USE OF PRE-OPERATIONAL SEISMIC WALKDOWNS IN CANDU 6 NUCLEAR POWER PLANTS

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ABSTRACT

In accordance with the recommendations of the IAEA Safety Guide No. 50-SG-D15, seismic walkdowns have been performed on all recently constructed CANDU®[1] 6 stations. The main objective of these walkdowns is to ensure that the as-built plant is seismically robust and can resist a design basis earthquake without impacting safety.

The purpose of this paper is to present the approach followed in the CANDU 6 pre-operational seismic walkdowns, which includes planning, walkdown, documentation and disposition of the observations. The paper also discusses typical observations identified in the walkdowns, the satisfactory resolution of which has resulted in plants which are both seismically robust as well as ensured that the construction had achieved the design intent specifically with respect to the safety systems.

The successful seismic walkdown with satisfactory disposition of the findings is an important factor in proceeding with the completion of commissioning and subsequently placing the plant into service. In addition, the significant observations become part of AECL's "lessons learned" program that is implemented in the subsequent stations to further improve the seismic robustness of the CANDU nuclear power plants.

1. INTRODUCTION

Seismic walkdowns are used in the nuclear industry to deal with seismic design and qualification of the reactors. For the operating Nuclear Power Plants (NPP), seismic walkdowns are carried out to assist the success path screening and fragility analysis in the seismic margin assessment (SMA) and the seismic probabilistic safety analysis (PSA) ([1],[2]). They are also applied to help the seismic control and the seismic configuration management activities in the NPPs.

International Atomic Energy Agency (IAEA) has issued a series of safety guides for the design, construction and operation of the nuclear power plants. In the seismic design and qualification safety guide No. 50-SG-D15 issued in 1992([3]), it states "It is recommended that all seismically qualified items in the nuclear power plant be walked down by qualified seismic design and earthquake experienced structural engineers prior to operation to ensure that the "as installed" items are capable of withstanding the design basis seismic effects without loss of structural integrity, with anchorage and seismic interaction effects taken into account". In 2003, IAEA issued a new Safety Guide NS-G-1.6 ([4]) to supersede the 1992 edition for the NPP seismic design and qualification, which also expresses the need of the seismic walkown for the new-built reactors: "…, all seismically qualified items in the nuclear power plant should be subjected to walkdown by structural engineers qualified in seismic design and with earthquake experience prior to operation.". In-line with the recommendations of IAEA, pre-operational seismic walkdowns have been applied to the seismically designed CANDU 6 reactors including recent overseas projects.

This paper is to present the objectives and procedures of the CANDU 6 pre-operational seismic walkdown. It also discusses typical issues detected in the recent walkdowns and the recommendations for satisfactory disposition of these issues.

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[1] CANDU (CANadian Deuterium Uranium) is a registered trademark of Atomic Energy of Canada Limited (AECL).

2. OBJECTIVES AND PROCEDURE

Seismic Walkdwon Objectives

A seismic walkdown (also called seismic survey) is not intended to replace the seismic design or any of the established quality assurance activities. Rather, it serves as an additional verification process involving mainly inspection and some spot-checking to ensure the as-built plant is seismically robust. To be more specific, the purposes of the seismic walkdown for a CANDU reactor are

- To provide an additional verification that seismically qualified (SQ) structures, systems and components (SSC) have been installed adequately;
- To verify that seismically qualified SSC have been adequately protected from National Building Code of Canada (NBCC) qualified SSCs. It is noted that the NBCC qualified SSCs are often termed as Non-Seismically Qualified (NSQ);
- To determine whether seismically qualified SSC have been adversely affected by field changes or add-ons;
- To ensure safe access from the Main Control Room (MCR) to the Secondary Control Area (SCA) after an earthquake;
- To uncover potential seismic induced hazards such as missiles, fire, and flooding;
- To gather information and data about any observed design or installation deficiencies for further evaluations;
- To record good and bad designs and installations to be used later as feedback to the design process.

Procedure

A pre-operational seismic walkdown for a CANDU 6 NPP consists of the following steps:

Orientation Training

The seismic walkdown team is composed of seismic specialists as well as site engineers from different disciplines who may not be familiar with the seismic design practices and seismic walkdown details. Orientation training is an effective way to get the team members to know the seismic issues. Generally, the orientation covers the fundamental seismic design and qualification concept for CANDU reactor and the details for the walkdown. The focus of the training is placed on the understanding of the seismic characteristics as well as potential seismic issues of various structures and equipment. A good practice is to show the team the previous findings observed in similar nuclear plants.

