NUREG-75/087

U.S. NUCLEAR REGULATORY COMMISSION
STANDARD REVIEW PLAN
OFFICE OF NUCLEAR REACTOR REGULATION

SECTION 2.5.2 VIBRATORY GROUND MOTION

REVIEW RESPONSIBILITIES

Primary - Site Analysis Branch (SAB)

Secondary - None

I. AREAS OF REVIEW

The SAB review covers the seismological and geological investigations carried out to establish the acceleration for seismic design of the plant, the procedures and analyses used by the applicant to determine the safe shutdown earthquake (SSE) and the operating basis earthquake (OBE) for the site, and the seismic design bases for foundations.

Specific areas of review include; seismicity, relationship of earthquake occurrence to geologic or tectonic characteristics of the region, determination of the earthquake-generating potential of the geologic structures and tectonic provinces in the region, characteristics of seismic wave transmission at the site, and determination of the level and properties of the vibratory ground motion at the site resulting from potential earthquakes in the region.

II. ACCEPTANCE CRITERIA

1. The required investigations are described in 10 CFR Part 100, Section IV(a) of Appendix A. The acceptable procedures for determining the seismic design bases are given in Section V(a) of the same appendix. The seismic design bases are predicated on a reasonable, conservative determination of the safe shutdown earthquake and the operating basis earthquake. As defined in Section III of 10 CFR Part 100, Appendix A, the SSE and OBE are based on consideration of the regional and local geology and seismology and on the characteristics of the subsurface materials at the site and are described in terms of the vibratory ground motion which they would produce at the site. No comprehensive definitive rules can be promulgated regarding the investigations needed to establish the seismic design bases; the requirements vary from site to site.

2. Subsection 2.5.2.1 (Seismicity): The applicant's presentation is accepted when the complete historical record of earthquakes in the region is listed and when all available parameters are given for each earthquake in the historical record. The listing should include all earthquakes MM intensity greater than IV or magnitude greater than 3 which have been reported in all tectonic provinces any parts of which are within 200 miles of the site. A regional-scale map should be presented showing all listed earthquake

epicenters and, in areas of high seismicity, should be supplemented by a larger-scale map showing earthquake epicenters within 50 miles of the site. The following information concerning each earthquake is required whenever it is available: epicenter coordinates, depth of focus, origin time, highest intensity, magnitude, seismic moment, source mechanism, source dimensions, source rise time, rupture velocity, total dislocation, fractional stress drop, and any strong-motion recordings; references from which the specified information was obtained should be identified. In addition, any reported earthquake-induced geologic failure, such as liquefaction, landsliding, landspreading, and lurching should be described completely, including the level of strong motion which induced failure and the material properties of the materials. The completeness of the earthquake history of the region is determined by comparison to the historical earthquake data (HED) file (Ref. 4) and other published sources of information (e.g., Refs. 5, 6, 7). When conflicting descriptions of individual earthquakes are found in the published references, a reasonable description which results in the more conservative interpretation of the seismicity is accepted.

3. Subsection 2.5.2.2 (Geologic and Tectonic Characteristics of Site and Region): The applicant's presentation is accepted when all regional geologic structures and tectonic activity which are significant in determining the earthquake potential of the region are identified. Information presented in Section 2.5.1 of the applicant's safety analysis report (SAR) and information from other literature sources (e.g., Refs. 8, 9, 10, 11, 12) dealing with regional tectonics should be developed into a coherent, well-documented discussion to be used as the basis for determining tectonic provinces and the earthquake-generating potential of the identified geologic structures. Specifically, each tectonic province, any part of which is within 200 miles of the site, must be identified. Those characteristics of geologic structure, tectonic history, present and past stress regimes, and seismicity which distinguish the various tectonic provinces and the particular areas within those provinces where historical earthquakes have occurred should be described. Alternative regional tectonic models from available literature sources should be discussed. When several of the alternative models conform equally well with the observed phenomena, the model which results in the more conservative assessment of the earthquake potential at the site is accepted. In addition, in those areas where there are capable faults, the results of the additional investigative requirements described in 10 CFR Part 100, Appendix A, Section IV(a)(8), must be presented. The discussion should be augmented by a regional-scale map showing the tectonic provinces, earthquake epicenters, locations of geologic structures and other features which characterize the provinces, and the locations of any capable faults.

