International Conference on Mechanical, Industrial and Materials Engineering 2015 (ICMIME2015)
11-13 December, 2015, RUET, Rajshahi, Bangladesh

Paper ID: ET-30

Seismic Design Considerations for Nuclear Power Reactors

M.A.R. Sarkar[*1], I. Ahmed[*2], R. Islam[*3] and M ALI Zulquarnain [**4]
* Department of Mechanical Engineering, Bangladesh University of Engineering and Technology,
** Member Planning, BAEC, Sher-E-Bangla-Nagar, Dhaka 1000, Bangladesh.
E-mail: irfanahmed.me@gmail.com

Abstract

Nuclear power reactors pose special problems of earthquake safety that are different from those encountered in the earthquake for a coal-steam power generating station. In case of the nuclear power reactor, the occurrence of earthquake damage could lead to uncontrolled nuclear fission with the possibility of explosion and release of fission products into the atmosphere. One of the most severe operating conditions for a reactor is a loss of coolant accident (LOCA), which can lead to a reactor core meltdown.
Two levels of seismic ground motion should be considered during Nuclear power plant design. The S1 level is the level of ground motion which can be reasonably expected to be experienced at the site area once during the operating life of the plant. The S2 level ground motion is the maximum potential vibratory ground motion at the site based on the maximum earthquake potential of the (site) region. Proper measures which should be taken considering these two motions have been discussed in this paper.
This paper reports a complete overview of seismic design considerations of nuclear power reactors.

Keywords: *Earthquake, Reactor, Structure, Operate.*

1. Introduction

Experience of the March 11 2011, Great Tohoku earthquake clearly demonstrated that the earthquakes might be the dominating contributors to the overall risk of nuclear power plants (Institute of Nuclear Power Operations [INPO], 2011); International Atomic Energy Agency [IAEA], 2007). The seismic probabilistic safety assessments of several nuclear power plants are also provided similar results. On the other hand, experiences show that plants survive much larger earthquakes than those considered in the design base, as it was the case of Kashiwazaki-Kariwa plant, where the safety classified structures, systems and components survived the Niigata-Chuetsu-Oki earthquake in 2007 without damage and loss of function (IAEA, 2007). In spite of the nuclear catastrophe of the Fukushima Daiichi plant caused by the tsunami after Great Tohoku earthquake 11th of March 2011, the behavior of thirteen nuclear unit in the impacted area on the East-shore of the Honshu Island demonstrated high earthquake resistance. Consequently, proper understanding and assessment of the safety for the case earthquake (and generally for the external hazards) is very important for the operating nuclear power plants. For the operating plants basic questions to be answered are:
Whether the nuclear power plant (NPP) is safe enough within the design basis and whether the operation can be continued safely if an earthquake hits the plant. The designer and operators were mainly focusing on the first question, i.e. whether the reactor can be shut down, cooled-down, the residual heat can be removed from the core and spent-fuel stored at the plant, and the radioactive releases can be limited below the acceptable level in case of an earthquake [1].
The second question became important especially after series of events when large nuclear capacities were shut down for assessment of plant post-earthquake condition and justification of safety before their restart. In this paper following subjects have been discussed:

-Safe shutdown condition for BWR and PWR during emergency
-Relationship between Peak Ground Acceleration (PGA) and Instrumental Intensity
-Classification of Seismic Design
-Formulation of Design Basis Earthquake Ground Motion (DBEGM)

2. Safe Shutdown Condition

Safe Shutdown Condition for Boiling Water Reactor

In the case of events that cause a nuclear power plant to exceed its operating parameters (for example, an earthquake or a critical component's failure) design safety features must provide a means to control reactivity and cool the reactor [1]. During normal operation, reactor cooling relies on the water that enters the reactor vessel and the generated steam that exits. During safe shutdown, after the fission process is halted, the reactor core continues to generate heat by radioactive decay and generates steam. The heat from this a radioactive decay initially equals about 6% of the heat produced by the reactor at full power and gradually declines. Under this condition, the steam bypasses the turbine and diverts directly to the condenser to cool the reactor. When the reactor vessel pressure decreases to approximately 50 psi, the shutdown-cooling mode removes residual heat by pumping water from the reactor recirculation loop through a heat exchanger and back to the reactor via the recirculation loop. The recirculation loop design limits the number of pipes that penetrate the reactor vessel [2].

A typical boiling water reactor has been presented in the figure along with containment structure design. BWRs are inherently simpler designs than other light water reactor types. Since they heat water and generate steam directly inside the reactor vessel, they have fewer components than pressurized water reactors.

