GI 199 and 2011 Mineral, VA Earthquake Impact to North Anna Nuclear Power Plant

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SUMMARY
Although the ground motion from the 2011 Mineral, Virginia earthquake exceeded both Operating Basis Earthquake and Design Basis Earthquake at the North Anna Nuclear Power Station, the plant's Structures, Systems and Components experienced no significant damage and maintained their functionality and operability. Experience from the post-earthquake investigations at the plant site confirmed the premise expressed in the US Nuclear Regulatory Commission's draft Generic Letter. The premise is that there is no imminent safety concern for US Nuclear power plants because of their substantive seismic design margin. Nevertheless, based on the NRC's defense-in-depth policy, a seismic hazard reevaluation is needed because hazard perception has been changed since those plants characterized their seismic hazard several decades ago. This paper presents detailed observations based on the authors' post-earthquake investigations, and also discusses the relationship between what was learned from the earthquake's impact to the plant and the draft Generic Letter of Generic Issue199.

Keywords: ground motion, Generic Issue, seismic design, earthquake

INTRODUCTION

A magnitude 5.8 (Mw) earthquake occurred near Mineral, Virginia, United States in August 23rd 2011. This earthquake is one of the largest recorded events occurring east of the Rocky Mountain since seismic instrumentation was deployed. North Anna nuclear power station (NANPS) is located about 18 km from the epicenter and it is the first US commercial nuclear power plant in which a seismic trip was triggered initiating a safely shutdown[1]. Although both the Operating Basis Earthquake (OBE) and Design Basis Earthquake (DBE) or Safe Shutdown Earthquake (SSE) at the North Anna site were exceeded, the plant's structures, systems and components (SSCs) experienced no significant damage and the plant's functionality and operability were maintained.

On September 1st of 2011, days after the Mineral, VA earthquake, US Nuclear Regulatory Commission (NRC) published the draft Generic Letter (GL) for public comments. Although the draft GL publication's date was almost coincident to the earthquake's occurrence, the GL's preparation went through a painstaking process and experienced many working stages, including screening, regulatory analysis, panel decisions and others. The tipping point for initiating GI 199 is the relative contrast of site-specific ground motion response spectra between operating nuclear power plants and recent Early Site Permit (ESP) or Combined License Application (COL) at the co-located sites, and

[1]Safe shutdown means nuclear reaction is stopped in a controlled manner by inserting the controlling rods into a reactor

the latter is generally larger than the former. Because design ground motions for existing nuclear power plants were determined some decades ago using a deterministic method (DSHA), the seismic hazard perception, including the views on seismic source, ground motion propagation and site response as well as the methodology all have gone through significant change. Current practice is to use a probabilistic seismic hazard analysis (PSHA) method, instead of a DSHA. Therefore, the PSHA method in combining with the latest updates from sources, wave propagations and site responses triggered all the changes for site specific seismic hazards. The reality is that earthquake occurrence at a region is not changed but people's understanding to the potential seismic hazard has been changed and the change is still continuing. For example, before 1998, a general consensus on the return period of the New Madrid seismic zone (NMSZ) was 1,000 years, but later the return period was changed into 500 years. More recently, a new model was proposed, that is, earthquakes in NMSZ were assumed to have occurred in such a fashion that frequent large earthquakes occur within a relatively shorter time window (in the cluster), followed by a relatively longer quiescence (out of the cluster).

This paper summarizes the observations made during post-earthquake investigations at NANPS. The fact that the plant still did not experience any significant damages although the site SSE was exceeded is due to earthquake ground motion itself and the large safety margin embedded in the original seismic design for the plant. The paper then discusses draft GL which was published as the progression of GI 199 process and the correlation between the observations established on the post-earthquake investigations at the NANPS site and the essence of the draft GL. Finally, the paper will explain the relationship between the draft GL and recent NRC's 50.54(f) letter issued on March 12, 2012.