4. Subsection 2.5.2.3 (Correlation of Earthquake Activity with Geologic Structure or Tectonic Provinces): Acceptance is based on the development of the relationship between the relatively short history of earthquake activity and the geologic structures or tectonic provinces of a region. The applicant's presentation is accepted when the earthquakes discussed in Subsection 2.5.2.1 of the SAR are shown to be associated with either geologic structure or a tectonic province. Whenever an earthquake epicenter or concentration of earthquake epicenters can be reasonably correlated with geologic

structure, the rationale for the association should be developed considering the properties of the geologic structure and the regional tectonic model. The discussion should include identification of the methods used to locate the earthquake epicenters, an estimate of their accuracy, and a detailed account which compares and contrasts the geologic structure involved in the earthquake activity with other areas within the tectonic province. Particular attention should be given to determining the capability of faults with which instrumentally-located earthquake epicenters are associated.

The applicant may choose to define tectonic provinces to correspond to subdivisions generally accepted in the literature. A subdivision of a tectonic province is accepted if it can be corroborated on the basis of detailed seismicity studies, tectonic flux measurements, contrasting structural fabric, different geologic history, differences in stress regime, etc. If detailed investigations reveal no significant differences between areas within a tectonic province, the areas should be considered to compose a single tectonic province. The presentation should be augmented by a regional-scale map showing the tectonic provinces, the earthquake epicenters, and the locations of geologic structures and measurements used to define provinces. Acceptance of the proposed tectonic provinces is based on the staff's independent review of the seismicity, tectonic flux (Ref. 31), geologic structure, and stress regime in the region of the site.

5. Subsection 2.5.2.4 (Maximum Earthquake Potential): The applicant's presentation is accepted when the vibratory ground motion due to the maximum credible earthquake associated with each geologic structure or the maximum historic earthquake associated with each tectonic province has been assessed and when the earthquake which would produce the maximum vibratory ground motion at the site has been determined. Earthquakes associated with each geologic structure or tectonic province must be identified. Where an earthquake is associated with geologic structure, the maximum earthquake which could occur on that structure should be evaluated, taking into account such factors as the type of the faulting, fault length, fault displacement, and earthquake history, (e.g., Refs. 14, 15).

   In order to determine the maximum earthquake that could occur on those faults which are shown or assumed to be capable, the staff accepts conservative values based on historic experience in the region and specific considerations of the earthquake history, sense of movement, and geologic history of movement on the faults. Where the earthquakes are associated with a tectonic province, the largest historical earthquake within the province should be identified and, whenever possible, the return period for the earthquake should be estimated. Isoseismal maps should also be presented for the most significant earthquakes. The ground motion at the site should be evaluated assuming seismic energy transmission effects are constant over the region of the site and assuming that the largest earthquake associated with each geologic structure or with each tectonic province occurs at the point of closest approach of that structure or province to the site.

The set of conditions describing the occurrence of the earthquake which would produce the largest vibratory ground motion at the site should be defined. If different potential earthquakes would produce the maximum ground motion in different frequency bands, the conditions describing all such earthquakes should be specified. The description of the potential earthquake occurrence is to include the maximum intensity or magnitude and the distance from the assumed location of the potential earthquake to the site. The staff independently evaluates the effects on site ground motion of the largest earthquake associated with each geologic structure or tectonic province. Acceptance of the description of the potential earthquake which would produce the largest ground motion at the site is based on the staff's independent analysis.

6. Subsection 2.5.2.5 (Seismic Wave Transmission Characteristics of the Site): The applicant's presentation is accepted when the seismic wave transmission characteristics (amplification or deamplification) of the materials overlying bedrock at the site are described as a function of the significant frequencies. The following material properties should be determined for each stratum under the site: seismic compressional and shear velocities, bulk densities, soil properties and classification, shear modulus and its variation with strain level, and water table elevation and its variation. In each case, methods used to determine the properties should be described or a cross-reference should be given indicating where in the SAR the description is provided. For each set of conditions describing the occurrence of the maximum potential earthquake, determined in Subsection 2.5.2.4, the type of seismic waves producing the maximum ground motion and the significant frequencies must be determined. For each set of conditions an analysis should be performed to determine the effects of transmission in the site material for the identified seismic wave types in the significant frequency bands.

Where horizontal shear waves produce the maximum ground motion, an analysis similar to that of Schnabel, et al. (Ref. 16) is appropriate. Where compressional or surface waves produce the maximum ground motion, other methods of analysis (Refs. 17, 18) may be more appropriate. However, since the latter techniques are still in the developmental stages and no generally agreed-on procedures can be promulgated at this time, the staff accepts the shear wave model as representative of site amplification. The site amplification determined in this way should be compared with characteristics of site amplification in the epicentral area of the historical earthquake used as the basis for each maximum potential earthquake. If detailed soils investigations have been made in the epicentral area, the amplification analysis should be based on these. Because detailed geologic investigations are generally not available for the epicentral areas of historical earthquakes, several factors should be considered in assessing amplification effects there, including: regional geology and soil conditions, earthquake isoseismal maps, and descriptions of earthquake effects.