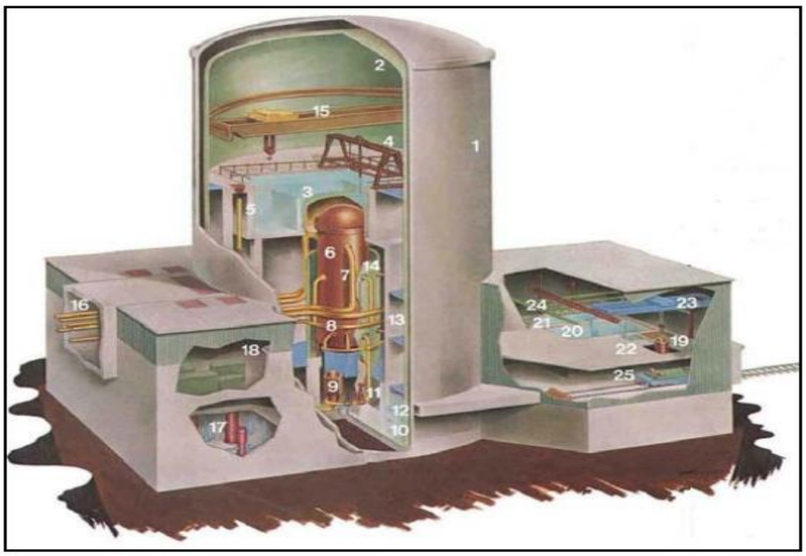

Fig. 1. General Electric Mark III Containment Structure [7]

Reactor Building	Auxiliary Building	Fuel Building
1. Shield Building	16. Steam Line Channel	19. Spent Fuel Shipping cask
2. Free Standing Steel Containment	17. RHR System	20. Fuel Storage Pool
3. Upper Pool	18. Electrical Equipment Room	21. Fuel Transfer Pool
4. Refueling Platform		22. Cask Loading Pool
5. Reactor Water Cleanup		23. Cask Handling Crane
6. Reactor Vessel		24. Fuel Transfer Bridge
7. Steam Line		25. Fuel Cask Skid on Railroad Car
8. Feed-water Line		
9. Recirculation Loop		
10. Suppression Pool		
11. Weir Wall		
12. Horizontal Vent		
13. Dry Well		
14. Shield Wall		
15. Polar Crane		

PWR Safe Shutdown Condition

During normal operation, a PWR does not generate steam directly. For cooling, it transfers heat via the reactor primary coolant to a secondary coolant in the steam generators. There, the secondary coolant water is boiled into steam and sent to the main turbine to generate electricity. Even after shutdown (when the moderated uranium fission is halted), the reactor continues to produce a significant amount of heat from decay of uranium fission products (decay heat). The decay heat is sufficient to cause fuel damage if the core cooling is inadequate. Auxiliary feed water systems and the steam dump systems work together to remove the decay heat from the reactor. If a system for dumping built-up steam is not available or inoperative, atmospheric relief valves can dump the steam directly to the atmosphere. Under normal operating conditions, water flowing through the secondary system does not contact the reactor core; dumped-steam does not present a radiological release.

As with BWRs, the most severe operating condition affecting a PWR is the loss of coolant accident (LOCA); the extreme case represented by the double-ended guillotine break (DEGB) [6] of large diameter pipe systems. In the event of a LOCA, the reactor's emergency core cooling system (ECCS) provides core cooling to minimize fuel damage by injecting large amounts of cool, borated water into the reactor coolant system from a storage tank. The borated water stops the fission process by absorbing neutrons, and thus aids in shutting down the reactor. The ECCS on the PWR consists of four separate systems: the high-pressure injection (or charging) system, the intermediate pressure injection system, the cold leg accumulators, and the low-pressure injection system (residual heat removal). The high-pressure injection system provides water to the core during emergencies in which reactor coolant-system pressure remains relatively high (such as small breaks in the reactor coolant system, steam break accidents, and leaks of reactor coolant through a steam generator tube to the secondary side) [2]. The intermediate pressure injection system responds to emergency conditions under which the primary pressure stays relatively high; for example, small to intermediate size primary breaks. The cold leg accumulators operate without electrical power by using a pressurized nitrogen gas bubble on the top of tanks that contain large amounts of borated water. The low-pressure injection system removes residual heat by injecting water from the refueling water storage tank into the reactor coolant system during large breaks (which would cause very low reactor coolant-system pressure) [3].

