Chapter 2
Assessment of Standard Seismic Motion

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Abstract Earthquake surveys in areas that may affect plant sites and assessment of ground motion are indispensable for earthquake-resistant design to prevent the loss of safety-related functions of nuclear power plants and to avoid the effects of radiation on the public in a large affected region. The standard seismic motion S_s is assessed based on the source properties of the active faults, the propagation characteristics of the seismic waves from the source to the plant site, the amplification characteristics of the ground motion through the subsurface soil, and the geological and soil conditions at the site. Furthermore, ground motion in cases where fault surveys cannot clearly identify active faults in advance should be also assessed. The seismic motion for elastic design S_d, is determined from the standard seismic motion S_s.

Keywords Standard seismic motion · Seismic motion for elastic design · Survey on seismic source · Virtual free surface of bedrock · Empirical Green's function method · Direct method by fault model

2.1 Overview of Assessment of Standard Seismic Motion

This section presents the standard seismic motion S_s assessment process, identification of the seismic source parameters that may affect the site, and the method of assessing ground motion.

Figure 2.1 is a flowchart for the assessment of standard seismic motion S_s. The standard seismic motion S_s is assessed by first identifying the seismic sources.

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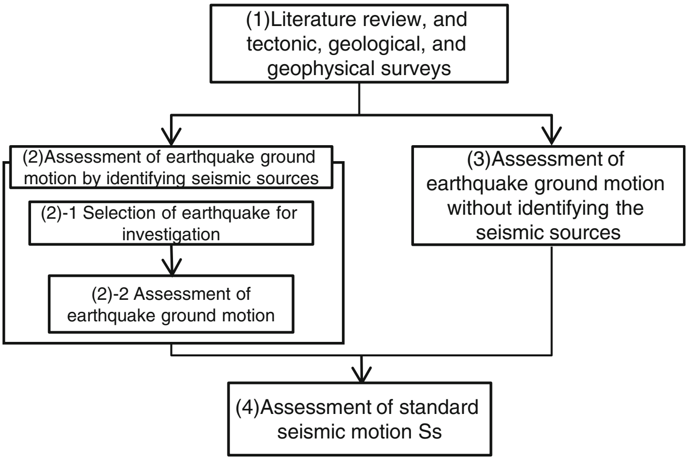

Fig. 2.1 Assessment of standard seismic motion S_s

(1) Literature review, and tectonic, geological and geophysical surveys (Sect. 2.2).
Literatures on past earthquakes are reviewed, and tectonic, geological, and geophysical conditions are surveyed to identify earthquakes that may significantly affect the site.

(2) Assessment of earthquake ground motion by identifying seismic sources (Sect. 2.3).
Seismic sources of earthquakes that may have significant impacts on the site are identified, and the standard seismic motion S_s is assessed.

  (2)-1 Selection of earthquakes for investigation.
  The earthquakes for the investigation are selected from inland crustal earthquakes, interplate earthquakes, and intra-oceanic plate earthquakes.

  (2)-2 Assessment of earthquake ground motion.
  The standard seismic motion S_s is assessed in the form of response spectra and time histories based on source models of the selected earthquakes. Various uncertainties about seismic source parameters for the assessment are taken into consideration.

(3) Assessment of earthquake ground motion without identifying the seismic sources (Sect. 2.4).
In the case when the seismic sources cannot be identified by the active fault survey, ground motion records of past inland crustal earthquakes are analyzed, and the standard seismic motion S_s is assessed based on these analyses.

(4) Assessment of standard seismic motion S_s (Sect. 2.5).
The standard seismic motion S_s in horizontal and vertical directions is assessed by identifying as well as not identifying the earthquake sources.