7. Subsection 2.5.2.6 (Safe Shutdown Earthquake): The applicant's presentation is accepted when the vibratory ground motion specified for the safe shutdown earthquake is described in terms of the level of acceleration for seismic design and its time history and is as conservative as that which would result at the site from the maximum potential earthquake (determined in Subsection 2.5.2.4) and considering the variations in site transmission effects (determined in Subsection 2.5.2.5). If several different maximum potential earthquakes produce the largest ground motions in different frequency bands (as noted in Subsection 2.5.2.4), the vibratory ground motion specified for the SSE must be as conservative in each frequency band as that for each earthquake, including site transmission effects (as noted in Subsection 2.5.2.5).

The amplitude of acceleration at the ground surface, the effective frequency range, and the duration corresponding to each maximum potential earthquake must be identified. The acceleration is to be expressed as a fraction of the acceleration of gravity (g). Where the earthquake has been associated with a specific geologic structure, the acceleration should be determined using a relation between acceleration, magnitude or fault length and distance from the fault (cf. Refs. 13, 15). Where the earthquake has been associated with a tectonic province, the acceleration should be determined using appropriate relations between acceleration, intensity, epicentral intensity, and distance (e.g., Refs. 19, 20, 21, 24).

Numerous correlations between intensity and acceleration are given in the literature (Refs. 19, 20, 21, 22, 23); several of them are considered acceptable by the staff. The correlation used is accepted if it is conservative when compared to the actual observational data. Acceptance is based on an analysis of the site's seismic energy transmission properties (Ref. 16, or equivalent). Conservatism should be assessed based on consideration of the amplification analysis and in comparison with the actual published data. The staff will generally accept an acceleration for seismic design as being conservative if, when applied at the ground surface, it results in a value at the foundation free field level as large as would be obtained from the empirical relation of the mean of the intensity acceleration values in Reference 23.

Available ground motion time histories for earthquakes of comparable values of magnitude, epicentral distance, and acceleration level should be presented. The spectral content for each potential maximum earthquake should be described; it should be based on consideration of the available ground motion time histories and regional characteristics of seismic wave transmission. The dominant frequency associated with the peak acceleration should be determined either from analysis of ground motion time histories or by inference from descriptions of earthquake phenomenology, damage reports, and regional characteristics of seismic wave transmission.

In some cases, the peak acceleration may not be as significant for engineering design purposes as a sustained acceleration at a lower level. One situation where the sustained acceleration level may differ from the peak acceleration is in proximity to the causative fault of the earthquake. It is appropriate in such cases to define the "reference acceleration for seismic design" as representative of the level of sustained acceleration. The "reference acceleration for seismic design" determined in this section of the applicant's SAR is taken to be the high frequency asymptote to the design response spectrum defined in Reference 2. At this time, the staff is not aware of any published relations between earthquake intensity or magnitude and sustained acceleration. Such relations could be developed from analyses of the response spectra of accelerograph time histories in those areas where magnitude and intensity measurements are also available. In lieu of such studies, the peak accelerations are considered to represent conservative reference accelerations for seismic design. Lower levels of reference acceleration may be justified on a site-specific basis.

The staff's review of proposed reference accelerations for seismic design considers: the proximity of the site to the geologic structure or province with which the potential earthquake is associated, characteristics of acceleration time histories at epicentral distances similar to that of the potential SSE, results of time-dependent spectral analyses of such time histories (cf. Refs. 25, 26), the level and dominant frequency of the peak acceleration, and seismic wave amplitude attenuation as a result of transmission from the source to the site and in the material underlying the site.

The design response spectrum is reviewed under Standard Review Plan (SRP) 3.7.1; however, as noted above there are certain seismological conditions which may require special modifications of the response spectrum. In general, the design response spectrum is acceptable if it is as conservative as the response spectrum from each of the potential earthquakes as described above.

The time duration of strong ground motion is required for analysis of site foundation liquefaction potential and for design of many plant components. The adequacy of the time history for structural analysis is reviewed under SRP 3.7.1. The time history is reviewed in this standard review plan to confirm that it is compatible with the seismological and geological conditions in the site vicinity and with the accepted SSE model. At present, there is no truly adequate model for deterministically computing the time history of strong ground motion from a given source-site configuration. It is, therefore, acceptable to generate the time history record from the design response spectrum for the SSE using the method of Tsai (Ref. 27) or an equivalent method. Total duration of the motion is acceptable when (1) it is as conservative as values determined using the procedure described by Bolt (Ref. 28) for hard rock sites or for analyses where nonstationarity of strong motion time functions is unimportant* and (2) the spectrum of the derived accelerogram is found acceptable in the review under SRP 3.7.1.