Walkdown Planning

Scheduling of a seismic walkdown has to consider two diverging aspects. The first is that seismic walkdown prefers the construction to be close to completion in order to check the whole plant and the interaction issues. The second aspect is that the walkdown observations will require corrective actions which need time and are difficult to implement at the late stage of construction. A seismic survey scheduled too late can potentially affect the plan for completion of commissioning and fuelling of the reactor. Hence, the optimum time in the schedule to perform the seismic walkdown is when the project is in an advanced stage of the construction yet with sufficient time to implement potential corrective actions.

The pre-operational seismic walkdown is a plant wide activity, covering the reactor building (RB), the secondary control area (SCA) and the emergency power supply (EPS) building, the high pressure emergency core cooling (HPECC) building, the service building (SB), the designated indoor and the outdoor safe passageways from the main control room (MCR) to the secondary control area (SCA), the emergency water supply (EWS) pump house and the balance of plant (BOP) consisting of the turbine building and the Class 3 diesel generator building. Some of these areas house critical safety equipment as well as major process and fuel handling equipment.

The walkdown routes and schedules are selected based on experience of the previous seismic surveys with consideration of input from site staff. During the walkdown, daily meetings are conducted for discussions

of the daily observations. A final close-out meeting is carried out with all the participants to summarize the observations and action recommendations.

Conducting Walkdown

The walkdown is conducted from room to room along the planned routes. The SSCs are visually inspected by the team members and whenever necessary additional physical checks are added like shaking or tapping. In addition to focusing on the seismic interaction issues, the walkdown looks for outliers, lack of similarity, lack of seismic braces, inadequate anchors or situations at odds with the team member's past experience. Taking notes and photos of the observations is mandatory which are to be used for the documentation and disposition purpose. During the seismic walkdown, the team is recommended to focus on the following aspects:

- Interactions

This is the most important aspect in the pre-operational seismic walkdown. Many types of interactions may appear in a newly built NPP, including: NBCC equipment is located above or close to SQ equipment; heavy NBCC equipment is attached to a qualified equipment; non-seismically designed block walls are in the proximity of the seismically qualified safety equipment; equipment actuator is located too close to a structure/wall for having potential pounding; and adjacent cabinets are close to each other but not rigidly linked together. These interaction issues may not be obvious in the design stage and shall be carefully dealt with in the walkdown process.

- Anchorage and Support

Equipment must be adequately anchored or supported since they rely on the supports and anchors to resist seismic induced inertial forces and movements. Attention in the seismic survey is directed to the following aspects: verify that there are no missing or loose bolts or nuts; check if anchorage appears to be tight and stiff; look for inadequate anchor spacing or distance to free edge, any non-uniformity in installation, insufficient welding, inadequate grout thickness or excessive concrete cracking; verify the sliding supports and the slotted holes to ensure that the installation is able to accommodate thermal expansion of large mechanical equipment; and make sure that the bearing plates are thick enough to avoid excessive prying action;

- Seismic Induced Hazards

A seismic event can potentially induce other hazards like missiles, fire and flooding. For the seismic induced missiles, the walkdown focuses on the gas bottles, fire extinguishers and acid drums to ensure they are well restrained particularly in the areas where the safety related system and equipment might be affected or the operator's personal safety might be threatened. The walkdown team also looks for flammable materials in the vicinity of the safety equipment to take care of the seismic induced fire hazard. For SQ equipment located low in the room with no drainage or sump pump, seismic induced flooding can be a concern. Large tanks located high can also be a flooding risk for the safety equipment at a lower elevation.

- Workmanship Issues

Although pre-operational walkdown is not intended to be a quality surveillance activity, past experience shows that workmanship issues constitute the majority of the observations identified in the walkdowns. The seismic survey team needs to check for any obvious non-uniformities or difficulties encountered in the installation of the equipment. Sharp cutting edges in the cable pans or cabinet openings without proper wrap-up can pose cable nicking risk whereas insufficient slackness of the cables and other instrumentation lines which are connected to different structures or equipment may not be able to accommodate large relative motions. Heavy add-ons may be installed for convenience, not really according to the design. Grating floor may lack proper clamps to be properly secured in place. If these issues are present, they shall be noted in the observations.

