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THE ACTIVITIES OF THE OECD/NEA IN THE FIELD OF EARTHQUAKE ENGINEERING

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ABSTRACT

The Working Group on the Integrity and Aging of Components and Structures (IAGE) is established under the senior committee on the Safety of Nuclear Installations (CSNI) of the OECD/NEA (Organization of Economic Cooperation and Development/Nuclear Energy Agency). This Committee deals with safety-related R&D aspects. The mandate of this Working Group is to advise the CSNI on the topical basis for management of plant ageing and to propose general principles to maintain the integrity of systems and components. The Working Group is composed of three sub-groups addressing metallic components, concrete structures and the seismic behavior of structures and components. The groups operate through annual plenary meetings, workshops, state-of-the-art reports, topical opinion papers and benchmarks to produce advises to the CSNI. Twenty five high level experts from fifteen countries attend the Seismic Group (safety authorities, researchers, utilities, and representatives from other international organizations (IAEA, EC)). In this paper the scope of activities and recent tasks of the Seismic Group are presented.

Keywords: International, reevaluation, seismic input, codes and standards, risk, facilities.

1. INTRODUCTION

Activities of the OECD in the area of seismic safety of nuclear facilities are carrying out by the seismic sub-group, which is part of the IAGE Working Group organized under the CSNI at the OECD/NEA. The mandate of the IAGE Working Group and subsequently of the seismic sub-group, is to advise the CSNI on the topical basis for management of plant ageing and to propose general principles to maintain the integrity of systems and components. The group is recognized as a forum to exchange technical information. It has no budget on its own and tasks are accomplished on a voluntary basis as are those of the senior Committee.

The group defines its program of work through a yearly plenary session and presents it to the CSNI for approval. Top-down directions are also given by the CSNI when needs arise. Proposals to address an issue can be as diversified as workshops, state-of-the-art reports, topical opinion papers and benchmarks, whatever is considered the most efficient. About twenty five high level experts from 15 countries (safety authorities, research organizations, utilities and representatives from other international organizations (IAEA, EC)) participate actively in the work of the group.

When the group was set up in 1996, the first task was to propose an action plan to the CSNI detailing key issues the group would address [1]. The followings have been considered as important:

- Piping analysis and design
- Engineering characterization of seismic input
- Aging effects
- Validation of analysis methods
- Re-evaluation of existing facilities and assessment of beyond design basis

The working group worked these topics through a logical manner and in the last years produced the following material:

(1) Report on seismic re-evaluation of nuclear facilities, mainly reactors [2]. To achieve this task, member countries responded to a detailed questionnaire on current practices and organized a workshop on the subject in 2001 [3],

(2) The proceedings of the workshop on Seismic Risk [4], held in 2000, organized jointly with the working group on Risk Assessment (WGRISK), and publication of a topical opinion paper on the topic [5],

(3) Report on three successive workshops on seismic input: the workshop on engineering characterization of ground motion, held in 1999 [6], the workshop on the engineering characterization of seismic input held in 2002 [7] and the workshop on the seismic input motion incorporating recent geological study [8] held in 2004,

(4) Report on differences in approach between nuclear and conventional seismic standards with regard to hazards definition [9],

(5) Report on shaking tables and other large testing facilities which have/had activities and competencies in the nuclear area [10],

(6) Report on survey for facilities which have experienced an earthquake is under preparation,

(7) Report on lessons learned from high magnitude earthquakes with respect to nuclear codes and standards [11].

The picture below illustrates the different areas of expertise and the topics addressed. Some of them are detailed in this paper.