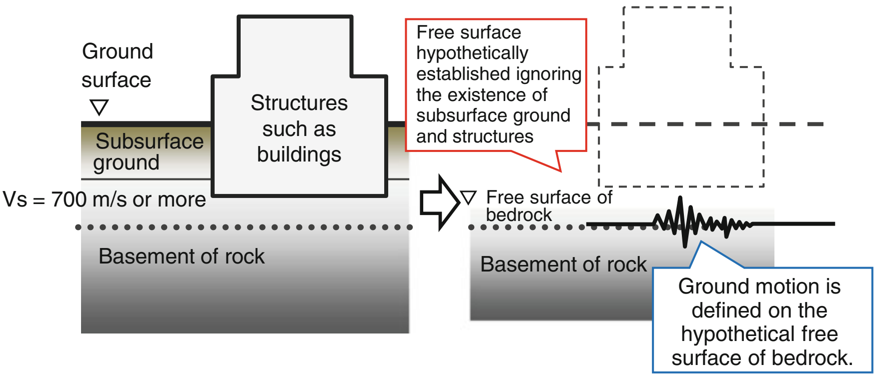

Fig. 2.2 Concept of the virtual free surface of bedrock

The standard seismic motion S_s is assessed on the virtual free surface of the bedrock, where it is assumed that no subsurface ground and structures exist on the ground surface (Fig. 2.2). The hypothetical free surface of the bedrock is defined as being an extensive, flat surface. The S wave velocity of bedrock is required to be more than 700 m/s. Figure 2.2 shows the concept of the hypothetical free surface of the bedrock.

2.2 Literature Review, Tectonic, Geological, and Geophysical Surveys

To model the seismic sources, past earthquakes, and active faults [faults active after the Pleistocene period of the late Quaternary (approximately 120,000–130,000 years ago) and faults that may become active in the future] in the area surrounding the site must be investigated.

A review of the existing literatures, including ancient documents and seismic observation records, investigations on tectonic geomorphology based on topographical and geological conditions, and geological and geophysical surveys, will be conducted. The literature review will provide an understanding of the geology and geological structure of a wide area, while the tectonic topography will be identified by the geomorphological investigation. Additionally, the geomorphological survey will identify the detailed characteristics and activeness of faults. The geophysical investigation will identify the locations and extent of faults and subsurface structures, including the seismic wave velocity distribution. The effects of the three-dimensional subsurface structure of the site and surrounding area on the characteristics of seismic wave propagation and ground motion amplification must be studied based on the above-mentioned series of investigations.

Additionally, assessments of the foundation ground bearing capacity and slope stability are carried out. Furthermore, a tsunami assessment survey is important for oceanic interplate earthquakes. These surveys are described in Chaps. 3 and 7.

2.2.1 Literature Review

Based on the existing literatures, the magnitudes of past earthquakes and the damage they caused, and the size and activity of faults in the areas surrounding the site will be surveyed. Figure 2.3 is one of examples of the existing literatures on active faults in Japan. Based on the ground motion recorded during past earthquakes, geodetic records using GPS, tectonic geographical surveys, the characteristics of faults that are highly probable to cause earthquakes, and the mechanism of the occurrence of earthquakes will be identified (refer to Part II, Chap. 13).

2.2.2 Tectonic Geomorphological Survey

The purpose of the tectonic geomorphological survey is to assess faults that may become active in the future (refer to Appendix 2.1) by observing the development process, the origin, and activeness of the topography, and focusing on the characteristic landscapes created by the displacement of active faults. Landscapes that may have been formed by fault activity are identified from aerial photographs and aerial laser surveys. For oceanic areas, seabed topography maps based on seawater depth measurements are used. When slippages caused by fault activity come close to the ground surface, they frequently leave continuously slipped landscapes on mountain ridges, valleys, and cliffs. However, these landscapes may also be eroded and covered by sedimentation. Therefore, the active faults must be assessed comprehensively with reference to the results of other surveys.

Fig. 2.3 Fault map of Japan

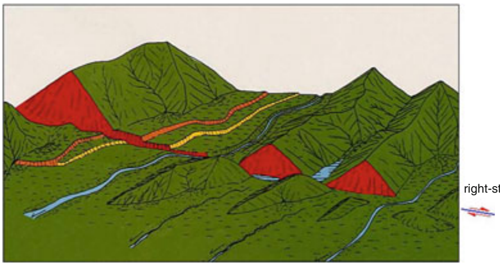

Fig. 2.4 Example of a landscape formed by displacement of an active fault [1]

Figure 2.4 is an example of a landscape created by the displacement of an active fault. In this figure, valleys and ridges are displaced in the same direction across the fault, and triangular cliffs are formed on the mountain ridges, which are cut by the fault. These characteristics indicate the presence of right-lateral faults.

