SEISMIC QUALIFICATION OF NUCLEAR POWER PLANTS BY INSPECTION

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SUMMARY

In Canada, seismic surveys of CANDU-PHW Nuclear Power Plants are now a pre-requisite to licensing. Such surveys provide greater confidence that nuclear plants can safely survive a Design Basis Earthquake.

In the U.S.A., there is no mandatory requirement for such surveys. However, such surveys have been used to qualify nuclear facilities where the original design did not consider current seismic design levels or methods of analysis. The paper considers the possible application of this approach to the seismic requalification of existing U.S. nuclear power plants for higher earthquake levels or analytical techniques different from those originally specified.

INTRODUCTION

In Canada, part of the licensing process involves the inspection of the entire CANDU Nuclear Power Plant in order to establish that the as-built, as-installed condition of the facility and its equipment can safely survive a Design Basis Earthquake (DBE). It is not only essential to examine the adequacy of construction of major structures, such as the containment building, but to ensure that all of the process and special safety-systems contained within the containment and associated service building are properly constructed and installed. In addition, it is essential to inspect for possible failure of or damage to safety-related structures or equipment from cascading effects due to collapse, failure or dislodgement of nearby structures or equipment not specifically designed for high earthquake resistance.

In the U.S.A., similar field inspections or seismic reviews have been used on a limited number of existing nuclear power plants (Dresden-2, Oyster Creek, Palisades, Ginna and Millstone station), to evaluate seismic backfit potential on the plant survey.

The seismic review was undertaken at the request of the U.S. NRC by a Seismic Review Team composed of recognized seismic design experts. The review by the Seismic Review Team was considerably different in scope and depth from current U.S. construction permit and operating license reviews, because it is designed to focus only on pertinent matters of significance in an effective manner, sufficient to identify safety issues and to provide

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an integrated and balanced approach to backfit considerations in accordance with current, applicable U.S. regulations. These regulations specify that backfitting will be required only if substantial additional protection can be demonstrated for public health and safety.

In addition to the application of such seismic review teams by the U.S. NRC, to a limited number of operating nuclear power plants, similar surveys have been performed on other types of nuclear facilities to permit seismic qualification for continued operation or start-up.

SEISMIC SURVEYS

In Canada, such an inspection program is called a 'Seismic Survey' and has the following purposes:

1. To ensure that all structures are built and equipment installed in accordance with drawings and specifications.

2. To ensure that there are no loose, unrestrained, improperly anchored, or inadequately constructed or reinforced systems or structures which could become a safety hazard in the event of a DBE.

3. To ensure, by proper inspection, that containment integrity will be preserved in the event of such an earthquake.

4. To determine that systems important to safety will preserve their safety function following a DBE.

5. To ensure that there is unobstructed access to areas essential for safe operation and maintenance of the Nuclear Power Plant (NPP) following a DBE.

The overall concern is for proper operation of safety-related systems and components during/after an earthquake and the risk of cascading effects from collapse or failure of unqualified systems affecting safety-related areas.

Seismic Survey - Stages

Ideally, a site seismic survey should be carried out when construction is well advanced, the plant is fully accessible, and construction platforms and the like are still in place. It is usually conducted in three stages, as follows:

1. A check by the Owner or major contractor that everything has been built and is in accordance with the drawings and specifications.
2. A follow-up site survey by a team of experts, not involved with the construction or installation of the plant, to provide an unbiased opinion as to the adequacy, not only of the construction and installation of the plant, but of its design and layout as well.
3. Finally, a follow-up survey involving the Owner, selected experts and, if possible, a representative of the regulatory body responsible for licensing the plant for operation.

Between each of these stages, suitable corrective actions, if any, are undertaken and reported. The final step is to have a representative expert or inspection team issue a statement to the Owner or licensee that the plant, when placed in operation, is in an acceptable condition to safely survive a Design Basis Earthquake.

Previous Seismic Surveys

Table 1 lists some of the seismic surveys which have been conducted. The requirement for such a survey as a pre-requisite for issuance of an operating license commenced with the Pt. Lepreau-1 NPP (See Fig. 1).

Seismic Survey - Approach

For the surveys conducted by outside inspectors, a suitably-expert team is assembled, including plant personnel with a wide knowledge of the plant layout and the purpose and function of each piece of equipment. This usually requires personnel covering at least mechanical, electrical and civil engineering disciplines.

The experts conducting the survey must have a good knowledge of the systems, items and functions important to overall plant safety. They must also be aware of the seismic design approach which has been applied to the plant and the earthquake accelerations which are expected at each level and in each part of the NPP. In addition to a thorough inspection of structures, systems and components and consultation with plant experts, some ad-hoc, in-situ vibration tests are conducted including:

> jumping, kicking, swinging from pipes and cable trays, striking pipes and components with a rubber mallet, twanging small tubes, pull-back or snap-back tests, shaking by hand, or setting a system into resonance by gripping it and swinging back and forth, using body mass only.