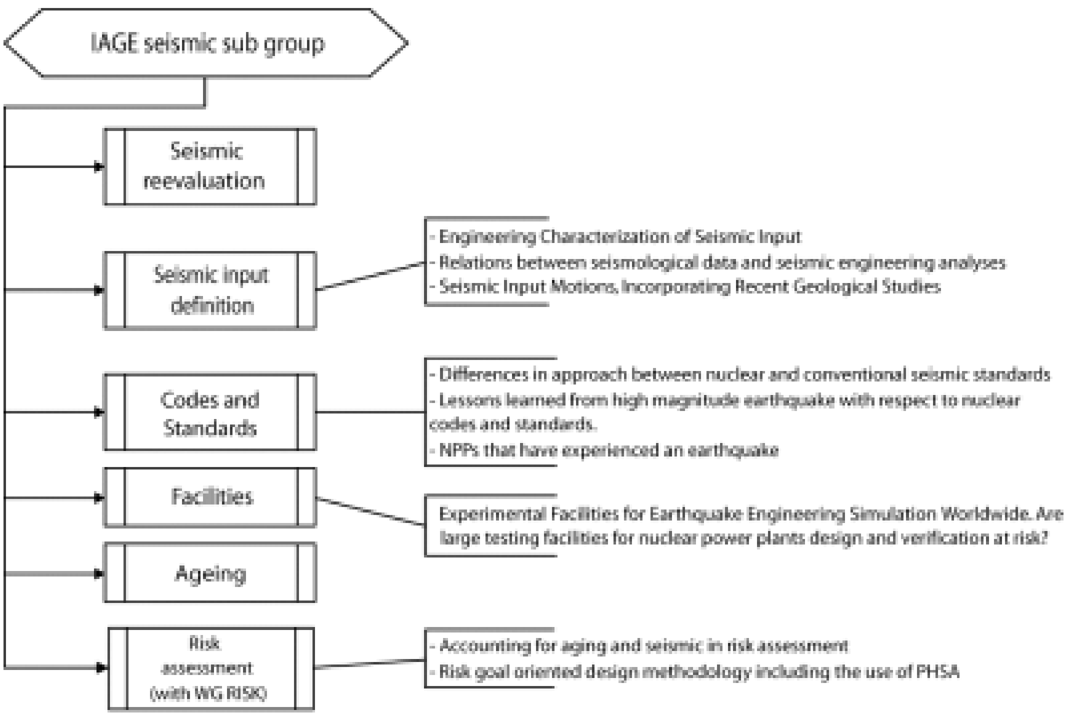

Figure 1: IAGE Seismic sub-group – topics addressed

2. SEISMIC RE-EVALUATION

2.1 1999 Status Report [1]

Seismic re-evaluation is identified as the process of carrying out a re-assessment of the safety of existing nuclear power plants for a specified seismic hazard. This may be necessary when no seismic hazard was considered in the original design of the plant, the relevant codes and regulations have been revised, when the seismic hazard for the site has been re-assessed or when there is a need to assess seismic capacity of the nuclear power plant (nuclear power plant) for an earthquake beyond the design basis. Re-evaluation may also be necessary to resolve an issue, or to assess the impact of new findings or knowledge.

The major topics of the report are:
- Overall Approach
- Input Definition and Analysis Methods
- Scope of Plant and Assessment of As-built Situation
- Assessment criteria
- Outcome of Re-evaluations

Seismic re-evaluation is a relatively mature process that has been developing for some time, with most countries adopting similar practices, often based on principles which have been developed by the US. Seismic re-evaluation of individual plants is typically carried out at intervals of approximately ten years.

Methods of seismic re-evaluation include PSA, margins assessments and deterministic analysis, and a common feature of the process is a seismic walkdown, often based on SQUG (Seismic Qualification Utilities Group) principles [10]. The input motion levels, seismic categorization, analysis methods and assessment criteria that are applied depend on the objectives of the re-evaluation. In several responses they are indicated to be generally similar to those specified for new plant. In situ inspection of structures and plant is generally adopted, although most countries use original specifications for material properties, with some in situ evaluation when possible. More realistic criteria than would usually be adopted for new plant are often employed in the assessment of plant behavior for severe accidents or risk estimates.