2.2.3 Geological Survey

Geological surveys will be conducted to identify topographical structures in an extensive area around the site based on the results of the literature review, and the tectonic and geomorphological investigations, and also to clarify the subsurface structure of the areas surrounding the faults.

Figure 2.5 shows geological surveys such as outcrop observation, trench surveys, and borings. A geological survey is conducted to discover faults and deformation in geological formations, and to find slippage and disorders in geological structures positioned across faults. Based on the results, the period during which the faults were active, the magnitude and direction of displacement, and the history of faulting are determined. Geological deformation is measured by trench surveys and boring surveys are used to study deep geological structures.

2.2.4 Geophysical Survey

Geophysical surveys are conducted to identify faults that are difficult to find by ground surface investigations, the extent of faults, gradient, and folding of geological formations, and the distribution of seismic wave velocity of the surface ground. Particularly in oceanic areas where it is impossible to directly confirm the deformation of geological structures by aerial photos and the outcrop observation, subsurface structures, and the locations and extent of faults can be identified by geophysical surveys.

Figure 2.6a shows seismic wave exploration (measurement of P and S wave's velocity) in a bored hole, and Fig. 2.6b shows elastic wave exploration to measure the gradient and folding of faults and geological formations, and the distribution of

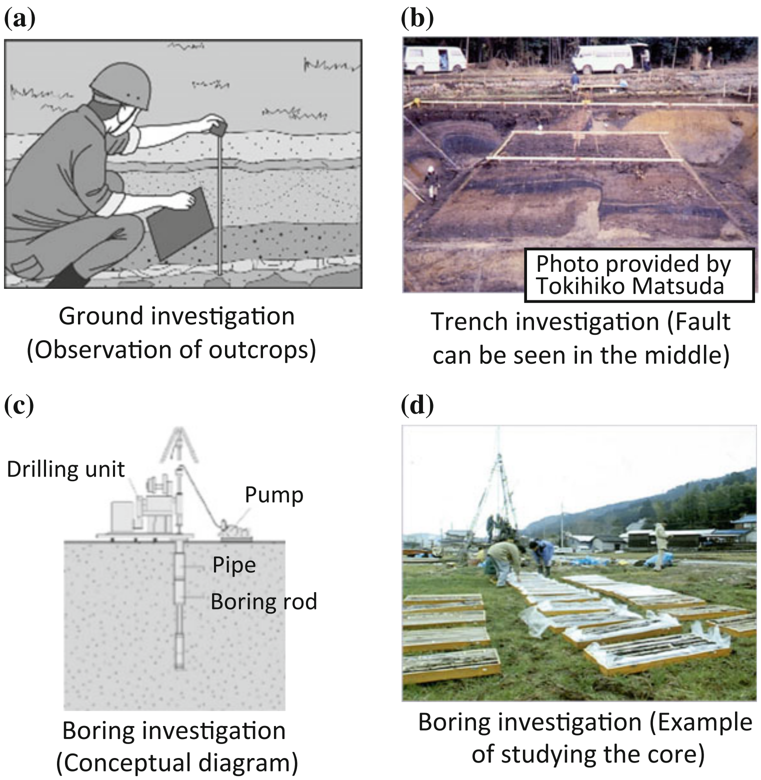

Fig. 2.5 Geological investigations. **a** Outcrop observation, **b** trench survey, and **c**, **d** boring survey [2]

seismic wave velocity in the ground by observing the propagation of artificially produced elastic waves. Microtremor observations are made by a vertical array of seismometers to determine seismic wave velocity structure. Earthquake observation records can provide information on the dynamic response characteristics of the subsurface ground. Moreover, the gravity prospecting method is useful to determine soil and rock density.