By this approach, it is possible to determine the approximate frequency characteristics, the maximum amplitude of vibration under low excitation, damping characteristics, areas of impact, missing or loose brackets, anchors and supports, and large amplifying effects in the system under test by excitation of attached equipment to much higher levels of motion. Where frequencies were high, amplitudes low or damping adequate, it was generally considered that the system had been well designed and properly installed. Where such ad-hoc tests and visual examinations were unsatisfactory, the adequacy of any suspicious structure or equipment was referred back to the designer, certain dynamic tests were called for, either in-situ or away from the plant, re-analysis or an alternative dynamic analysis was carried out or another opinion was sought, generally with reference to a similar, successful installation elsewhere.

Seismic Survey - Problem Areas

A number of problems were identified which made these seismic surveys particularly difficult. These included:

installation of equipment and systems by a wide variety of suppliers and sub-contractors with varying approaches; field runs of piping, tubing and conduits, cables, etc, by a number of sub-contractors, some of whom were following their own practices, rather than specific installation guides (including 'short cuts' which violated the Group 1 and Group 2 separation philosophy - see Fig. 2); field modifications made during construction or commissioning, which might not have received adequate seismic re-qualification.

75% of the problems disclosed were related to construction or installation errors or difficulties. At off-shore sites, some of the difficulties were related to the practices of indigenous contractors and the use of substitute materials and methods. There is no doubt that greater feedback between the designer and site during all stages of construction, installation and commissioning would avert many of the problems that were disclosed during some of these surveys. This, however, is particularly difficult to control at off-shore sites, which are far removed from the originating design office. In some cases, design concepts initiated by one consulting engineer were detailed by another and installation and construction carried out by still another group at the site. Interface control among the groups, would avoid many of the problems that were disclosed during the seismic surveys.

Seismic Surveys - Results

Table 2 gives examples of typical areas which were examined, the concerns which were expressed in relation to earthquake performance, and some of the proposed solutions. Not all of these were found in any one plant, but represent a typical range of findings and some of the actual solutions employed.

Advantages of a Seismic Survey

A Site Seismic Survey performed at an advanced stage of construction of an NPP, offers an excellent opportunity to perform an independent and overall evaluation of the plant design, layout, construction, installation, field modifications and general suitability for safe survival in the event of an earthquake. In addition, it provides excellent support to Probabilistic Risk Assessments which are carried out separately in conjunction with licensing activities; offers a chance to independently inspect for loose, missing or improperly-installed items of equipment; allows for simple but effective corrective actions to be undertaken at a time when important systems and equipment are readily accessible and there is sufficient time to carry out any necessary remedial actions.

In almost every case, the corrections, repairs, fixes or modifications which were proposed, as a result of such seismic surveys, were readily undertaken, in-situ, were generally inexpensive, and did not seriously affect the schedule for start-up of the plant.

The most important function of a seismic survey of a Canadian NPP is to permit certification of the plant from the safety standpoint in terms of seismic risk, as a definite pre-requisite for licensing such an NPP for operation.