In this report, it is recommended that some areas of the seismic re-evaluation process be considered in the future for the mutual benefit of the member countries. These include a better understanding of the benefits and disadvantages of the various methods employed in the re-evaluation process, the definition of the scope of plant to be selected for the re-evaluation process, definition of the criteria for re-evaluation and the role and scope of the peer review process. Also included are the strengthening of plant, the incorporation of operational and research data/experience into the re-evaluation process and the identification of areas of new research that could provide benefits and improvements for the re-evaluation process.

2.2 Status and Workshop on Seismic Re-Evaluation (2001, [2,3])

Seismic re-evaluation is not the same as design. The allowable limits and acceptance criteria can go beyond design criteria, provided the safety is not compromised. Followings are some of the major conclusions and general recommendations of the workshop on seismic design and re-evaluation.

Main conclusions:

(1) Application of displacement based and some non-linear analysis methods are encouraged.
(2) Users of experience based methods, such as SQUG [12], should make sure that the data is applicable to their specific case.
(3) Test results and post earthquake field investigations are of great importance for seismic re-evaluation. They provide much of the information that underlies the processes used.
(4) Seismic re-evaluation should make full use of as-built information and data should be verified on site as far as possible.
(5) A peer review is strongly recommended as part of seismic re-evaluation.
(6) To improve the seismic input from reviewed earthquakes, it is necessary to fully capture the existing uncertainties and these need to be incorporated into the state of the art of the knowledge to characterize the sources, attenuation and site effects.

Recommendations:

(1) Human factors, housekeeping and training are important throughout the life of the facility.

(2) Pre-earthquake preparations need more attention, particularly the selection and recording of damage indicators which aid post earthquake decision making.
(3) There should be an improved definition of acceptance criteria for nuclear facilities that are being re-evaluated. These criteria should consider the safety consequences of acceptable damage levels, and could be risk informed rather than solely deterministic.
(4) For nuclear facilities that are being re-evaluated, there should be an improved description of site-specific data (input motion, geotechnical data, etc …) that reflects the knowledge and understanding of the site as appropriate.
(5) Guidelines for strengthening following re-evaluation need to be developed. These should address design and performance criteria together with practicability measures.
(6) The output from the seismic re-evaluation should include a review or development of the data, procedures and associated criteria that help in post earthquake decision making.
(7) Discussion and information transfer regarding seismic re-evaluation should be pursued within the nuclear community. Cooperation with other industries with similar concerns would be of benefit.

3. DEFINITION OF SEISMIC INPUT MOTIONS

Three workshops ([6], [7], [8]) related to seismic input motions were successfully organized from 1999 to 2004. In the following paragraphs, conclusions and recommendations of the workshops are presented.

3.1 Workshop on the Engineering Characterization of Seismic Input (1999, [6])

In the workshop, participants reached a consensus that there have been large improvements in the knowledge of seismic input since the present nuclear power plants were designed and the current regulations were formulated. Under this recognition, the following conclusion and recommendations were adopted in the workshop.

Main conclusions:

(1) Several countries and the IAEA are revising their regulations and standards currently, in this framework the continuation of international interactions on this topic are essential.
(2) Trends in these revisions are:
- parallel use of both deterministic and probabilistic seismic hazard assessment,
- increased emphasis on risk informed methods,
- the use of site specific response spectra and uniform hazard spectra, and other descriptions of ground motion (e.g., scenario type earthquakes; energy content, etc.),
- incorporation of Global Positioning System and palaeo-seismological methods.

