Seismic Design Parameters for Nuclear Power Plants on the East Coast of Mainland China

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Abstract

The need for reliable electric power for the major cities and the proximity of the ocean for cooling water has stimulated an ambitious program of nuclear power plant development along the east coast of mainland China. For the coast north of about 34 degrees latitude, seismic hazard is controlled by active faults, especially the Tan-Lu Fault. South of the zone of influence of active faults, the coast does not have the high seismic hazard of other parts of China. However, a few large earthquakes have occurred in areas of ancient geologic structures and they have no obvious origin in terms of modern tectonics. A preliminary assessment of seismic hazard indicates that a Safe Shutdown Earthquake peak horizontal ground acceleration of about 0.2g is appropriate for much of the east coast, but values in excess of 0.4g may be appropriate in a few areas near active faults or epicenters of strong historical earthquakes.

1. Introduction

Seismic loads for nuclear power plants often govern design and the determination of basic seismic input is fundamental to that design. The design input motion is widely termed the Safe Shutdown Earthquake (SSE) and is defined by the USNRC [1] as "that earthquake which is based upon an evaluation of the maximum potential considering the regional and local geology and seismology and specific characteristics of local subsurface material..." Current procedures for SSE evaluation are generally based on deterministic concepts which account for the worst estimated seismic effects that a site can reasonably be expected to experience.

The deterministic approach followed in deriving SSE ground motion is defined in the United States by Appendix A to 10 CFR 100 [1]. Although some revision to this regulation is warranted [2], it can be used to outline the basic steps of a deterministic analysis followed throughout most of the world's nuclear industry, as follows:

- The most severe earthquakes associated with active geologic structures and/or seismotectonic provinces in the region surrounding a given site are identified. A determination is made as to whether the most severe historical event is a suitable maximum event for the province or structure.
- If the region surrounding a site includes capable faults or other similar active geologic structures, the maximum earthquakes associated with these features are determined by considering their deformational history.
- The vibratory ground motion at the site is then determined by postulating that the maximum earthquake for each active geologic structure or seismotectonic province determined in the previous two steps occurs at a point on the active geologic

structure or seismotectonic province nearest to the site.

- The postulated earthquake which could cause the maximum vibratory ground motion at the site is designated the SSE.

The ease with which the above steps can be followed is highly dependent on the level of understanding that exists of the tectonics and earthquake history of a region. Eastern China benefits from having a long, well documented earthquake history. Knowledge of the tectonic conditions that produce the earthquakes, however, is not uniform. Some areas in eastern China are studied to the point that Chinese scientists have been able to predict the occurrence of a major event, as in the case of the Haicheng earthquake of February 4, 1975. The coastal area where nuclear power plants are being sited is not as well understood in terms of the origin of earthquake activity. As in other areas of the world where uncertainties exist, these uncertainties must be reflected in the degree of conservatism prudent for defining the seismic design criteria. This study reviews the seismotectonic setting of the eastern coast of mainland China and provides preliminary values of SSE peak horizontal ground acceleration that may be appropriate for different areas. The values presented are intended to indicate approximate SSE accelerations based on available information and the author's experience in nuclear power plant siting. They do not replace the need for comprehensive local studies which could result in significant variations to the estimates presented.

2. Seismotectonic Setting

The active plate boundaries in the world circumscribe twelve major plates. Virtually the entire territory of China is included within the Eurasian Plate with only the periphery of the Indian Plate present in the Himalayas and the Phillipine Plate in the Coastal Range of Taiwan [3]. The Eurasian Plate itself has been formed by the progressive accretion of mountain belts around a few Precambrian continental cratons as a result of plate convergence since Precambrian Time. Many ancient sutures are present within the landmass of China that formed during this accretionary process. At the present time, China is profoundly affected by convergence with the Indian and Phillipine Plates and many of these old sutures have become reactivated.

One of these reactivated sutures is the Tan-Lu (Tancheng-Lujiang) Fault, which extends from the Yangtze River northward through Podhai Bay and into the U.S.S.R., a distance of at least 2,500 kilometers (Figure 1). Major earthquakes have occurred along this fault, including the great Tancheng earthquake of 1668 (M = 8.5), one of the most devastating earthquakes to have occurred in world history. Because of the large population living near the fault, it is one of the most dangerous faults on earth. In addition to the Tan-Lu Fault, numerous other active faults comprising the Hopei Plain Fracture Zone are present west of Podhai Bay (Figure 1). These faults have generated great earthquakes, such as the Tangshan earthquake of July 26, 1976 (M = 7.8), and the Sanho-Pingku earthquake of September 2, 1679 (M = 8.0).

Active faults control the seismic hazard along China's coast north of about 34 degrees latitude. Farther south, active faults have not yet been defined near the coast which could control the definition of a SSE and it is necessary to assess seismic hazard in terms of seismotectonic provinces.