2011 Mineral, VA earthquake's impact to the North Anna nuclear power plant

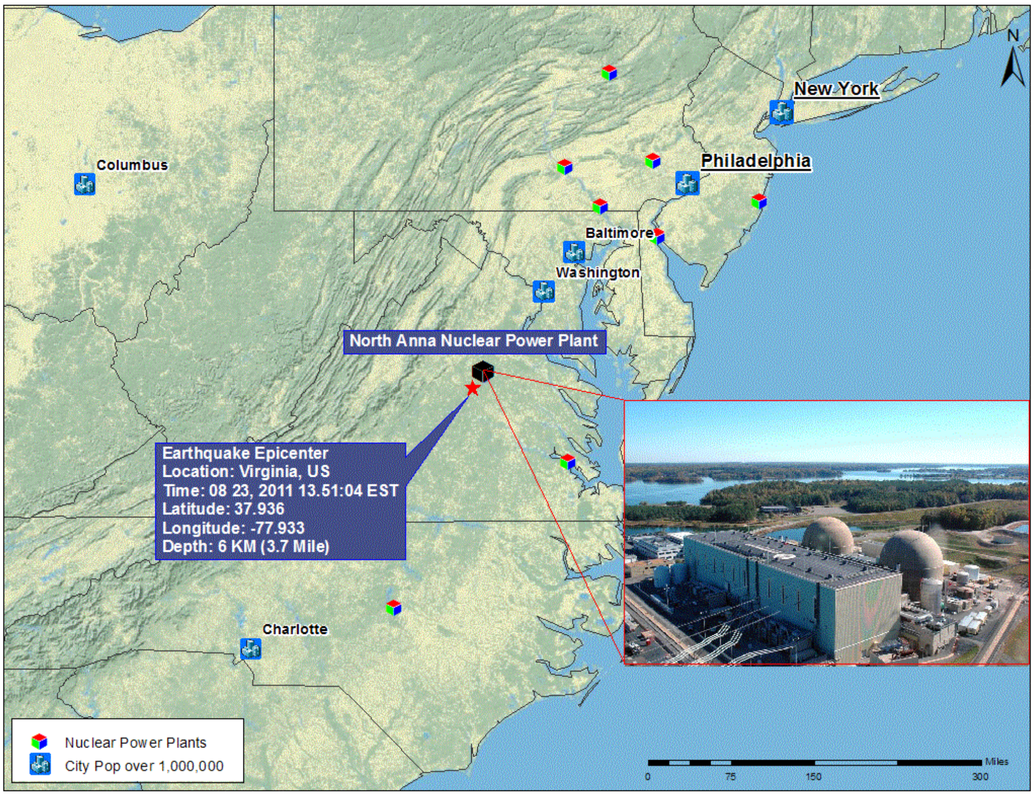

Figure 1. Location of 2011 Mineral, VA Earthquake and the inset is North Anna nuclear power plant

The Mineral, VA earthquake occurred at about 13:51 hours and the main shock occurred at a shallow depth about 6 km from the surface. The earthquake is associated with a reverse fault and most likely the fault strikes in the north or northeast direction, according to the US Geological Survey focal mechanism solution (USGS, 2011). However, there is no known specific fault source associated with the earthquake. Following the main shock, there were quite a few aftershocks and the largest aftershock was of a magnitude 4.5. The main shock and aftershocks were all located inside the Central Virginia seismic zone (CVSZ) where small earthquakes often occur. The largest historical earthquake known to have occurred in the CVSZ before 2011 is a magnitude 4.8 (estimated because no seismic monitors were available at that time) Goochland County earthquake, which occurred in 1875 (USGS, 2011). Since 1984, when seismic instrumentation was deployed, earthquakes that occurred in this zone were estimated ranging from 4.0 to 4.6 in magnitude and between 5 and 8 km in depth.

NANPS (see inset of Figure 1) has two pressurized water reactors (PWR) units that were commissioned into operation in 1978 and 1980, respectively. Each unit has an output core power of approximately 980 Megawatt Electrical (MWe). The site is located in Louisa County, Virginia, about 65 km northwest of Richmond, VA and 114 km southwest of Washington DC. The plant cooling water source is Lake Anna which is a man-made lake impounding excess water from the North Anna River.

The plant's safety-related structures are founded either on rock or soil. For the structures founded on rock, the horizontal design basis earthquake (DBE), or safe shutdown earthquake ground motion (SSE) is anchored at peak ground acceleration (pga) of 0.12g. For structures founded on soil, the horizontal DBE is anchored at 0.18 g. The vertical component of the ground motion is taken as two-third of the horizontal motion. Also, the operating basis earthquake (OBE) for the plant is anchored at one-half of the DBE level. The corresponding spectral shapes of DBE were developed by enveloping the response spectra from 1935 Helena earthquake and 1957 San Francisco earthquake, respectively. During the 1990's Individual Plant External Event Evaluation review process, the plant was reviewed against a Review Level Earthquake (with spectral shape based on historical strong ground motion data from western US) anchored at pga of 0.3 g.