Recommendations:

(1) There should be a wider dialogue between design engineers and ground motion specialists.
(2) The new ideas challenging established concepts of seismic design response spectra.
The difference in engineering between response spectra defined on soil surface and rock surface should be discussed.
(3) The various methods for ground motion estimation (e.g., Empirical Greens Function, etc) should be validated:
Validation against the data both in low and high seismic (including near field) areas not only for peak values but also for other parameters such as spectral responses, energy content, and duration should be done;
(4) Data collection is a critical common need, not uniquely nuclear. It is therefore recommended that
- dissemination of data be improved, and that data should be made freely available,
- the quality (e.g., site conditions) and format of data be improved and standardized,
- more data be collected in low seismic areas.
(5) It is recommended that site characterization issues be resolved:
- hard rock versus soft rock and deep versus shallow soil sites amplification issues;
- effects of source mechanism, source location, travel path, and local superficial geology, and geotechnical conditions with respect to the site,
(6) It is recommended that methods for transferring data from high seismic areas to low seismic areas (e.g., hybrid methods) be validated and improved.
(7) There is a need for better understanding and definition of vertical motions.

3.2 Workshop on the relations between seismological data and seismic engineering analyses. (2002,[7])

The workshop was held as a follow-up of the workshop on *the Engineering Characterization of Seismic Input* to gather seismologists and engineers.

Main conclusions:

(1) Contact between seismologists and engineers have proved to be very valuable and should be pursued,
(2) Significant progress have been accomplished recently in computation of strong ground motion at a site using physical properties of seismic fault, travel path and site effects,
(3) There is a strong tendency for seismic codes to consider PSHA,
(4) The computation of strong ground motions at a site using the physical properties of the seismic fault, a travel path and site effects has great promises for the future. The new revision of the IAEA safety guide on seismic hazard analysis for nuclear power plants also suggests the use of synthetic Green's function when appropriate,
(5) At present, near field earthquake (NFE) effects seem not mature enough for prescriptive regulation, e.g.,
- Moderate magnitude NFE effects represent the fact that high acceleration may be present near the epicentre without significant damages at least for engineered structures;
- High magnitude NFE represents particular characteristics (e.g. directivity) near the fault. Some recent earthquakes (e.g. Kobe, Northridge, Chi-Chi, Izmit) showed that this effect can be very damaging

Recommendations:

⇒ ***Damaging Capacity of Seismic Motions***

(1) The key parameters for loss of safety functions of SSC 's (Systems, Structures and Components) :
- The acceleration is usually not a key for the failure. Velocity may represent better damage potential and may be the more appropriate parameter to understand the effect of NFE
- The elastic response spectrum is not a key but rather the shape of the pulse has more significant effect on the loss of safety functions for some SSCs.

(2) Data collection is the key for the progress in this field and efforts must be sustained (earthquake observations at near faults, co-operative work between seismologists and engineers for appropriate instrumentation to answer data needs, to define systematically and to constrain uncertainties).

⇒ ***Seismic Input Motion for Design Purpose***

(1) The mathematical processes that are being used to replicate the mainshock strong motions should be validated towards observations,
(2) Tools to address the peculiarities of the site response and its associated damage should be developed.
(3) Different methods used to model ground motion should be compared both for efficiency and adequacy.
(4) More work is needed to validate PSHA techniques against historical data and to define the relation between rock and soil ground motions. It is recommended that more attention including data collection should be given to soft soil sites.

⇒ ***Regulatory Aspects***

(1) Performance based seismic engineering should be promoted
(2) Special site-specific design spectra should be developed
(3) NFE effects in a prescriptive regulation.

3.3 Workshop on the Seismic Input Motions, Incorporating Recent Geological Studies (2004, [8])

This workshop was the third in the series of workshop on seismic input definition. Recent geological advances in seismic source characterization of fault zones using data from deep geological investigations and their possible contribution to improve seismic input definition have been discussed. The conclusions of the different sessions are reproduced below:

⇒ ***Session 1: Regulatory and seismological considerations***

A common recognition was confirmed that adequacy and sufficiency of seismic safety design tend to be considered and confirmed by risk assessment, however there remained large uncertainties in the methodologies currently applied to evaluate seismic safety. The uncertainties are treated either in deterministic (DSHA) or probabilistic (PSHA) methods that would give the best result for the site considered. PSHA allow a more exhaustive exploration of the uncertainties on the hazard level both for model and random uncertainties. Thus it was confirmed necessary that some scenarios covering these uncertainties in source parameters.