8. Subsection 2.5.2.7 (Operating Basis Earthquake): The vibratory ground motion for the OBE should be described with the SSE and the acceleration level at the site specified. The minimum value of the acceleration level for the OBE is currently one-half the reference acceleration for seismic design corresponding to the SSE. For sites in highly seismic regions, mainly in the western United States, the complete description of the OBE, as given in 10 CFR Part 100, Appendix A, Section III(d),

*For sites on sediments or for analyses where nonstationarity is important, more conservative values may be required. See, e.g., Refs. 24 and 30.

is required. In some cases, probability calculations, like those described by Algermissen (Ref. 29), would be helpful in estimating the acceleration level reasonably expected to affect the plant site during the operating life of the plant. Acceptable source regions that can be used as input to these calculations are those geologic structures or tectonic provinces with which historical earthquake activity has been associated. Such descriptions should include the acceleration level of the OBE and a determination of the probability of exceeding t..t level during the 40-year operating life of the plant.

III. REVIEW PROCEDURES

1. Upon receiving the applicant's SAR, an acceptance review is conducted to determine: compliance with the investigative requirements of 10 CFR Part 100, Appendix A, and conformance with the Standard Format (Regulatory Guide 1.70). The reviewer also identifies any site-specific problems, the resolution of which could result in extended delays in completing the review.

2. After SAR acceptance and docketing, those areas are identified where additional information is required to determine the earthquake hazard and to establish the design acceleration. These are transmitted to the applicant in requests for additional information (Q-1).

3. A site visit is conducted during which the reviewer inspects the foundation conditions, local faulting, and other geologic conditions. During the site visit the reviewer also discusses and clarifies the Q-1 questions with the applicant and his consultants so that it is clearly understood what additional information is required by the staff to continue the review.

4. Following the site visit a revised set of requests for additional information (Q-2), including any additional questions which may have been developed during the site visit, is formally transmitted to the applicant. At the Q-2 stage the review procedure consists mainly of an evaluation of the applicant's response to the Q-1 questions. The reviewer prepares requests for additional clarifying information and formulates positions which may agree or disagree with those of the applicant. These are formally transmitted to the applicant.

5. The safety analysis report and supplements responding to the requests for additional information (Q-1, Q-2) are reviewed to determine that the information presented by the applicant is acceptable according to the critieria described in Section II above. Based on information supplied by the applicant, obtained from site visits, or from staff consultants or literature sources, the reviewer independently identifies the relevant seismotectonic provinces, evaluates the capability of faults in the region, and determines the earthquake potential for each province and each capable fault using procedures noted in Section II above. The reviewer evaluates the vibratory ground motion which the potential earthquakes could produce at the site and defines the safe shutdown earthquake and operating basis earthquake.

IV. EVALUATION FINDINGS

For construction permit (CP) reviews, the findings are included in the staff's safety evaluation report and consist of statements (including or referencing diagrams, maps, etc.) describing the applicant's and the staff's (1) definitions of seismotectonic provinces; (2) evaluations of the capability of geologic structures in the region; (3) determinations of the SSE acceleration at ground surface, reference acceleration for seismic design, time duration of strong ground motion, and any alterations in the design response spectrum based on evaluation of the potential earthquakes; and (4) determinations of the OBE acceleration at ground surface. If the staff's findings are consistent with those of the applicant, staff concurrence is stated; otherwise, a statement requiring use of the staff's findings is made.

For operating license (OL) reviews, the staff's positions from the CP review are referenced and a detailed review of any new data which might affect the seismic design bases is presented.

V. REFERENCES

1. 10 CFR Part 100, Appendix A, "Seismic and Geologic Siting Criteria for Nuclear Power Plants."

2. Regulatory Guide 1.60, "Design Response Spectra for Seismic Design of Nuclear Power Plants," Revision 1.

3. Regulatory Guide 1.70, "Standard Format and Content of Safety Analysis Reports for Nuclear Power Plants," Revision 2.

4. "Historical Earthquake Data File," National Geophysical and Solar-Terrestrial Data Center, National Oceanic and Atmospheric Administration.