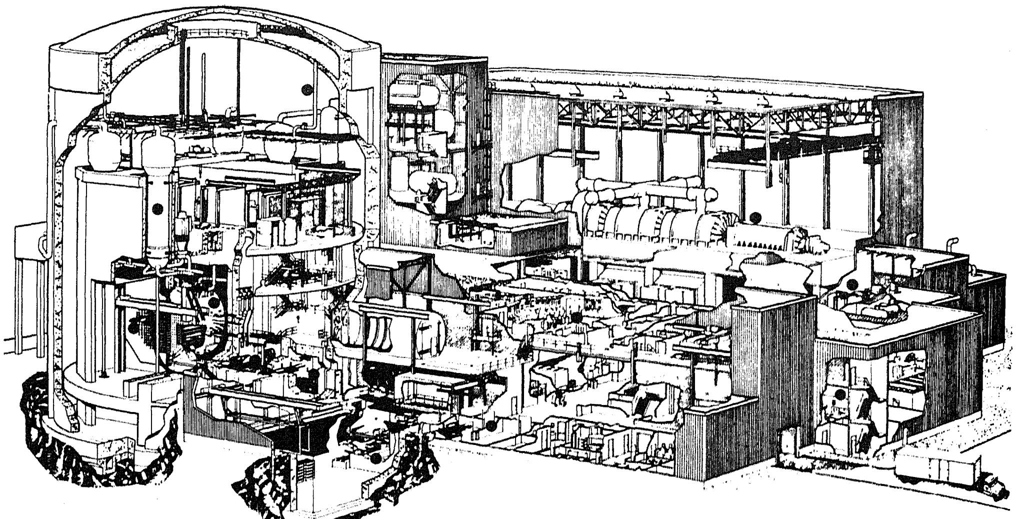
CONCLUSION

The use of seismic survey teams, composed of recognized seismic experts, as a significant part of the seismic qualification procedure in nuclear power plant facilities in Canada and with limited application in the U.S. has been shown to be an extremely efficient and cost-effective method for developing overall assurance of seismic design adequacy. It is hoped that this favourable experience to date can be applied more broadly to nuclear-power-plant seismic qualification world-wide, as a means of reducing the design and/or analytical effort required and to better identify important interfaces and interactions which are essential for assuring overall nuclear safety.

REFERENCES

1. 'Canadian Seismic Design Criteria and Methods for CANDU-PHW Nuclear Power Plants', by C.G. Duff, presented at the 4th Pacific Basin Nuclear Conference, Vancouver, Canada, September 1983.

2. 'Use of the Delphi Approach in Seismic Requalification of Electrical and Mechanical Equipment', by J.D. Stevenson, presented at the International Meeting on Thermal Nuclear Reactor Safety, Chicago, Illinois, U.S.A., September 1982.



1 REACTOR
2 FUELLING MACHINE
3 STEAM GENERATOR
4 DOUSING SYSTEM
5 NEW FUEL HANDLING
6 SPENT FUEL HANDLING
7 SPENT FUEL INSPECTION AND STORAGE
8 MAINTENANCE AND INSPECTION
9 CONTROL CENTRE
10 MECHANICAL WORKSHOP
11 WATER TREATMENT
12 TURBINE AND GENERATOR

600 MW(e) NUCLEAR GENERATING STATION

FIGURE

TABLE 1 - CANADIAN SEISMIC SURVEYS

Name of Reactor	Location	Power MW(Gross)	Type of Survey	Date of Survey	First Power
Pickering-1	Ontario	542	Reactor vault only	1969	1971
Pickering-2	Ontario	542	Reactor vault only	1970	1971
Bruce-1	Ontario	826	Walk through	1976 May	1977
Bruce-2	Ontario	826	Walk through	1976 May	1977
Gentilly-2	Quebec	685	1st walk through	1977 Sept	1982
"	"	"	2nd full survey	1981 Oct	"
Cordoba	Argentina	679	Walk through	1979 Oct	1983
Pt.Lepreau-1	New Brunswick	680	1st full survey	1981 May	1982
"	"	"	2nd full survey	1982 Mar	"
Wolsung-1	Korea	679	Full survey	1981 Nov	1982

SEISMIC QUALIFICATION AND SYSTEMS SEPARATION
FOR A 600 MWe STATION ON AN OCEAN SITE

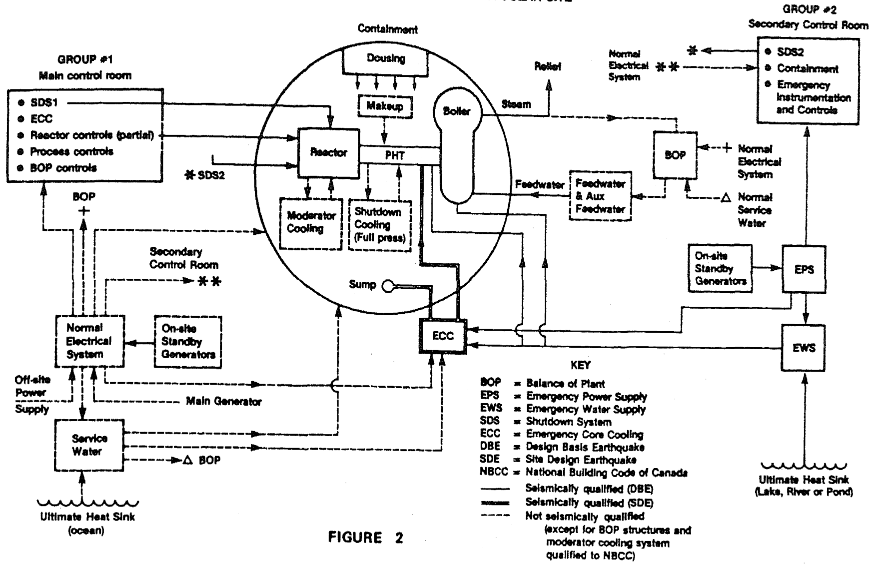


FIGURE 2

TABLE 2 - TYPICAL CANADIAN NUCLEAR POWER PLANT SEISMIC SURVEY - Key: EQ = Earthquake SQ = Seismically Qualified NSQ = Not Seismically Qualified

