

SEISMIC AND GEOLOGIC SITING CONSIDERATIONS

FOR NUCLEAR FACILITIES ^I

by

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SYNOPSIS

The seismic and geologic conditions affecting a site must be carefully evaluated before adequate engineering design can be developed for a proposed nuclear facility. Some of the current procedures and some of the seismic and geologic criteria being used in the United States in evaluating the suitability of proposed sites for nuclear facilities are presented. Especial emphasis is given to a discussion of earthquake criteria, and of procedures used for determining design bases for earthquake-produced vibratory ground motion anticipated at the site, and for determining whether--and to what extent--the facilities need be designed to withstand surface faulting.

INTRODUCTION

The seismic and geologic aspects of siting are important factors that should be considered in selecting and evaluating sites proposed for any major industrial plant, particularly those sites proposed for nuclear facilities. The possibility of an uncontrolled release of radioactive material into any part of the environment, owing to damage of a nuclear facility by an earthquake, constitutes a serious potential hazard to the health and safety of the public, particularly in the immediate vicinity of the facility. The current trend is toward the construction of larger and larger nuclear-fueled generating units, and toward the multiple installation of these larger units at single sites. As these generating units increase in size and number at a site, comparable increases also can be expected to occur in their structural complexities, in their potential impact on the environment, and in the amount of total capital that must be invested at a single site.

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Before the suitability of a proposed site for a nuclear facility can be evaluated, and before the engineering design criteria can be established for the proposed facility, the engineering geologist and the engineering seismologist must provide comprehensive descriptions and evaluations of the local and regional geologic, tectonic, and seismic conditions of importance to the safety and environmental changes, and of the physical properties of the rocks and soils underlying the site. Without such detailed knowledge, the design engineer cannot be fully cognizant of the geologic conditions at the site, or of the kinds of potential problems at the site that might influence the foundation design and subsequent performance of the plant structures. These data also provide the basis for determining the maximum expectable earthquake intensity at the site and the potential for surface faulting occurring at or in the immediate vicinity of the site.

The size of the area to be investigated and the scope of the investigations usually will be determined by the type and size of the proposed facility, by the pertinent local and regional geologic and seismic environments, and by the potential hazard of the proposed facility to public health and safety. Ideally a site should be in a geologically stable area; i.e., one that is low in seismicity, free of active faults, underlain by competent foundation materials, and free from the possible adverse effects of other geologic hazards, such as subsidence, uplift, tilting, flooding, landsliding, volcanism, and liquefaction. Deficiencies in any of these environmental aspects must be recognized by the design engineer and adequately compensated for in the engineering design of the facility.

The purpose of this paper is to describe briefly some of the procedures and criteria currently being used in the United States by the Atomic Energy Commission in its evaluations of sites proposed for nuclear facilities, with respect to geology and seismology (1). These procedures and criteria have been developed from experience accumulated during the past several years by the Atomic Energy Commission and its advisors (namely, the U.S. Geological Survey and the National Oceanic and Atmospheric Administration) and the utility industry and its consultants, in evaluating the geologic and seismic conditions at a large number of sites throughout the United States. Because evaluations of many of the geologic aspects of siting for nuclear facilities may differ very little from those for other types of major industrial siting--except perhaps in the scope of the investigations, and in the degree of conservatism applied to the design bases for nuclear facilities--this paper will be concerned mainly with the seismic aspects of siting, and especially with some

of the earthquake criteria. These criteria have been developed with an appreciation of the fact that the current state-of-art in the earth sciences does not now provide us with any large amount of precise information about earthquake occurrences and effects.

CURRENT PRACTICE

The Atomic Energy Commission is charged with the responsibility of evaluating the suitability of sites proposed for nuclear production or utilization facilities in the United States, with respect to the natural environmental characteristics of the site, including seismology, geology, hydrology, and meteorology, and with respect to the adequacy of the design bases established by consideration of these environmental characteristics. Natural environmental conditions that might affect the site include such phenomena as: shaking from earthquakes, surface displacement on faults, and other ground cracking; subsidence, tilting, landslides, and other earth movements or failures; hurricanes and other violent winds; floods and water waves, volcanic activity; erosion; ground-water conditions; and potential changes in the physical state of the naturally occurring materials underlying the site.

In order to provide reasonable assurance that a nuclear facility can be constructed and operated at a proposed site without undue risk to the health and safety of the public, the Atomic Energy Commission requires that a preliminary safety analysis report be submitted for review and evaluation. The report must include a description and a safety assessment of the site on which the facility is to be located, with appropriate attention given to the natural environmental conditions affecting the facility design, and with sufficient data included to justify the design basis for the facility.