The investigations and findings

After the earthquake, the NANPS licensee performed extensive walkdowns of the plant structures, systems and components (SSCs) to look for and identify damage caused by the earthquake. NRC investigation teams also implemented focused walkdowns of SSCs, both safety or non safety related, at the plant as well as spent fuel storage facility in the field (2011, NRC). From these multiple walkdowns and other related activities, it was determined that no significant damage occurred to the plant's SSCs and to the spent fuel storage facility. The functionality and operability of the nuclear power plant SSCs were maintained. Typical earthquake damages observed during the investigation are summarized as follow.

1. **Cracks on walls**

Common damages observed were cracks on interior walls and those cracks occurred mostly inside non safety-related structures. There are generally two types of cracks in terms of their orientation on the affected structural elements. One is horizontal and the other is inclined, and those cracks are generally hairline cracks (Figure 2). Most horizontal cracks were either developed from pre-existing weaker interfaces, for example, construction joints between lifts and in some cases between the ceiling and the wall. These cracks did not affect the structures' functionality.

Figure 2. Inclined crack on the internal wall of turbine building. The width of the crack is about 0.25 mm

2. Spalling of anchored bases

Spalling was also observed at some tank bases (Figure 4), and those base plates were anchored to the floor. However, some small displacements occurred at other support bases which were not anchored.

Figure 3. Horizontal cracks developed from construction joints between lifts in the Auxiliary building.

3. Sloshing at the spent fuel pool

A common phenomenon that could be expected at nuclear power plants when seismic waves propagate through is spent fuel pool (SFP) sloshing. For example, at Kashiwazaki nuclear power plant in Japan, the spent fuel pool water spilled over and diverted into the ocean through the structures' openings during the July 16, 2007 earthquake. However, based on the NRC staff's walkdown of the SFP at NANPS and interviews with the plant employees, no spill happened at the NANPS SFP and no significant sloshing occurred during this earthquake.

Figure 4. Spalling at an anchored Phase Separator tank base.

Figure 5. Transformer's bushing and the flange

4. Transformer damage

Transformers (located outside of turbine building) were damaged due to the earthquake (see Figure 5). The transformer bushings are made of porcelain and they are in contact with metallic flanges. These heavy bushings projected out from the transformer with one end fixed and the opposing end free to move during vibration, which resulted in cracks of those bushings. The damage to transformer's bushings caused the loss of offsite power. However, all four emergency diesel generators automatically started to provide cooling to the plant.

5. Dry Cask storage

There are two types of dry casks at the NANPS site to store nuclear spent fuel: TransNuclear vertical cask and NUHOMS horizontal cask. Both types of casks were impacted by earthquake ground motion. Each TransNuclear cask weighs about 115 Tons when loaded. Twenty five (25) out of twenty seven (27) of the TransNuclear casks experienced different amounts of movements and the largest displacement is 11.4 cm (Figure 6). In addition, there are twenty six horizontal NUHOMS casks and half of those casks were empty. Gaps between some of the casks changed slightly and spalling was also observed at the roof vent of cask structures (Figure 7). Sensors installed inside the casks indicated that no change to radiological conditions occurred and these conditions remained normal.

Figure 6. TransNuclear casks at the NANPS (left) and some of the casks were moved as far as 11.4 cm (right).

Figure 7, NUHOMS dry casks at NANPS plant (left) and the spalling damage at the top of cask (right)

Discussions

Seismic safety of US commercial nuclear power plants

All the post earthquake investigations carried out at NANPS had confirmed that no significant damages to either safety related or non safety-related SSCs although the specific Design Basis Earthquake criteria were exceeded at several frequency ranges. Cracks and spalling are the most common observed damage and no impact to functionality and operability of the nuclear power plant's SSCs. The plant shutdown safely and cooling was maintained throughout the entire event period. This observation could be attributed to two factors: 1) the characteristics of earthquake vibration itself, and 2) the conservative seismic design of nuclear power plant. The Mineral, VA earthquake's strongest shaking was of relatively short duration, and the strong ground motion only lasted about several seconds. On one hand, the threshold of 0.16 g-second of Cumulative Absolute Velocity, a criterion used (in addition to the OBE ground motion being exceeded) in determining if a nuclear power plant needs to be shutdown was exceeded slightly in only one direction of three components. On the other hand, seismic design for nuclear power plants is very conservative with a considerable safety margin. Studies indicate that for U.S. plants in lower seismic zones for which SSE levels are commonly determined to be between pga values of 0.12g and 0.25g, the seismic probabilistic risk assessment indicated that the dominant seismic risk coming from earthquake ground motion is 2 to 5 times greater than the design SSE level (EPRI, 1991). Nevertheless, in consideration of the lessons learned from Japan's Fukushima nuclear power plant accident, NRC has initiated systematic reevaluation of seismic (and flood) hazards for all the US commercial nuclear power plants.