2.2.5 Analysis of Earthquake Observation Records

Since the 1995 Kobe earthquake, earthquake ground motion including micro-earthquake-caused motion have been measured on land and the seabed surrounding Japan by the Japan Meteorological Agency (JMA), the National Research Institute for Earth Science and Disaster Prevention, the Japan Agency for Marine-Earth Science and Technology, and several universities. The source

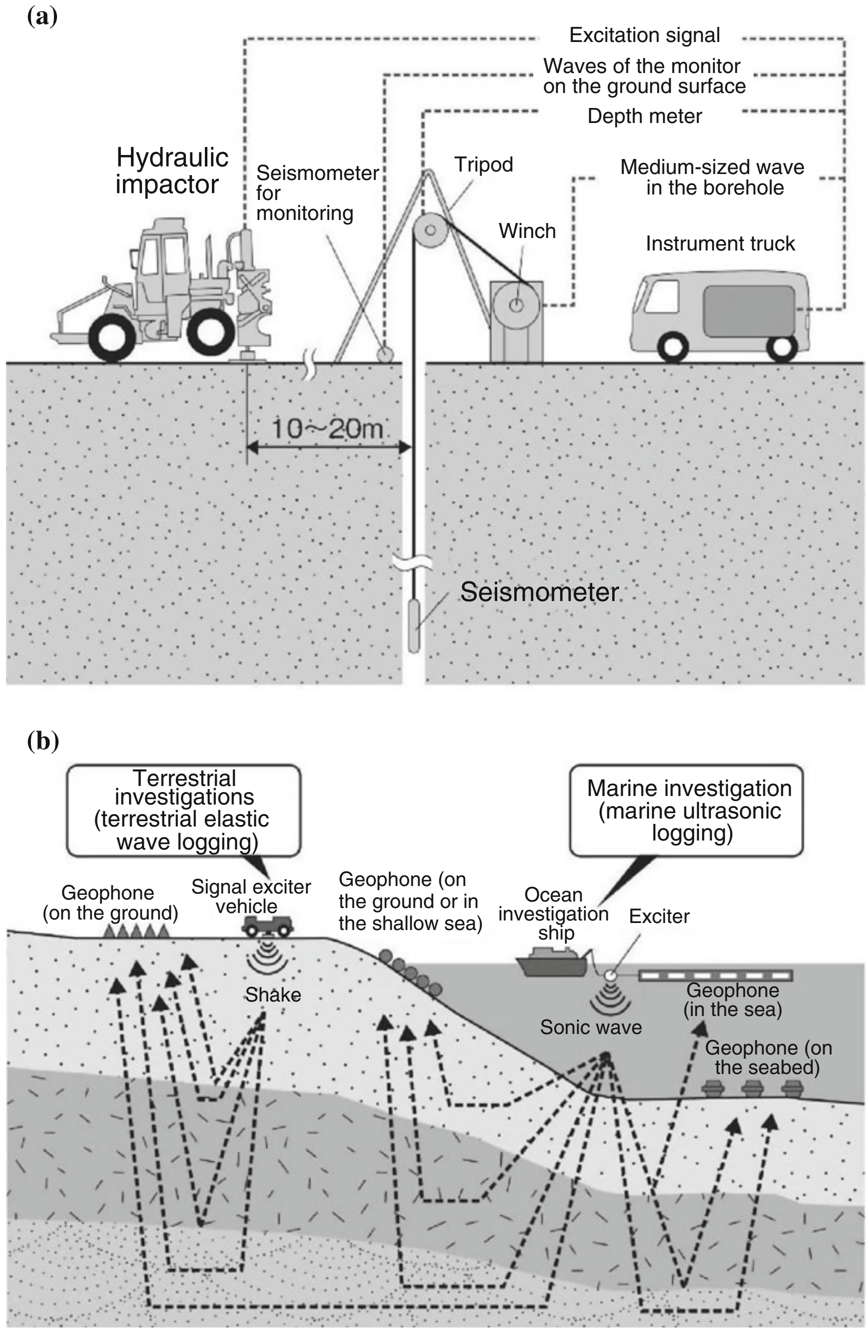

Fig. 2.6 Geophysical surveys, **a** physical logging (PS logging), **b** elastic wave logging

mechanism and propagation characteristics of seismic waves have been studied by analyzing these records. The seismic intensity distribution of earthquakes reported by JMA can be used to create the seismic source model. The subsurface structure model is developed to assess ground motion at the site, with reference to the distribution of seismic wave velocities and the damping characteristics of the surface ground.