In developing the aseismic design of the major plant structures, the engineers are concerned both with the elastic design of the structures, for no loss of function, and with the elasto-plastic design of the structures, for a safe and orderly shutdown. Thus, the design bases for nuclear facilities normally include a consideration of the potential occurrence of two different earthquakes, each with specific intensities of ground motion. These two earthquakes commonly are referred to as the "operating basis earthquake" and the "safe shutdown earthquake."

The current philosophy concerning the selection of the operating basis earthquake is to permit the licensee to select, without specific approval by the Atomic Energy Commission, the earthquake to

which the plant will be designed to remain functional. In most cases this "operating basis earthquake," or OBE, is considered to be either the maximum earthquake that has occurred at or in the vicinity of the site, or that has been experienced at the site, in historic time, and which might reasonably be expected to occur again during the life of the plant. Shutdown of the facility, then, is required if vibratory ground motion occurs, at any time during the life of the plant, which exceeds that specified by the OBE, or which results in maximum ground motion greater than 5 percent of gravity, if no OBE is specified. Before the plant can again become operable, the licensee must demonstrate, however, that no functional damage has occurred to features necessary for the continued safe operation of the plant.

The selection by the licensee of the safe shutdown earthquake, or SSE, on the other hand, must be agreed upon and approved by the Atomic Energy Commission. The SSE, which also has been termed at various times as the maximum potential or maximum credible earthquake, most probably has not occurred in the vicinity of the site during historical times. Instead, it is determined by a detailed determination and evaluation of the geologic conditions, tectonic structures, and seismicity of the site and the region surrounding the site within a radius of at least 200 miles. For this earthquake the facility should be designed so that all features of the facility necessary to protect the health and safety of the public will remain functional, both during and after the earthquake. Stresses in the structural components are permitted to enter the plastic range, and although the structure may suffer partial to even severe damage, the design must be such as to allow for a safe and orderly shutdown beginning with the seismic event. In addition, all safety-related structures, systems, and components must be designed to withstand the effects of vibratory motion of at least 50 percent of the SSE, in combination with other appropriate loads well within elastic limits.

SEISMIC AND GEOLOGIC CONSIDERATIONS

The earthquake potential of a proposed site is an especially important consideration for a large nuclear facility. Vibratory ground motion accompanying major earthquakes can cause extensive damage to plant structures and component parts, particularly to those structures erected on subsurface materials with poor earthquake-response characteristics. Also, because these earthquake-induced ground motions can be felt by every feature of a facility, complex multiple failures can occur.

Both the vibratory ground motions that could result from a major, nearby earthquake and the potential for surface faulting at the site must be evaluated, not only for the obvious direct effects upon the plant itself, but also for any possible indirect effects on the site, such as a loss of cooling water supply or a decrease in stability of the foundation materials underlying the site. The earthquake response of the material underlying and surrounding the facility and its possible effects on the foundation stability of the facility is an important consideration in site evaluation. Gross failures may arise from such varied adverse phenomena as differential compaction; subsidence, uplift, or collapse; landsliding; and liquefaction--to list only some of the more important effects.

DETERMINATION OF THE SEISMIC AND GEOLOGIC DESIGN BASES

The first step in determining the vibratory ground motion that might be experienced at a site consists of a thorough review of the seismic and geologic history of the site and the region in which the site is located. This review entails a compilation and evaluation of all historical earthquakes, including their dates of occurrence and highest intensities, that are known to have affected the site, or that could reasonably be expected to have affected it. The maximum historical earthquake is determined from an evaluation of the historical record of these earthquakes; only minor consideration is given to the general geology and regional tectonic structures at this time. Such an evaluation should also consider non-tectonic events, such as mine bumps or cave-ins, that should perhaps be eliminated from the record. The earthquake with the highest intensity recorded or calculated on the foundation material at the site commonly is selected as the operating basis earthquake.

The next step is to determine the safe shutdown earthquake. For this earthquake it is necessary to review and evaluate in detail, not only the seismic history of the region, but also the local and regional geologic conditions and the characteristics of major tectonic structures underlying the site and the region surrounding the site, including the tectonic history of the area. Particular attention, of course, must be given to faults, and other tectonic structures in the vicinity of the site that might influence the earthquake potential at the site.

Where possible, epicenters of historically reported earthquakes are correlated with known or postulated tectonic structures. If an earthquake has occurred on a tectonic structure which passes through or in the vicinity of the site, it is postulated that this same

earthquake also could occur at any place along the tectonic structure, including at the point closest to the site. An earthquake which might reasonably be expected to produce the maximum intensity within the foundation materials underlying the plant, and which is related to such a tectonic structure, is then selected and designated as the safe shutdown earthquake.