3. Relationship between Peak Ground Acceleration (PGA) and Instrumental Intensity

Peak ground acceleration (PGA) is a measure of earthquake acceleration on the ground and an important input parameter for earthquake engineering. Unlike the Richter and moment magnitude scales, it is not a measure of the total energy (magnitude, or size) of an earthquake, but rather of how hard the earth shakes in a given geographic area [4]. The peak horizontal acceleration (PHA) is the most commonly used type of ground acceleration in seismic design consideration of nuclear power reactor. Earthquake energy is dispersed in waves from the epicenter, causing ground movement horizontally (in two directions) and vertically. PGA records the acceleration of these movements, while peak ground velocity is the greatest speed reached by the ground, and peak displacement is the distance moved. Peak ground acceleration can be expressed in ***g*** (the acceleration due to Earth's gravity, equivalent to g-force) as either a decimal or percentage; in m/s^2. [4] Correlation between Mercalli Scale and PGA has been given below:

Instrumental Intensity	Acceleration (g)	Velocity (cm/s)	Perceived Shaking	Potential Damage
I	**< 0.0017**	< 0.1	Not felt	None
II-III	**0.0017 - 0.014**	0.1 - 1.1	Weak	None
IV	**0.014 - 0.039**	1.1 - 3.4	Light	None
V	**0.039 - 0.092**	3.4 - 8.1	Moderate	Very light
VI	**0.092 - 0.18**	**8.1 - 16**	Strong	Light
VII	0.18 - 0.34	**16 - 31**	Very strong	Moderate
VIII	0.34 - 0.65	**31 - 60**	Severe	Moderate to heavy
IX	0.65 - 1.24	**60 - 116**	Violent	Heavy
X+	> 1.24	**> 116**	Extreme	Very heavy

Fig. 2. Relationship between Instrumental Intensity and PGA [7]

At the time of designing nuclear reactor the PGA level of that place should be taken into consideration.

4. Classification of Importance in Seismic Design

Importance in seismic design of the Facilities shall be classified as in the following [2], considering the possible impacts of radiation to the environment caused by an earthquake.

(1) Classification of Functions

Class S: The Facilities containing radioactive materials or their relevant Facilities, loss of functions of which might lead to the release of the radioactive materials to the environment; the Facilities necessary to prevent such events; and the Facilities with significant roles to mitigate the consequences of radioactive release in case such accidents occur,

Class B: The Facilities of the same functional categories as above Class S, with lower roles,

Class C: The Facilities other than Class S or B, necessary to ensure equivalent safety as conventional industrial facilities.

(2) Facilities of Classes

Following are the specific Facilities in the above-defined classification of importance in the seismic design,

(a) Class S Facilities:

(i) Equipment/piping systems composing the ‘reactor coolant pressure boundaries’.

(ii) The Facilities to store spent fuels.

(iii) The Facilities to insert negative reactivity to quickly shut down the reactor and the facilities to maintain the reactor in the shutdown mode.

(iv) The Facilities to remove the decay heat from the reactor core after reactor is shut down.

(v) The Facilities to remove the decay heat from the reactor core after the accident of the loss of reactor coolant pressure boundaries,

(vi) The Facilities to function as the pressure barrier for preventing the immediate release of radioactive materials when the reactor coolant pressure boundaries are broken.

(vii) The Facilities, other than those in the above category to mitigate the radioactive release to the environment at an accident which may cause radioactive release.

(b) Class B Facilities:

i) The Facilities directly connected to the reactor coolant pressure boundaries, which contain or may contain radioactive materials therein [8].

ii) The Facilities containing radioactive wastes, but not those facilities which have sufficiently low risks of radiological exposure to the public due to their break as compared with the annual exposure dose limit outside the peripheral observation area, because of their limited inventory of radioactive waste or their storage capabilities.

iii) The Facilities relevant to radioactive material other than radioactive waste and their break may cause excessive radiological exposure to the public and the operational personnel.

iv) The Facilities to cool the spent fuels.

v) The Facilities other than Class S, to mitigate external release of radioactive materials to the environment at an accident.

(c) Class C Facilities:

Those Facilities other than Class S or B

5. Formulation of Design Basis Earthquake Ground Motion (DBEGM)

The ground motion to be established as the seismic design basis of the Facilities shall be formulated appropriately as the one, postulating to occur in a very low probability over the service period of the Facilities from the seismological and earthquake engineering point of view on geology, geological structures, seismicity, etc. in the vicinity of the proposed site, and having risks to give serious damages to the Facilities (the ”Design Basis Earthquake Ground Motion (DBEGM) Ss”) [4].

DBEGM Ss shall be formulated on the following principles.