- Safe Passageway

In a DBE event, the operators of a CANDU reactor may be required to move from the MCR to the DBE qualified SCA to control and monitor the reactor. The route for the operators to go from the MCR to the SCA is termed as the safe passageway and is designed to DBE. The walkdown of the safe

passageway needs to focus on the interaction of blockage and release of chemical gases due to the failures of gas bottles and non-DBE qualified items. Fire extinguishers and gas bottles in the vicinity of the passageway are inspected for seismic adequacy. Loose objects need to be tied down appropriately. Besides, proper installation of DBE qualified emergency lighting on the path is essential for the safe passage of the operators.

Documenting and Closing-out Seismic Walkdown

The team takes notes and photos of the observations during the walkdown, which shall be subsequently summarised for inclusion in the walkdown report. The team also discusses and provides recommendations to dispose of the observations. The recommended actions can generally be categorised as: a) implementing corrective measures; b) reviewing design documents to confirm the seismic adequacy; or c) performing additional analyses to ensure the seismic capacity.

To close out the issues, proper actions have to be taken to implement the recommendations. The corrective actions can be hardware installation or modification. But, they can also mean operating procedure change or notification. In rare cases, an alternative solution has to be worked out to dispose of an issue because the recommended action is not feasible to apply in the circumstances. Some issues can be resolved by reviewing the design drawings and design reports to confirm that the installation is according to the design or covered by the design analysis.

3. LESSONS LEARNED FROM PAST WALKDOWNS

Pre-operational seismic walkdowns have been successfully carried out for the CANDU 6 projects. The observations and feedbacks from the seismic walkdowns served as lessons learned, which have been applied to improve the design and construction of more recent CANDU plants. Some examples of the improvements include:

- Securing hatch covers by chains;
- Improving anchorage of the panels in the MCR and SCA;
- Adding support chains or rods to secure lighting;
- Strengthening the ducting supports;
- Enhancing seismically qualified tubing supports;
- Replacing large expansion anchors with embedded parts for anchoring the seismically qualified heavy equipment;
- Restraining the NBCC qualified valve actuators where interaction is a concern;
- Eliminating block walls near safety systems;
- Improving restraints for the batteries;
- Adding restraints to better secure gas bottles and loose items.

The implementation of these measures further enhanced seismic robustness and reduced seismic risks of the CANDU 6 NPP.

The experience coming from the seismic walkdowns is briefly summarised and described below in terms of SSC categories.

Civil Structures

The major CANDU buildings and structures are DBE qualified. Non-load bearing mansory block walls for fire protection or other reasons have been gradually replaced by the reinforced concrete walls because of the interaction concerns in a seismic event. During the walkdown, it is normally difficult to identify the reinforcement details to judge the adequacy of the block walls. Pre- and post walkdown review of the drawings has been the choice to facilitate the walkdown activities. The seismically designed structures have generally appeared to be constructed well and very few issues have been identified in the walkdowns.

In some cases, the grating floors have been found without sufficient anchoring clamps, which may create interaction issues. All corrective actions have been subsequently carried out.

Passive Mechanical Components

This category includes tanks, vessels, HXs and SGs, etc.. Many of these components inside the reactor building are DBE qualified. They are designed with sufficient restraints to take seismic loads. Installation of the large DBE qualified components has been found satisfactory. Because of the large size, they are not vulnerable to the falling down of light equipment nearby. However, for NBCC qualified tanks outside of R/B building, there have been some observations that required additional checks to confirm NBCC seismic capacity. One of the issues is related to large horizontal tanks with one fixed saddle support at one end and the rollers without lateral restraints at the other. The recommendation calls for adding simple lateral restraints to the roller supports.

Active Mechanical Components

Pumps, valves, diesel generators, fans and local air coolers are the major active mechanical components. Some of them are DBE Category "B" qualified. In CANDU design, seismic Category "B" requires that the equipment must keep pressure boundary integrity as well as operability during and after a seismic event. The active components are generically seismic rugged provided supports and restraints are properly installed. Review of the design and analysis before and after seismic walkdown helps to confirm the installation and seismic adequacy. There was a potential cascading failure issue identified in the walkdown, where a heavy-head in-line mounted NBCC qualified valve without lateral restraint has been located in the vicinity of DBE qualified valves. Additional restraints have been subsequently installed for the NBCC valve to avoid consequential damage. In addition, some valve actuators have been found in contact with conduit lines or very close to structures. Removal or modification of the conduits and structures have been recommended.