If epicenters cannot be reasonably correlated with known faults or with a specific tectonic structure in the area, they are identified with a seismotectonic province. A seismotectonic province is defined as a region characterized by both equipotential seismicity and a unity of geologic structural features. The boundaries of the province are determined through a regional analysis of the geologic and tectonic environments and the seismic history. For such cases, it is assumed that earthquakes with intensities comparable to those characteristic of the province could occur anywhere within the province including the immediate vicinity of the site. The maximum earthquake selected that might conceivably occur anywhere in the province, then, becomes the safe shutdown earthquake.

The effects on the structural components of the facility, of the two postulated earthquakes selected for design purposes, are determined by the use of a response spectrum corresponding to the ground accelerations estimated for the site. Ideally these ground accelerations should be based on instrumental recordings from strong-motion seismographs installed in the area. However, owing to the rather limited number of ground-motion acceleration records in critical areas, the accelerations commonly are estimated based on intensity values assigned to the design earthquakes, using the Modified-Mercalli Intensity Scale (MM) of 1931 (2). Despite the fact that an earthquake intensity is a subjective measure of ground shaking, and is not an engineering measure of acceleration, numerous attempts (see Barosh (3) for a review of the literature of this subject) have been made to establish quantitative correlations between earthquake intensities and accelerations; all of these correlations, however, should be used with some caution. One example of a correlation between acceleration and intensity is shown in figure 1. The correlations shown on this figure appear to be provisionally valid, where short epicentral distances are involved, for estimating average maximum acceleration values that result from given intensities up to intensity VIII(MM). For intensities higher than VIII(MM), other factors, such as duration, may alter this empirical relationship.

In the foregoing discussion, the earthquake intensities and accelerations determined for the site were assumed to have been recorded

on, or calculated to have occurred on competent foundation materials, such as bedrock or other well-consolidated material. Where the proposed nuclear facility will be located on other than competent bedrock or well-consolidated material, the initially selected ground accelerations must be multiplied by a soil amplification factor in order to obtain the final acceleration used for design. This amplification factor, which may range from slightly more than one to as much as five, is determined from an evaluation of the physical and engineering properties of the materials underlying the site. At present the criteria for determining what this soil amplification factor should be largely are empirical. Further investigations of the problem currently are being conducted by or for the Atomic Energy Commission.

SURFACE FAULTING

Surface faulting generally is not a problem throughout much of the United States, but there are many places in the western U.S. where the possibility of differential surface displacement due to faulting must be considered in evaluating a site. Unfortunately the period during which measurements have been made of large earthquakes and of surface faulting in the United States is extremely short by geological standards. Insufficient data, therefore, are now available to permit the development of any precise relationships among earthquake magnitude, fault-zone width, subsidiary faulting, and probable relative displacement. Thus, the general criteria on surface faulting, as developed to date from these limited data, of necessity, are both conservative and somewhat arbitrary; and they may be difficult to apply at some specific sites.

In general these criteria include requirements for additional detailed investigations of all significant geologic structures greater than 1 mile long, any part of which falls within certain specified distances from the site, and for the determination of whether these geologic structures have been active in the past, and thus, are potentially capable of future surface displacement. Determination of whether or not a fault is considered to be active is based on several lines of evidence, chiefly those relating to its history of prior displacements. Most faults show evidence of repeated movement; some are known to have had recurrent movements for millions of years, while others may show evidence of recurrent movements occurring only for a few thousands to hundreds of thousands of years. For nuclear-facility siting some of the criteria defining fault activity have been arbitrarily selected; for example, a fault is considered active if evidence indicates that movement along it has occurred at least once

in the past 35,000 years, or more than once in the past 500,000 years.

In order to determine whether a nuclear facility must be designed to withstand the effects of surface faulting, the location of the site with respect to geologic structures capable of surface displacement must be considered. Because one of the best guides to the location of future faulting is the location of past faulting, all Quaternary fault traces in the vicinity of the site are mapped in detail and determinations made as to whether any of these traces are also traces of active faults. The maximum width of the zone of potential faulting is determined from the mapping of the active fault traces. Because surface faulting sometimes has occurred beyond the previously mapped limit of a fault zone, the maximum width of the fault zone under consideration must be increased by a multiplication factor, but in no instance shall the determined width of the fault zone be less than one-half mile. The multiplication factor, which is dependent upon the largest magnitude earthquake which might be related to the faulted structure, has been selected to range from 1 to 4 times the determined width of the fault zone. This larger width, then, delineates a zone, called the zone requiring detailed faulting investigations, within which the possibility of surface faulting must be considered. If a nuclear facility is to be located within this zone, the engineering design must assume that the potential displacement associated with surface faulting can occur in any direction and under any part of the facility; it also must consider the estimated rate at which surface displacement may occur.