Earthquake ground motions have been observed by seismometers installed in buildings and ground at nuclear power plants. The earthquake ground motions observed is used to verify the assumptions and the ground motion assessment process.

2.3 Assessment of Earthquake Ground Motion by Identifying Seismic Sources

This section describes the assessment procedure of the standard seismic motion S_s, by identifying the seismic sources that may have a significant impact on the site.

2.3.1 Selection of Earthquakes for Design

Earthquakes are selected for the earthquake-resistant design according to the earthquake type (inland crustal, interplate, and intra-oceanic plate earthquakes) based on the geological and geophysical survey results. The standard seismic motion S_s is assessed as time history record and/or response spectra based on the seismic source data for the selected earthquakes (refer to Part II, Chap. 14, Sect. 14.1 for the response spectrum).

2.3.2 Considerations of Uncertainties

Source models of selected earthquakes are developed by identifying the location, extent, and inclination of the faults, and by assuming the fault rupture patterns. To develop source models, variations of the parameters must be taken into consideration, because not all of the uncertainties will be identified.

Examples of considerations for uncertainties in an earthquake source model development are shown in Fig. 2.7. The survey committee of the Nankai Sea Trough mega-thrust earthquake affiliated with the Cabinet Office developed several

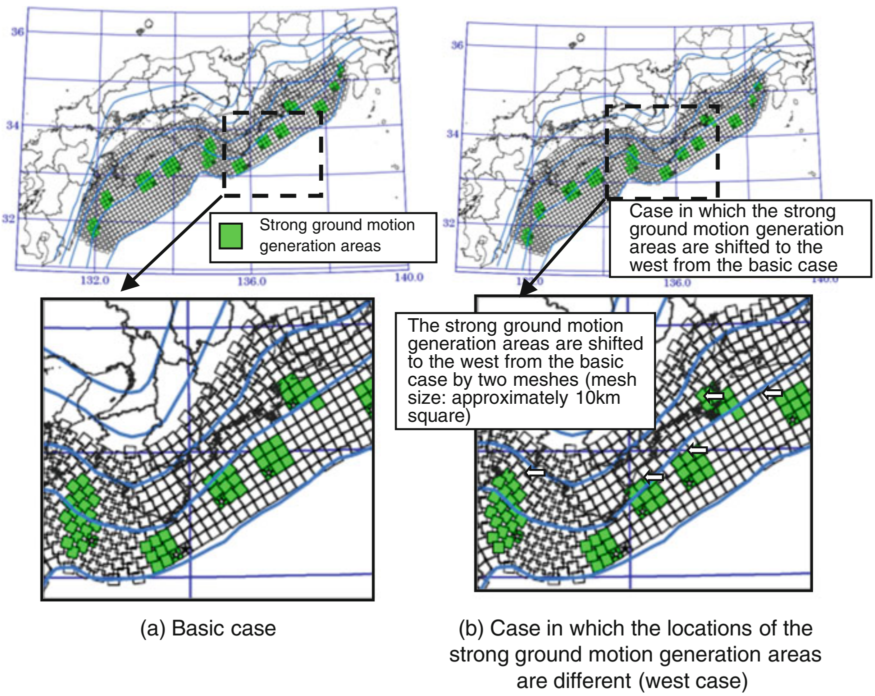

Fig. 2.7 Various seismic source models that consider uncertainties [3]

models with different areas for the generation of earthquake ground motion. The reason for the adoption of the different source areas is the fact that the earthquake ground motion may change compared with that of past earthquakes along the Nankai Trough.

2.3.3 Assessment of Standard Seismic Motion S_s by Source Models

The standard seismic motion S_s is assessed on the virtual free surface of the bedrock by the two methods as shown in Fig. 2.8. In the first method, the response spectra are evaluated from the magnitude of the earthquake source and the hypocentral distance. The time histories of the seismic motion are obtained to fit them with the spectra. In the second method, the time histories of the ground motion are directly developed based on the earthquake source models and the wave propagation characteristics from the source to the site.