(1) DBEGM Ss shall be formulated as the following two types of earthquake ground motions in the horizontal and vertical directions on the free surface of the base stratum at the proposed site: The ”Earthquake ground motions with the site specific earthquake source locations”; and the ”Earthquake ground motions with no such specific source locations.

(2) The DBEGM Ss for the earthquake ground motions with the site specific epicenter shall be formulated on the following principles.

(a) Earthquakes (more than one) are assumed which may have severe impacts to the proposed site, taking account of the characteristics of active faults, the earthquakes experienced in the past and at present in the vicinity, and classifying these earthquakes by their outbreak modes (hereinafter referred to as "Earthquakes for investigation").

(b) Following consideration shall be made concerning the 'characteristics of the active faults around the proposed site' in (a) above.

i) The active faults to be considered in the seismic design shall be identified as the one whose activities since the late Pleistocene epoch cannot be denied. The faults can be identified depending upon whether or not the displacement and deformation exist by the faults in the stratum or on the geomorphic surface formed during the last interglacial period.

ii) The active faults shall be thoroughly investigated by integrating geomorphological, geological and geophysical methods, etc. to make clear their locations, shapes, activity characteristics, etc. as a function of the distance from the proposed site.

(c) For each "Earthquake for investigation" selected in (a) above, DBEGM shall be formulated by the following two evaluation methodologies, respectively: i) with the response spectra; and ii) by the method with fault models [5]. In evaluating the earthquake ground motions, sufficient consideration shall be made to the various characteristics due to the earthquake breakout modes, seismic wave propagation channels, etc. (including the regional peculiarities).

i) Evaluation of earthquake ground motions with response spectra for respective "Earthquakes for investigation," responses spectra shall be evaluated by appropriate methods and the design response spectra shall be defined based on these spectra [4]. Earthquake ground motions shall be evaluated appropriately in considering their characteristics such as duration times, time dependent change of amplitude-enveloping curves suitably.

ii) Evaluation of earthquake ground motions by the method with fault models for respective "Earthquakes for investigation," earthquake grounds motions shall be evaluated by setting the epicenter characteristics parameters with appropriate methods.

6. Summary and Closing Remarks

(1) Seismic Design Considerations of nuclear power reactor are important cause during earthquake situation the condition of reactors may venerable and bring catastrophe without those particular steps.

(2) The design earthquake and the associated impacts shall be specified on the basis of the results of Deterministic and probabilistic analyses.

(3) The results of the probabilistic and deterministic procedures shall be compared and differences explained. The design earthquake is specified under consideration of the reliability of the results of the deterministic and probabilistic analyses. In case of doubt, the larger seismic impacts shall be referred to as design parameters. The specification of the relevant parameters shall be substantiated.

(4) Seismological surveys shall be traceable and reviewable. The data used shall completely be enclosed, unless not generally accessible, to the survey in a suitable manner.

(5) Safe shutdown arrangement should be ensured to control the decay heat and prevent the reactor core melt down.

(6) Post-earthquake actions should be planned for a nuclear power plant, even if an automatic scram system is installed.

(7) The immediate notification of the regulatory body and its involvement in the restarting of the plant should be specified in appropriate procedures.

(8) Recommendations and guidance on operational procedures following an earthquake, including the timing of, responsibilities for and tracking of the necessary actions, should be ensured.

11. References

[1] Tamas Janos Katona "Seismic Safety Analysis and Upgrading of Operating Nuclear Power Plant", *INTECH,* Vol.1, No.4, pp. 77-121, 2012.

[2] Antony Andrews, Peter Folger, "Nuclear Power Plant Design And Seismic Safety Consideration", *Congress Research Sercice,* Paper No.R41805, pp. 1-37, 2012.

[3] In-Kil, Young-Sun Choun, Jeong-Moon Seo, " Scenario Earthquakes for Korean Nuclear Power Plant Site Considering Active Faults" SMIRT17, 2003.

[4] Robin K. McGuire, Walter J. Silva, Roger Kenneally "New Seismic Design Spectra For Nuclear Power Plants" *Pacefic ngineering and analysis*, Paper No:14,2000.

[5] K K Vaze, " Structural Intigrity Aspects of Reactor Safety" *Sadhana*, Vol.13,Part.5,pp.991-997, 2013
[6] R.I. Skinner, R. G. Tyler, S. B. Hodder, "Isolation of Nuclear Power Plants From Earthquake Attack" pp.199-204,1986.
[7] Aybars Gupinar, "Seismic Re-Evulution and Upgrading of Nuclear Power Plants" *IAEA,1993.*
[8] "Seismic Design Considerations of Nuclear fuel Cycle Facilities", *IAEA*, 2001.