The east coast of mainland China south of 34 degrees latitude can be broken up into three major tectonic provinces (Figure 1):

- Yangtze Craton
- South China Accretionary Foldbelt
- Maritime Accretionary Foldbelt

These three divisions represent the most recent research into the plate tectonic evolution of China, but it is not at all clear that the tectonic activity which produced these provinces actually relates to current earthquake activity. Careful examination of earthquake occurrence must also be made in order to divide the tectonic provinces into seismotectonic provinces significant to an assessment of seismic hazard.

The Yangtze Craton covers nearly the entire territory of the Yangtze River drainage and is characterized by a Precambrian basement rock that completed consolidation during the Yangtze Orogeny, approximately 800-850 million years ago. It is difficult to relate current earthquake activity to the ancient tectonics of a Precambrian Craton, and the most recent tectonics must be considered in order to identify seismotectonic provinces. Within the Yangtze Craton, one such area is the East China Basins, where basin development is apparently still active based on the accumulation of thick Quaternary sediments and the occurrence of earthquakes (Figure 1).

A large cluster of events, including the recent event of May 21, 1984, has occurred in an offshore extension of the East China Basins north of Shanghai (Figure 1). This cluster appears to extend onshore to include moderately strong earthquakes, such as occurred in 1624 and 1913. When the epicenters have been located on land, intensity values of VII have been assigned in the Catalog of Chinese Earthquakes [4]. However, it should be noted that these events caused the collapse of buildings and had very large felt areas, suggesting that the epicentral intensities could have been higher than indicated.

For the offshore area, where epicentral intensity is unknown, the use of the Intensity-Magnitude relationship by Gupta and Combs [5] and the Magnitudes assigned by Qin-Zu and Xin-Chang [6] would suggest they could be as high as IX. Even though this intensity is probably exaggerated, substantial damage on land was nevertheless documented for the offshore earthquakes of 1910 and 1927, suggesting that the offshore events could be associated with a high epicentral intensity.

Within the Yangtze Craton, the overall level of earthquake activity is fairly low but a few significant historical earthquakes have occurred, particularly those of 1585 and 1743. Both of these earthquakes caused the collapse of structures presumed to be poorly constructed, suggesting the epicentral intensity of each could have been somewhat higher that the intensity VII assigned in the seismic catalog [4] and could have been in the range of VII - VIII.

The South China and Maritime Accretionary Foldbelts are both areas that were part of the passive margin of the Yangtze Craton during late Precambrian to early Paleozoic time. At different times during the Paleozoic they were subjected to intense compression that produced their tectonic character. Their significance in terms of being seismotectonic provinces is not well defined as few earthquakes are known to have occurred in either province. The situation is similar to that of the eastern U.S., where the association of earthquake activity to ancient tectonic structures is not well defined.

Within the South China Accretionary Foldbelt the seismic activity is generally low. The maximum historically recorded intensity is a VII - VIII for the earthquake of January 11, 1806. The seismicity of the Maritime Accretionary Foldbelt also is not high, except that one of the largest earthquakes known to have occurred in China affected the province in 1604. This earthquake does not have any obvious tectonic origin and is analogous to the Charleston Earthquake of 1886 in the eastern United States. This event has not been considered to have potential for occurrence anywhere along the coast, as it is an anomalous, isolated event uncharacteristic of the rest of the tectonic province in which it is located. If it were considered to have an equal potential for occurring anywhere within the Maritime Accretionary Foldbelt, it would be abortive to most nuclear plants in eastern China. However, it is clear that considerable additional investigations will be required to fully characterize the event of 1604.

3. Safe Shutdown Earthquake Zoning

The derivation of the SSE ground motion for a discrete site is based on postulating that the largest earthquakes associated with each seismotectonic province and capable fault occur on the points of each source closest to the site. For eastern China, the earthquake sources are identified in Figure 1 and are listed in Table 1, along with the largest recorded earthquakes. The maximum historical seismic intensity felt along the east coast was mapped on the basis of a review of damage descriptions from the seismic catalog [4] (Figure 2). In consideration of China's long historical record and the size of the largest events, it does not appear necessary to postulate the occurrence of events larger than those which have already historically occurred.

Attenuation has been estimated based on a review of historical records for the largest earthquakes. Most of the east coast exhibits very slow attenuation, similar to the eastern U.S., except for the areas west and north of Podhai Bay, which exhibit a more rapid attenuation, comparable to the western U.S.

The SSE peak horizontal ground acceleration was derived for a number of discrete sites following the deterministic procedures described above and by converting intensity to acceleration by means of the relationship of Trifunac and Brady [7]. These values were then contoured to produce a SSE zonation map (Figure 3). The zonation presents the basic assumption that the SSE ground motion should be at least as severe as indicated by historical record. In addition, the largest historical events along the Tan-Lu Fault and faults of the Hopei Plain Fracture Zone have been postulated to occur anywhere along the structures. A local origin has been assumed for the 1604 event on the coast across from Taiwan, but considerable research will be required to confirm this assumption.