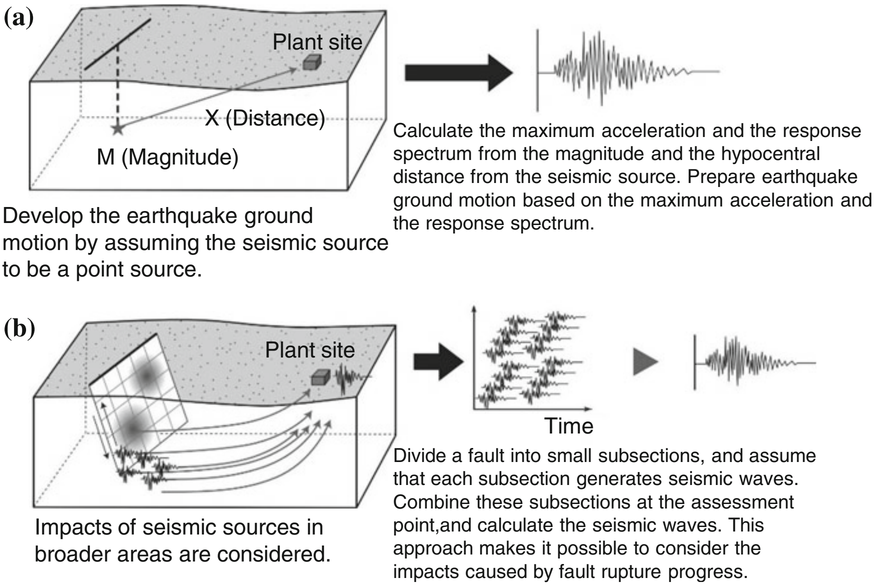

Fig. 2.8 Two methods of assessing of basic earthquake ground motion, **a** ground motion assessment based on the response spectrum, **b** ground motion assessment by the fault model

2.3.3.1 Method by Response Spectra

In this method, the response spectra of the standard seismic motion S_s on the virtual free surface of the bedrock are assessed according to a distance attenuation formula. Generally, there are two types of distance attenuation formulas. The first one provides a maximum value such as acceleration and velocity, and the second method provides the response spectra. The second method is used to assess basic earthquake ground motion S_s.

The distance attenuation formulae show the relationship between the intensity of ground motion, e.g., maximum accelerations and velocities, and the distance from the seismic source to the site. The formulae are developed by statistical analysis of the observed seismic motions during past earthquakes. Figure 2.9 compares the maximum accelerations observed during the 1995 Kobe earthquake and a proposed attenuation formula.

Figure 2.10 shows the process of assessing seismic motion based on the response spectrum. First, the response spectrum of the seismic motion on the virtual free surface of the bedrock is calculated from the magnitude of the earthquake and the equivalent hypocentral distance. Here, the equivalent hypocentral distance is the distance between a point representing the whole fault plane and the site. The response spectrum for the earthquake-resistant design is then developed as the envelope response spectra. Next, the time histories of the earthquake ground motion on the virtual free surface of the bedrock are produced to fit them with these

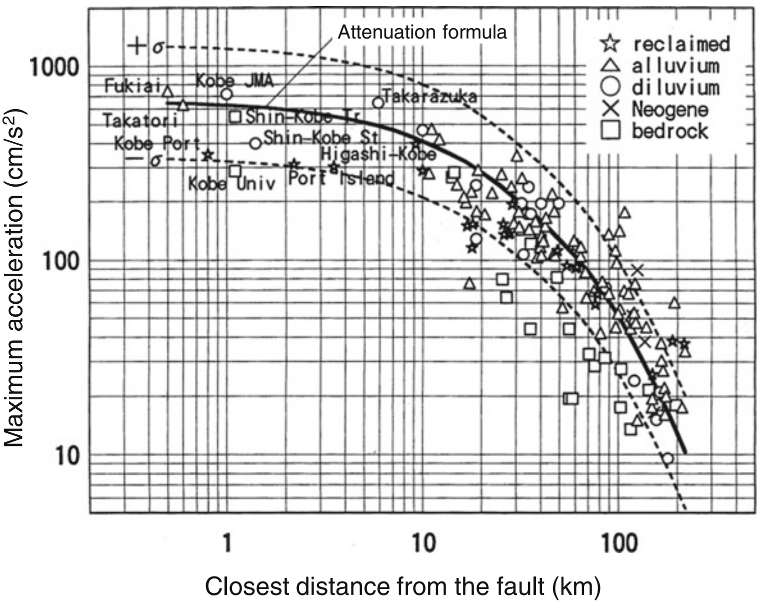

Fig. 2.9 Comparison of the maximum accelerations observed during the 1995 Kobe earthquake and those obtained from the attenuation formulae [4]

