EARTHSQUAKES SAFETY

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INTRODUCTION

An unexpected magnitude 5.8 earthquake occurred in August 2011 on the USA's East Coast. The Nuclear Regulatory Commission (NRC) requires the nation's 104 nuclear reactors to withstand a certain predicted level of ground motion, or acceleration also designated as the g-force.

Figure 1. North Anna Reactor, Mineral, Virginia, shut down in response to a nearby earthquake on August 23, 2011.

NRC EARTHQUAKE DESIGN CRITERIA

The Nuclear Regulatory Commission (NRC) requires USA reactors to withstand a "predicted level of ground motion, or acceleration, specific to a given site." Ground acceleration is measured relative the acceleration caused by Earth's gravity "g".

An earthquake's magnitude described on the Richter scale, is a reading on a seismograph instrument. It correlates empirically with intensity or the intensity scale of the earthquake. It is not possible to directly transform a given magnitude alone to ground acceleration at a given site.

Many factors affect the relationship between an earthquake's magnitude M and associated ground acceleration g, including the distance from the earthquake, the depth of the quake and the site's local geology such as hard rock or sandy soil. A small earthquake close to a site could generate the same peak ground acceleration as a large earthquake farther away.

The NRC regulation for a nuclear power plant's design is to account for the ground acceleration that is appropriate for its location, given the possible earthquake sources that may affect the site and the makeup of the nearby faults.

Existing nuclear power plants were designed on a “deterministic, mechanistic,” or “scenario earthquake” basis through the examination of its site’s seismological history. This provides an estimate of the largest earthquake and associated ground acceleration expected at a plant site.

Applications for new nuclear power plants have taken a “probabilistic” approach to determining the seismic hazards, looking at a wide range of possible quakes from sources that could affect a given site. The NRC has spent several years examining how these newer techniques can be used to re-evaluate existing nuclear power plant sites.

EARTHQUAKE MAGNITUDE AND STRENGTH SCALES

MAGNITUDE SCALE

Referred-to in Japanese as “san ten ichi ichi” or 3/11, the Fukushima accident earthquake on March 11, 2011 affected two 50 miles thick tectonic slabs and unleashed energy of about 480 Mt of TNT-equivalent moving the position of part of the coastline 3.6 m to the east. In comparison, the Nagasaki nuclear device yield was in the range of 20-22 kT of TNT equivalent. The Mount Saint-Helen’s volcanic eruption released 10 Mt of TNT-equivalent in its eruption. The “Tsar Bomba,” largest thermonuclear device ever tested yielded 50 Mt of TNT-equivalent. The seabed buckled along a 300 km stretch along the fault line involved. An estimated 67 km^3 of ocean water moved towards 860 km of the Japanese coastline with a wave reaching about 24 m in height.

The reported M9.0 magnitude earthquake was more powerful than the design-basis magnitude M8.6 earthquake.

The difference between two Richter scale magnitudes is given by:

$$\Delta M = \log_{10}\frac{M_2}{M_1} = \log_{10} M_2 - \log_{10} M_1 \quad (1)$$

The ratio of magnitudes can be calculated by using the relation:

$$\begin{aligned} &e^{\ln x} = 10^{\log_{10} x} = x \\ &\frac{M_2}{M_1} = 10^{\log_{10}\frac{M_2}{M_1}} = 10^{\Delta M} \end{aligned} \quad (2)$$

Since the Richter magnitude scale is a base 10 logarithmic scale, each whole number increase corresponds to a factor of 10 increase in the measured amplitude:

$$\Delta M = \log_{10}\frac{10M_1}{M_1} = \log_{10} 10 = 1$$

The difference between the design and experienced earthquakes is a factor of:

$$\frac{M_2}{M_1} = 10^{(9\ 0-8\ 6)} = 10^{0\ 4} = 2.5$$

Mistakenly considering it as a base e logarithmic scale yields an underestimated value of:

$$\frac{M_2}{M_1} = e^{(9\ 0-8\ 6)} = e^{0\ 4} = 2.718^{0\ 4} = 1.4$$

STRENGTH, ENERGY RELEASE, DESTRUCTIVENESS

The magnitude scale compares the measured amplitudes of waves on a seismograph and does not describe the strength described by the energy release from an earthquake. The energy release is what affects structures and causes the actual damage.