CONCLUSIONS

The generalizations given in this paper represent some of the current geologic and seismologic criteria and considerations used for evaluating nuclear power plants and nuclear fuel processing plant sites in the United States. Although the geologic and seismic considerations involved in the siting of these nuclear facilities are similar to those involved in the siting of other types of major industrial facilities, the higher degree of potential hazard of nuclear facilities necessitates that a more conservative approach be used in their evaluation. Especial care and emphasis must be placed on evaluating the problems of foundation stability, shaking due to earthquakes, and surface faulting. Until more data are available on earthquakes and on surface faulting associated with earthquakes, the criteria for their consideration are preliminary and intended as an interim guide only.

Despite the value of these criteria in providing useful guidelines for geologic and seismic siting considerations, it will always be necessary to make careful evaluations of the geological characteristics of each individual site, not only with respect to the adequacy of the material underlying the site to support the proposed facility, but also with respect to the potential for surface faulting at or adjacent to the plant site. The existing criteria, therefore, should be applied in a flexible but still conservative manner, depending on the local site conditions, and revised as needed or as new and more precise earth-science data become available.

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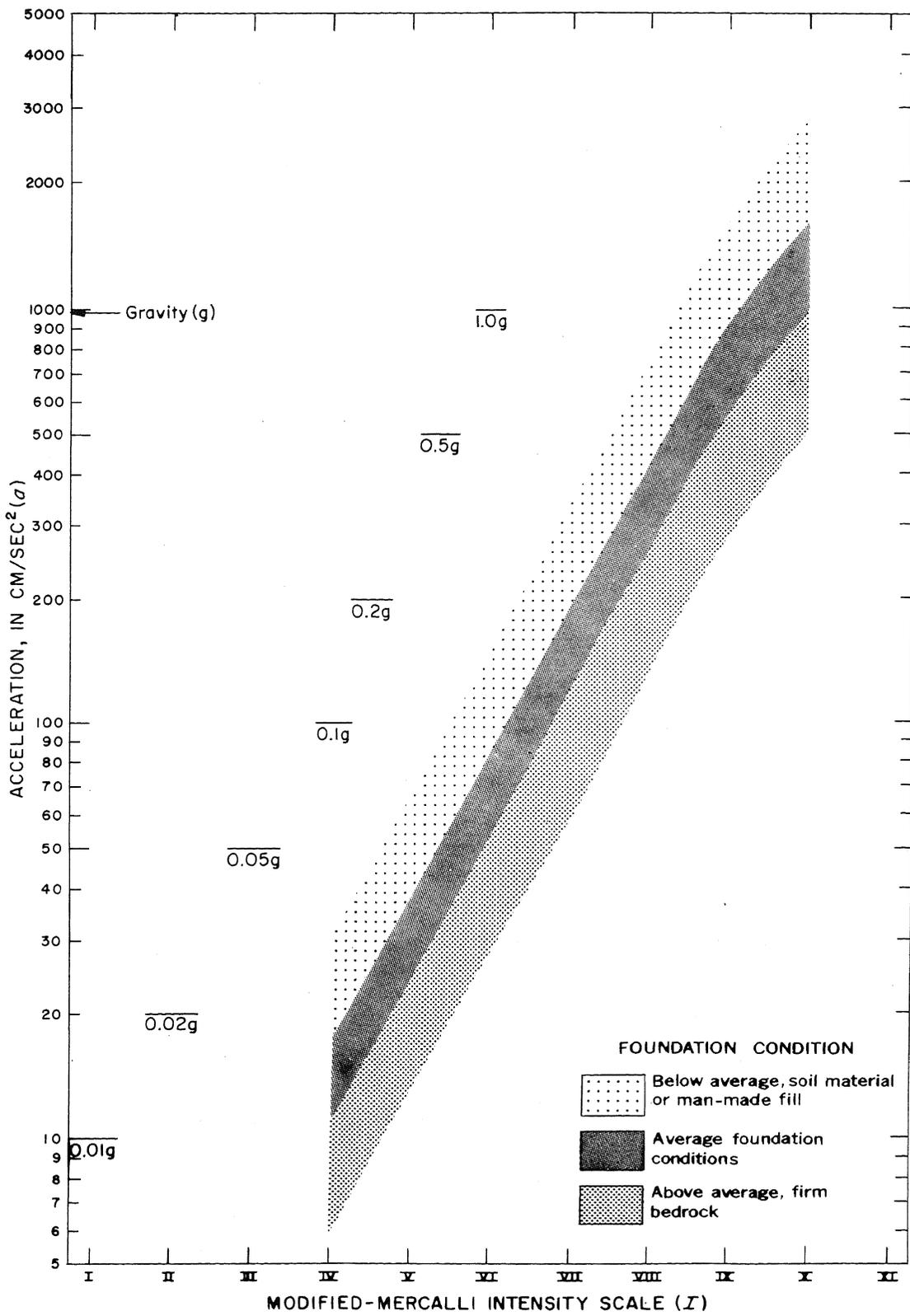


Figure 1.-- Acceleration vs. Intensity