⇒ ***Session 2 : Application of deep borehole research and monitoring***

Seismologists have been developing techniques to estimate future ground motions including of their various uncertainties (e.g., due to the lack of a priori knowledge of fault zone asperities). Through surveys of the structure of capable faults and soil strata based on deep bore-hole studies by geologists, on-site measurements and other advanced methodologies may be reduced these uncertainties.

⇒ ***Session 3: Engineering consideration***

Fortunately, to date, nuclear power plants have not been struck by any big earthquake nor have experienced any damages due to earthquakes. Nevertheless it is important to develop new technology improving our understanding of the behavior and potential for damage of structures under a big earthquake. Soil properties exhibit considerable variation even within "homogeneous" layers. Deterministic approaches based on either the "expected" value or the "equivalent" value, or conservative extremes may be misleading. Considering the uncertainty in site response may help to generate more realistic input into structures. Thus works on characterization of damage parameters of seismic input motions should be pursued. Study on simulations of structure responses and soil structures interaction and tests of real structures to understand the behavior during earthquake are confirmed still ongoing.

⇒ ***Session 4 : Seismic safety consideration and main conclusions***

- There is a tendency to consider that the adequacy and sufficiency of seismic safety design should be confirmed by risk assessment.
- PSHA and DSHA can be used complementary for seismic safety evaluation.
- Accounting for uncertainties using probabilistic methods is valid for both the evaluation of seismic ground motion and the SSC's seismic response analysis to finally obtain estimates of the frequency of accident scenarios.
- Deep borehole drilling seems promising for engineering purposes in the future, and scientists and engineers need to work together in a more collaborative manner.

4. CODES AND STANDARDS

4.1 Differences in approach between nuclear and conventional seismic standards

The key features of nuclear and conventional codes, including trends for future codes, are summarised and the significant differences discussed. The options for addressing the discrepancies identified in the current implementation of the requirements for the seismic design and qualification of structures for nuclear use are considered and recommendations presented.

The first part of this study, related to seismic analysis in codes was published [9]. It encourages the use of performance based engineering and displacement based methods, where appropriate. A second part will address the apparent discrepancies with regard to hazards definition.

4.2 Lessons learned from high magnitude earthquake with respect to nuclear codes and standards.

In the last ten years, highly populated and densely industrialized regions in the world were strongly affected by high magnitude earthquakes. For each significant event, specialists have gathered relevant information with respect to design practice and given expert judgment regarding the nuclear design and the specific needs for codes and standards. The Reports have been written about the following events.

- Northridge (California) : January 1994 – magnitude 6.7 (Mw)
- Hyogoken-Nanbu (Japan) : September 1995 – magnitude 6.9 (Mw)
- Kocaeli (Turkey) : August 1999 – magnitude 7.4 (Mw)
- Chi-Chi (Taibei, China): September 1999 - magnitude 7.6 (Mw)

The highlighted topics for the nuclear facility design were summarized as follows [10]:

(1) The codes should give more importance to the site conditions on the definition of the design accelerations and spectra: presence of active faults, the focusing effects, the accelerations greater than expected observed on soft layers in case of nearby earthquakes.

(2) Because in general, the nuclear codes don't allow the use of ductility for seismically categorized structures, the problem of the determination of the real limit values for the structural elements is of less importance, but this should be correctly evaluated for margins evaluations.

(3) More importance should also be given on the construction details and on their check and controls in the field for reinforced concrete elements and for welded beams and columns.

(4) These earthquakes have shown the importance of the external power energy network and telecommunication

system outside the plant and the need for a realistic evaluation of their availability in case of high magnitude events. It was demonstrated that with those events off site power might not be back for a long period of time, which might exceed safety requirements. Due to certain external conditions specific to the selected site, is the current required period of availability of emergency equipments and systems sufficient enough?