To estimate the energy release E, an empirical formula is usually used that relates it to the magnitude M as:

$$\log_{10} E \;\; \alpha_\ell \;\; 1.5M \tag{3}$$

The energy release or strength can be estimated from:

$$\begin{aligned} 10^{\log_{10} E} \;\; &\alpha_\ell \;\; 10^{1\ 5M} \\ E \;\; &\alpha_\ell \;\; 10^{1\ 5M} \end{aligned} \tag{4}$$

From which:

$$\frac{E_2}{E_1} = \frac{10^{1\ 5M_2}}{10^{1\ 5M_1}} = 10^{1\ 5(M_2-M_1)} \tag{5}$$

Thus a change of 0.1 in the magnitude M implies:

$$\frac{E_2}{E_1} = 10^{1\ 5(0\ 1)} = 10^{0\ 15} = 1.41$$

or 1.4 times the energy release.

Each whole number increase in the magnitude M corresponds to:

$$\frac{E_2}{E_1} = 10^{1\ 5(1)} = 10^{1\ 5} = 31.62 \simeq 32$$

times the energy release by the earthquake.

Each increase of 0.2 in the magnitude corresponds to a doubling of the energy release:

$$\frac{E_2}{E_1} = 10^{1\ 5(0\ 2)} = 10^{0\ 3} = 1.995 \simeq 2$$

The ratio between the strengths or energy releases of a 9M and an 8.6M earthquakes can be estimated as:

$$\frac{E_2}{E_1} = \frac{(10^{1\ 5})^{9\ 0}}{(10^{1\ 5})^{8\ 6}} = 10^{(1\ 5)^{9.0-8.6}} = 10^{(1\ 5)^{0.4}} = 10^{1\ 176} = 14.99 \simeq 15$$

times the strength and hence the destructiveness.

Large earthquakes have much larger strength or energy release factors than small ones and are hence are much more devastating.

Thus, for the Fukushima accident, on a magnitude basis, the actual earthquake exceeded the actual earthquake by a factor of:

$$\frac{M_{actual}}{M_{design-basis}} = 2.5,$$

but on a strength, energy release, or destructiveness basis the actual earthquake exceeded the design-basis earthquake by a larger ratio of:

$$\frac{E_{actual}}{E_{design-basis}} \simeq 15.$$

MINERAL, VIRGINIA EARTHQUAKE EVENT

NRC research suggests that the seismic risks for eastern and central USA nuclear power plants have increased. The North Anna nuclear facility, situated near an earthquake's epicenter in Mineral, Virginia was successfully shut down on August 23, 2011. Having lost its offsite power source, it initiated its emergency diesel generators. One of these generators failed because of a water leak and was replaced by a backup generator. The plant declared an “alert” emergency state, the second-lowest of NRC's four emergency classifications. It regained its offsite power 7 hours later.

Twelve other nuclear power plants along the USA East Coast and upper Midwest declared an “unusual event,” the lowest emergency classification. They resumed normal operation by the end of the day. These plants were: Peach Bottom, Three Mile Island, Susquehanna and Limerick in Pennsylvania; Salem, Hope Creek and Oyster Creek in New Jersey; Calvert Cliffs in Maryland; Surry in Virginia; Shearon Harris in North Carolina; and D.C. Cook and Palisades in Michigan.

Dominion Virginia Power the operator of the North Anna plant, reported that its two reactors were built to withstand a ground motion of 0.12-0.18g. Depending on whether the foundation is rock or soil, this translates into 5.9 - 6.2M on the Richter magnitude scale.

REFERENCE

1. United States Nuclear Regulatory Commission, NRC, “NRC Clarifies Earthquake Mesurements and Design Criteria,” August 25, 2011.