EI&C Equipment

Large amount of Electric, Instrumentation & Control equipment are housed in the cabinets. In CANDU design, safety cabinets are seismically designed and qualified by shake table testing in a free standing state whereas the equipment are normally qualified by device type of testing to satisfy conservative generic required response spectra specified for plant wide applications. The structural integrity of the SQ cabinets is not considered as a concern. However, pounding of the adjacent cabinets has been found to be an issue where the neighboring safety cabinets are not bolted together, or NBCC cabinets are close to the safety cabinets. Recommendations have been given to link the cabinets to eliminate pounding induced relay chatters. Besides, some installation workmanship issues have also been identified particularly for NBCC cabinets. Corrective actions have been carried out. Seismically qualified batteries and battery racks are generally found adequately restrained and braced.

Electrical Distribution System

The cable tray and conduit systems in general have high seismic capacity if braces are properly provided. CANDU applies the separation principle in the design and puts safety related cables together in Group 2 whereas other cables are in Group 1. The Group 2 requires DBE qualification. The cable tray supports are designed and dynamically analysed with conservative assumptions on the seismic loads and damping of the cable tray systems. To avoid interaction, the Group 2 cables are separated and installed above the non-safety Group 1 cables. Besides, routing and installation of the cable trays and conduits follow the technical specification with requirements on the support spans and the flexibility to accommodate relative motions. In the electrical distribution system, sharp edges without protective measures have been identified in the seismic walkdowns as a concern. They occur at the cable pan end cutting and the cabinet opening cutting. Wrapping rubber bands around or removing the sharp edges has been recommended to eliminate cable nicking risks in a seismic event.

Piping& HVAC Ducting

The DBE qualified piping and HVAC systems are well designed with sufficient restraints and supports. But, the non-DBE qualified piping and HVAC systems is less rigid and less restrained. During the seismic walkdowns, issues have been observed in these systems, particularly the field run lines. Recommendations have been provided to strengthen the lines in certain cases. Checking the non-DBE qualified items in the seismic walkdows has been performed mainly in the area where safety systems are present.

Additional Items

Gas Bottles and fire extinguishers can produce potential missile hazards. However, proper seismic supports or restraints have not been observed for some of them. Addition or modification of the restraints for certain gas bottles has been recommended. The effort to deal with this hazard has been directed to ensure the safety systems and the safe passageway from MCR to SCR would not be affected by the missile hazard. Another issue identified during the walkdowns is the improper parking of the overhead hoisters and cranes, which pose interaction risks to the seismically qualified safety equipment. Procedure notice with addition of restraints or brakes in certain cases has been recommended to minimize the consequential failure risk to the safety systems.

4. DISCUSSIONS

Observations on NBCC Qualified Equipment

Compared to the DBE qualified equipment, the NBCC qualified items are designed to a lower level of seismic loading. Past experience shows that the majority of the walkdown observations are related to the NBCC qualified equipment. The complete inclusion of all observations in the walkdown report is unnecessary. Many of the findings can be resolved with no additional actions. However, the disposition of these issues should take into account: a) Is interaction of the NBCC qualified item with safety related systems a concern? b) Can the observation render the equipment vulnerable to survive an NBCC seismic event since all CANDU 6 equipment must meet NBCC requirement as a minimum? Any findings related to these issues need to be included in the walkdown report and require actions to close out.

Practicality and Recommendation

The pre-operational seismic walkdown is generally performed in the end stage of the construction and during commissioning. Large scale retrofitting or modification is very difficult. The recommendations, thus, must take into account the modification effort and the feasibility in addition to the seismic effectiveness. The best choice from a seismic perspective may not be adopted as a recommendation because of the practicality reason. Measures, which seem not in line with general rules, may have to be considered to deal with a particular issue. For example, if a non-DBE qualified cabinet is close to a DBE qualified cabinet and interaction in terms of pounding is perceived as the seismic risk, the first choice to resolve this issue would be to relocate either of the cabinets so as to eliminate the interaction issue entirely. However, this would involve a great deal of effort or might not even be feasible because of the space limitation. Alternative measures must be considered in this circumstance. Linking the cabinets together can be considered as a solution in this particular case if the strength of the non-DBE qualified cabinet is ensured and collapse is out of question. This recommendation effectively solves the interaction issue with minimum work involved.

5. CONCLUSIONS

The pre-operational seismic walkdowns have been successfully carried out in the recent CANDU 6 projects in accordance with the IAEA's recommendation. The walkdowns have confirmed the seismic robustness of the CANDU 6 NPPs. They also have revealed various observations and resulted in improvements on the design and construction of the CANDU reactors. The pre-operational seismic walkdown is an effective process to further enhance the seismic capability of the new built nuclear power plants and is recommended for all future new built projects.

6. REFERENCES

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