropriate information for use in design. Design of nuclear structures has generally been deterministic with deterministic definitions of the seismic input and reliance on experience data to determine the design-basis or extreme-basis earthquake. The role of the regulatory bodies should be to: (1) closely follow the progress made in both areas, (2) listen to the opinions from both sides, (3) allow the regulatory guidelines to be more conducive to change by permitting implementation of new findings that challenge the established practice while maintaining safety, and (4) guide experimental and field studies that exhibit common denominators between the interests of various groups. [3]

Recent Publications

Over the last several years, the seismic subgroup has published the following material:

- NEA/CSNI/R(2004)22, "Proceedings of the CSNI Workshop on Seismic Input Motions, Incorporating Recent Geological Studies," hosted by NIED, Japan in Tsukuba, November 15–17, 2004. This report documents the conclusions and recommendations of the workshop to review the state of the art in defining realistic seismic input for the design and reevaluation of nuclear facilities.
- NEA(CSNI)/R(2006)9, "Differences in Approach Between Nuclear and Conventional Seismic Standards With Regard to Hazard Definition," in preparation. This report addresses the apparent discrepancies between nuclear and conventional seismic standards with regard to hazards definition. It examines various aspects, such as the safety philosophy behind seismic nuclear and conventional standards, the differences in approach regarding the seismic hazards definition, and the differences in the designs and the methods of analysis.
- "Survey for Facilities That Have Experienced an Earthquake", in preparation. This report will document the findings of information collected on the seismic experiences of NPPs worldwide.
- "Proceedings of the Specialist Meeting on Seismic Probabilistic Safety Assessment (SPSA) of Nuclear Facilities held in Jeju, Korea, November 6–8, 2006," in preparation. This combined WGRisk and IAGE meeting reviewed the recent advances in SPSA methodology, discussed practical applications, reviewed the current state of the art, and identified methodological issues that would benefit from further research.

CURRENT ACTIVITIES

Strategic Plan

The strategic plan of the seismic subgroup's activities for the next 5 years nominally covers 2006 through 2010 and begins with a review of the plans adopted following the subgroup's organizational meeting in 1996. At that meeting, the organizers outlined the following five areas for action:

1) piping analysis and design
2) engineering characterization of seismic input
3) aging effects and the seismic behavior of structures and components
4) validation of analysis methods
5) reevaluation of existing nuclear facilities and assessment of beyond design basis

The subgroup has been able to work on specific products for four of the five areas and is addressing the fifth. Under the new strategic plan, the subgroup proposes to address the following topics:

- The subgroup, in conjunction with a group from IAEA, is collecting a database of nuclear facilities that have experienced an earthquake; the subgroup is considering the analysis that should be applied to the database rather than simply making the data available. Under consideration is the format and fragility characterization that was performed for the SQUG (Seismic Qualification Users Group) data. The subgroup is also examining the potential for using the data to develop or propose a better indicator of damage than peak ground acceleration.
- The issue of plant aging on the structural capacity of structures and components is a potential area for collaboration with the metals subgroup for a joint analysis activity.
- Soil-structure interactions for the new and advanced reactors are an area for activity, including consideration of new fully embedded structures.
- The role of performance-based or reliability-based approaches to the use of probabilistic techniques in regulation and regulatory guidance is a definite area in need of more complete characterization. The issues raised during the Jeju workshop on seismic probabilistic risk assessment mentioned earlier in this paper are topics for further research and discussion.

SMART 2008 Benchmark

The seismic subgroup is sponsoring a blind benchmark competition of a model three-story reinforced concrete (RC) structure organized by CEA and Electricite de France (EDF). Because three-dimensional (torsion) effects and nonlinear response are a concern in the field of earthquake engineering research and building regulation, CEA and EDF have proposed this benchmark competition. A three-story RC structure at ¼ scale will be built on the AZALEE shake table at the CEA Laboratory in Saclay, France. The aim of the proposed benchmark is to compare and validate various approaches used by the international participants to model the dynamic response analysis techniques for RC structures subjected to simulated earthquakes and exhibiting both three-dimensional (torsion) and nonlinear behavior. This analysis includes evaluation of loads induced by internal equipment, quantification of margins in design methodologies, and conducting realistic methods to quantify variability to produce fragility data.

The blind benchmark competition has the following two objectives:

1) assess design methods for structural dynamic response analysis and floor response evaluation
2) compare best-estimate methods for structural dynamic response analysis and floor response evaluation including various practices, depending on participants' experiences:
   - linear equivalent approaches
   - nonlinear approaches

CEA and EDF envision a two-phase program with the first phase being associated with pre-test activities, such as the following:

- design and construction of the ¼-scale model
- dissemination of the model parameters/specification
- participant analysis of model and prediction of its behavior under test conditions
- delivery of blind predictions to CEA and EDF

Phase two would encompass the following:

- actual model testing and recording of the test data
- comparison of the blind predictions to the test data
- comparison of the blind prediction by individual analysis technique
- development of lessons learned

Workshop on PSHA in Areas of Low-to-Moderate Seismicity

As a follow-on activity to the recommendations from the Jeju workshop on Seismic PSA, the seismic subgroup plans to conduct a workshop on PSHAs for areas of low-to-moderate seismicity in the Spring of 2008.

REFERENCES

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