4. Summary

The rich historical record and the tectonic setting indicate that eastern China possesses some of the same characteristics as both the western and eastern U.S. Active faults control the seismic hazard of much of the northern part of the coast, similar to California. South of the zone of influence of the active faults, the origin of earthquakes is poorly defined, but a few damaging earthquakes have occurred, similar to the environment of the eastern U.S.

Considerable research still remains to document the origin of several large earthquakes critical to the definition of the seismic design criteria for nuclear power plant sites. In addition, further research may identify capable faults not currently known to exist. Seismic hazard is not negligible anywhere along the coast, and may be exceptionally high north of about 34 degrees latitude and immediately across from Taiwan.

List of References

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TABLE 1

LARGEST EARTHQUAKES WITHIN EACH SEISMOTECTONIC PROVINCE OR ALONG AN ACTIVE FAULT

Province or Fault	Date	Coordinates	Intensity (MMI or MSK)	Magnitude	Source
Yangtze Craton	1585 3 6	31.2N - 117.7E	VII-VIII		[8]
East China Basins	1910 1 8	35.0N - 122.0E	IX?	6-3/4	[6]
South China Accretionary Foldbelt	1806 1 11	25.3N - 115.7E	VII-VIII		[8]
Maritime Accretionary Foldbelt	1604 12 29	25.0N - 119.5E	>X	8	[8]
Tan-Lu Fault	1668 7 25	35.3N - 118.6E	XII	8.5	[4]
Hopei Plain Fracture Zone	1679 10 2	40.0N - 117.0E	XI	8.0	[4]

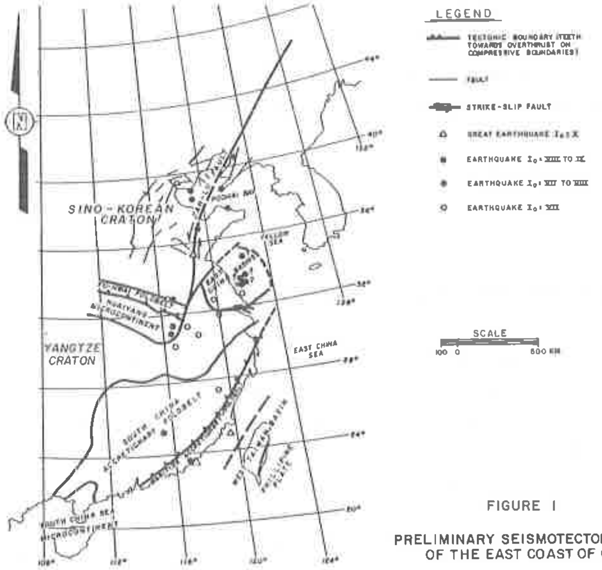

FIGURE 1

PRELIMINARY SEISMOTECTONIC MAP OF THE EAST COAST OF CHINA

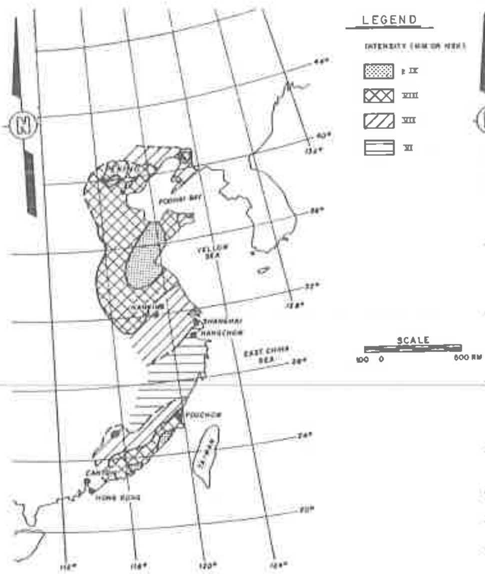

FIGURE 2

MAXIMUM HISTORICAL SEISMIC INTENSITY

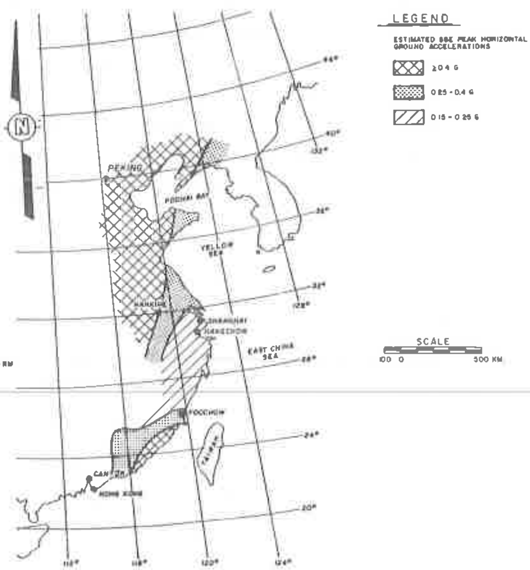

FIGURE 3

ESTIMATED SSE PEAK HORIZONTAL GROUND ACCELERATIONS