Draft Generic letter for GI 199

Since 2003, NRC has received quite a few applications for ESP and COLA. However, reviewing those new applications revealed that in many co-located sites where both operating reactor sites and new sites are neighboring to each other, SSEs or site-specific ground motion response spectra (GMRS) determined for the new sites are generally higher than those for the operating reactor sites. The contrast between the two may lead to a perception that the existing reactor is perhaps under-designed in SSE. The NRC decided that this observation needs to be assessed, which eventually led to the creation of Generic Issue (GI)-199, "Implications of Updated Probabilistic Seismic Hazard Estimates in the Central and Eastern United States on Existing Plants." GI-199 was established on June 9, 2005. The initial screening analysis for GI-199 suggested that estimates of the seismic hazard for some currently operating plants in the CEUS have increased. The conclusion from the screening analysis was that GI-199 should proceed to the safety/risk assessment stage of the Generic Issue Program (GIP). Subsequently, during the safety/risk assessment stage of the GIP, the NRC staff reviewed and evaluated the new information received as a part of the ESP/COL submittals, along with 2008 U.S. Geological Survey seismic hazard estimates and recent geological research literature. In addition, the staff also compared the new seismic hazard data with the earlier evaluations conducted as part of the IPEEE program. From this evaluation, the staff further concluded that the likelihood of exceeding the seismic hazard used in the IPEEE program could be higher than previously understood for some currently operating CEUS sites.

An Information Notice (IN) 2010-018, "Generic Issue 199, 'Implications of Updated Probabilistic Seismic Hazard Estimates in Central and Eastern United States on Existing Plants,'" was issued on September 2, 2010, summarizing the results of the GI-199 safety/risk assessment. Finally, after going through multiple stages of assessment, a draft GL, "Seismic Risk evaluation for Operating reactors" was published in Federal Register for public comments on September 1, 2011. In the draft GL, NRC requests licensees for CEUS nuclear power plants to reevaluate their site's seismic hazards based on specified regulatory guidance and standards. Then, pending up the comparison between the new GMRS with the existing SSE at their sites, the licensees might need to implement either an SMA or an

SPRA. The overarching premise is that although no immediate safety concern be present regarding seismic hazards at the CEUS plant sites, a systematic seismic hazard reevaluation and a subsequent seismic risk analysis is needed to identify if there is still adequate seismic margin in the plant's seismic design.

Observations from post earthquake investigations and the central idea of the draft GL

There are some lessons learned from the post-earthquake investigations at NANPS, such as seismic instrumentation issues and others. However, the observations based on multiple walkdowns at the plant site confirmed the draft GL's basic premise, based on the NRC's defense-in-depth policy, a seismic hazard reevaluation and subsequent seismic margin analysis may be needed to identify seismic vulnerability for plant's SSCs, although no immediate safety concern is present.

A final note is that draft letter for GI 199 was subsumed by NRC's recent issued 50.54 (f) letter. The 50.54(f) letter requests US nuclear reactor licensees to systematically re-evaluate seismic hazard using current standards and criteria as a result of lessons learned from Japan's Fukushima nuclear power plant accident. The request is to all US commercial nuclear power plant licensees, instead of just the CEUS nuclear power plants, as indicated in the draft GL, and included, in addition to seismic hazard, evaluation of not just seismic hazards but other natural hazards, such as flood hazards too. Same as the draft GL, the 50.54(f) letter also requested a seismic margin analysis or a seismic probabilistic risk analysis after hazard reevaluation, where applicable. Through this systematic effort, vulnerability of each nuclear power plant to earthquake hazards (floods) will be identified and potential design and plant modification may be warranted.

Disclaimer

The views expressed in the paper are those of the authors' and should not be construed to reflect the official positions of US Nuclear Regulatory Commission.

References

EPRI (1991). A method for Assessment of Nuclear Plant Seismic Margin. Technical Report.
USGS (2011). M 5.8 Central Virginia Earthquake of 23 august 2011 Summary Map.
US NRC (2011). Augmented Investigation Report on North Anna Nuclear Power Plant.
Draft Generic Letter (2011). Federal Register, September 1, 2011.