(5) The interaction of non-safety related structures, equipment and components with safety related equipment should be examined more accurately. In some circumstances, for non-safety related elements, the stability criteria given by the non-nuclear seismic codes may not suffice to guarantee serviceability or functionality conditions or any interaction effects.

4.3 Survey on Nuclear Facilities That Have Experienced an Earthquake

“Have nuclear power plants experienced real earthquakes? how have they responded to it ? How do you substantiate the fact that seismic hazard is duly addressed in the design of nuclear facilities ?. The CSNI approved in 2001 a proposal from the IAGE Working Group to collect information on the seismic feedback experience of nuclear power plants worldwide in full co-operation and coordination with the IAEA.

An important conclusion is that although several nuclear power plants have experienced an earthquake, none have been damaged. More conclusions and feedback will be presented in a joint IAEA/NEA report that will assemble the information provided by countries.

5. EXPERIMENTAL FACILITIES

In line with the CSNI report "Nuclear Safety Research in OECD Countries: Major Facilities and Programmes at risk", the seismic group had collected information on large shaking tables and other testing facilities which have/had an activity in the nuclear field and that may be at risk due to the decrease in research budget worldwide. A total of 83 facilities have been identified: 51 large shaking tables and 32 reaction walls. The report “Experimental Facilities for Earthquake Engineering Simulation Worldwide. Are large testing facilities for nuclear power plants design and verification at risk?” referenced [11] gives full details.

The report concludes that there are sufficient testing capabilities throughout the world. The situation is not the same if regions are considered individually. New techniques under development may also help in using existing smaller size tables to test large components/structures.

6. USE OF RISK IN SEISMIC ANALYSIS (1999, [3,4])

In 1999, the CSNI decided to review the status of the use of risk-informed methodologies in seismic engineering. A joint workshop with the CSNI/RISK working group concluded that the seismic PSA/Margin methods had been used and were being studied worldwide, providing useful information for safety improvement or decision making, and great amount of experience had been accumulated, although the status of programs in member countries vary widely. The objectives of such studies include the followings:

- To examine whether there are cost effective ways to improve safety from ALARP point of view,
- To assist in decision making in backfitting by identifying cost effective improvements,
- To demonstrate the seismic margin of existing or future plants,
- To examine the vulnerabilities in protection against severe accident,
- To improve design of future reactors by identifying relatively weak points,
- To assist in selection of new sites for nuclear power plants.

Although numerical results from seismic PSA had not been directly used in seismic design as an alternate or supplement to current deterministic analysis methods, some countries had already adopted the use of probabilistic seismic hazard analysis (PSHA) for determining design basis earthquakes (SSE in USA) and some activities were ongoing to develop methods for wider use of seismic PSA technology for design of nuclear power plants.

The CSNI Technical Opinion Paper on Seismic Probabilistic Safety Assessment for Nuclear Facilities [5] represents the consensus of risk analysts and experts in the NEA Member countries on the current state of the art in seismic probabilistic safety assessment (SPSA) for nuclear facilities. The objective is to present a clear technical opinion on the current state of seismic PSA to decision makers in the nuclear community.

7. COLLABORATION WITH INTERNATIONAL ORGANIZATIONS

International organizations such as IAEA and EC participate actively to the work of the Group. It allows coordination of activities to avoid overlapping and to complement each organization capabilities.

With IAEA, the technical collaboration has been active for a long time. In the report Ref. [1], the special effect of NFE (Near Field Earthquake) has been mentioned as an important topic to develop. The IAEA launched a cooperative Research Program (CRP) on this matter, which is under way. As already mentioned above, the seismic feedback experience of nuclear power plants around the world is a common between the IAEA and the OECD-NEA.

As the main objective of the Seismic Group is to exchange information, overcome discrepancies and reach international consensus on technical issues, it is expected that collaborations with international organizations will continue and increase.

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CSNI reports are available at http://www.nea.fr/html/nsd/