Item	Concern	Solution
• Concrete block partition walls	Insufficient reinforcing. Risk of collapse	Rebuild or properly reinforce walls, dowel to floor or tie into steel work.
• Instrument stands and equipment platforms	Too shakey	Add cross bracing; brace back to wall
• Cable trays (stacked trapeze-type and cantilevered)	Too flexible. Insufficient end anchorage. Unprotected from falling objects.	Add bracing. Tie back to wall. Anchor ends and 90° turns. Add protective covers. Lockweld joints.
• Drilled-in expansion anchors in lieu of cast-in	Pull out in an earthquake	Qualify by testing, replace or supplement by stronger anchors. Higher-strength anchor bolts. Redundant anchors.
• Conventional pipe hangers	No lateral resistance. Threaded types could snap off in an EQ.	Add lateral restraints or snubbers. Replace rigid rods by swivel type.
• Tank and equipment supports	Unbraced legs. Single anchors per leg	Add bracing. Double up anchors. Tie back to wall.
• Snubbers	Insufficient. Unprotected	Add snubbers as necessary. Add protective boots.
• Tall, overhung valves and valve operators	Excessive sway in an EQ	Add snubbers or lateral restraints.
• Overhead ductwork	Could collapse onto safety-related equipment	Strengthen duct joints. Add end restraints. Improve supports. Add back-up cables.
• Cantilevered small valves, gauges fittings, etc	Risk of snapping off in an EQ	Restrain valves or use shorter connections
• Small branch pipe or tube connections	High amplification, failure risk	Motion limits. Good anchorage. Proper flexibility

Item	Concern	Solution
• Vertical pipes with widely-spaced supports/anchors	Too flexible horizontally.	Add lateral restraints.
• Overhead lighting (tubular fluorescent and mercury-vapour bulbs)	Could collapse onto or sway against safety related equipment	Add lateral restraints, close chain hooks. Add protective covers
• Electrical equipment cabinets, consoles, racks and centres	Too flimsy. Glass doors. Inadequate anchoring. Door-hinges and latches insufficient. Tops unprotected from falling objects	Stiffen frames. Improve hinges/latches, Strengthen anchors, Tie cabinets together. Reinforce tops.
• Field-run tubing, small piping and electrical conduits, small valves and fittings	Too flexible. Not consistently wall anchored. Insufficient separation of Group 1 and 2	Re-Route as necessary. Improve clamping and supports.
• Local overhead coolers, heaters, intercoms, etc	Risk of collapse onto safety-related equipment. Too shakey.	Improve supports. Add lateral bracing. Add back-up cables.
• Water, fuel or lubricant lines and storage tanks	Risk of failure causing flood or fire	Improve support bracing. Add protective curbs and proper drainage, sprinklers, halon
• High-pressure gas storage bottles	Risk of falling over, snapping valves and becoming missiles	Secure storage racks.
• Pipe and pump clamps and anchors	Risk of failure or loosening in an EQ	Consider redundancy for critical anchors and adequate preload
• Building to building clearance	Impact during an EQ	Provide enough rattle space or use soft caulking

Item	Concern	Solution
• Safety-related equipment close to NSQ equipment or structures	Risk of collapse of NSQ onto safety-related equipment in an EQ	Increase separation. Cage or barricade NSQ equipment. Protect safety-related equipment. Secure NSQ structures or equipment to prevent collapse. Add redundant or diverse safety-related equipment (well separated).
• Storage batteries	Batteries needed for emergency power or diesel starting could collapse in EQ	Strengthen battery racks and anchors. Tie batteries to racks. Place batteries closer to floor level.
• Radioactive fuel/waste storage	Release of activity during an EQ	Secure storage areas. Confine cooling and shielding water. SQ ventilation systems.
• Cranes, hoists, jibs	Loads swinging against or dropping onto safety-related equipment	Tether hoists and lower loads onto safe area when not in use
• Ladders, handrails, guard rails, stairways, etc	Could collapse in an EQ. Also safety-related equipment supported from same could fail	Secure and lock handrails, ladders etc. Mount equipment on separate SQ supports.
• Instrument air reservoirs	Risk of loss of air to safety instruments in an EQ	Properly support check valves. Improve anchorage.
• Building wall penetrations	Risk of pull out or shearing off due to EQ building movement	Increase clearance around penetrations, use soft bedding, instal flexible terminations or bellows.
• Electrical equipment connections	Equipment sway may pull out rigid conduit connections	Add short length of armoured, sheathed cable at all connection points
• False or suspended ceilings. Loose furniture	Risk of injury to personnel or equipment	Secure ceilings and furniture. Add curbs and railings to consoles

3.3 Material Provisions