5. "Earthquake History of the United States," Publication 41-1, National Oceanic and Atmospheric Administration, U. S. Department of Commerce (1973).

6. S. D. Townley and M. W. Allen, "Description Catalog of Earthquakes of the Pacific Coast of the United States, 1769 to 1928," Bulletin Seismological Society of America, Vol. 29 (1939).

7. W. E. T. Smith, "Earthquakes of Eastern Canada and Adjacent Areas," Publications of the Dominion Observatory (1962).

8. P. B. King, "The Tectonics of North America - A Discussion to Accompany the Tectonic Map of North America Scale 1:5,000,000," Professional Paper 628, U. S. Geological Survey (1969).

9. A. J. Eardley, "Tectonic Divisions of North America," Bulletin American Association of Petroleum Geologist, Vol. 35 (1951).

10. J. B. Hadley and J. F. Devine, "Seismotectonic Map of the Eastern United States," Publication MF-620, U. S. Geological Survey.

11. M. L. Sbar and L. R. Sykes, "Contemporary Compressive Stress and Seismicity in Eastern North America: An Example of Intra-Plate Tectonics," Bulletin Geological Society of America, Vol. 84 (1973).

12. R. B. Smith and M. L. Sbar, "Contemporary Tectonics and Seismicity of the Western United States with Emphasis on the Intermountain Seismic Belt," Bulletin Geological Society of America, Vol. 85 (1974).

13. P. B. Schnabel and H. B. Seed, "Acceleration in Rock for Earthquakes in the Western United States," Report No. EERC 72-2, Earthquake Engineering Center, University of California, Berkeley (1972).

14. J. N. Brune, "Tectonic Stress and Spectra of Seismic Shear Waves from Earthquakes," Journal of Geophysical Research, Vol. 75 (1970).

15. D. Tocher, "Earthquake Energy and Ground Breakage," Bulletin Seismological Society of America, Vol. 48 (1958).

16. P. B. Schnabel, J. Lysmer, and H. B. Seed, "SHAKE-A Computer Program for Earthquake Response Analysis of Horizontally Layered Sites," Report No. EERC 72-12, Earthquake Engineering Research Center, University of California, Berkeley (1972).

17. M. D. Trifunac and F. E. Udwadia, "Variations of Strong Earthquake Ground Shaking in the Los Angeles Area," Bulletin Seismological Society of America, Vol. 64 (1974).

18. L. A. Drake, "Love and Rayleigh Waves in Nonhorizontally Layered Media," Bulletin Seismological Society of America, Vol. 62 (1972).

19. N. N. Ambraseys, "Dynamics and Response of Foundation Materials in Epicentral Regions of Strong Earthquakes," Proceedings of the Fifth World Conference on Earthquake Engineering (1973).

20. F. Neumann, "Earthquake Intensity and Related Ground Motion," University of Washington Press (1954).

21. B. Gutenberg and C. Richter, "Earthquake Magnitude, Intensity, Energy, and Acceleration," Bulletin Seismological Society of America, Vol. 46 (1956).

22. N. N. Ambraseys, "The Correlation of Intensity with Ground Motions," Paper presented at Trieste Conference on Advancements of Engineering Seismology in Europe (1974).

23. M. D. Trifunac and A. G. Brady, "On the Correlation of Seismic Intensity Scales with Peaks of Recorded Strong Ground Motion," Bulletin Seismological Society of America, Vol. 65 (1975).

24. O. W. Nuttli, "State-of-the-Art for Assessing Earthquake Hazards in the United States, Report 1, Design Earthquakes for the Central United States," Miscellaneous Paper S-73-1, U. S. Army Engineer Waterways Experiment Station (1973).

25. V. Perez, "Peak Ground Accelerations and Their Effect on the Velocity Response Envelope Spectrum as a Function of Time, San Fernando Earthquake, February 9, 1971," Proceedings of the Fifth World Conference on Earthquake Engineering (1973).

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27. N. C. Tsai, "Spectrum-Compatible Motions for Design Purposes," Journal Engineering Mechanics Division, American Society of Civil Engineers, Vol. 98 (1972).

28. B. A. Bolt, "Duration of Strong Ground Motion," Proceedings of the Fifth World Conference on Earthquake Engineering (1973).

29. S. T. Algermissen and D. M. Perkins, "Techniques for Seismic Zoning: 1. General Considerations and Parameters," Proceedings of the International Conference on Microzonation for Safer Construction Research and Application (1972).

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31. P. St. Amand, "Two Proposed Measures of Seismicity," Bull. Seism. Soc. Am., Vol. 46, pp. 41-45 (1956).

SRP 2.5.3