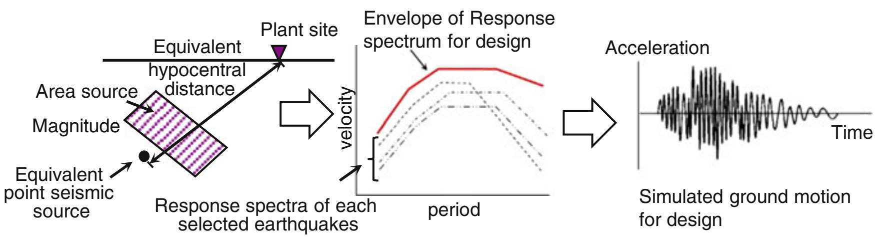

Fig. 2.10 Assessment of response spectra and time histories of earthquake ground motion based on the magnitude of the earthquake and the equivalent hypocentral distance

response spectra. The details of ground motion assessment based on response spectra are presented in the Technical Guidelines for the Seismic Design of Nuclear Power Plants issued by the Japan Electric Association (JEAG 4601-2008) (refer to Appendix 2.2).

2.3.3.2 Ground Motion Assessed Directly by a Fault Model

The source faults are divided into multiple small segments as shown in Fig. 2.11. It is assumed that small earthquakes are caused by each fault segment according to the propagation of the fault rupture. The effect of the propagation of the fault ruptures

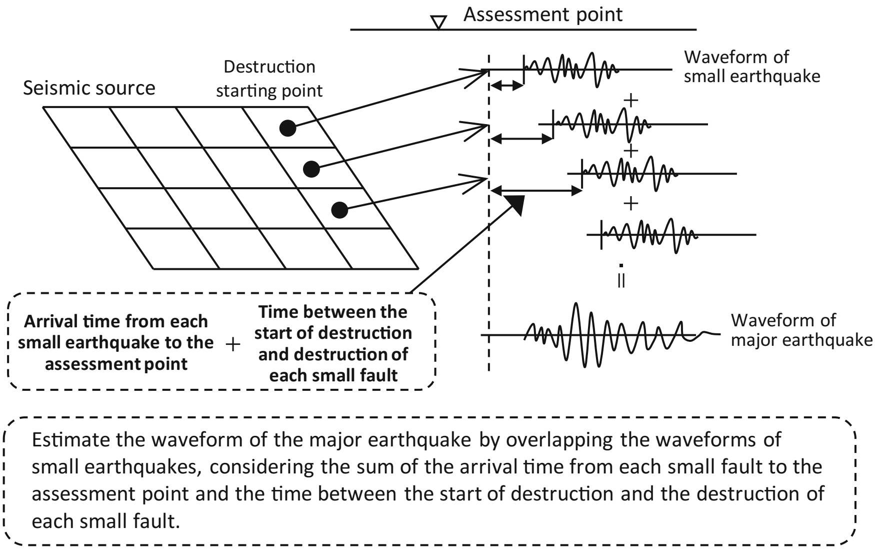

Fig. 2.11 Assessment of earthquake ground motion by fault models

and of the areas of the ruptured zone can be taken into consideration for the assessment of the earthquake ground motion. The standard seismic motion S_s is the sum of the ground motions caused by each of its segments.

The semiempirical methods (empirical Green's function method, statistical Green's function method) and theoretical methods are used to assess earthquake ground motion by the fault model. There is also an approach called the hybrid method, which combines the assessment of short period components of earthquake ground motion by semiempirical methods, and the assessment of long period components by theoretical methods.

As shown in Fig. 2.12, response spectra are calculated from the time histories of the earthquake ground motion assessed by the fault model and are compared with the response spectra assessed by the response spectra method mentioned in the previous section. If the response spectra by the fault model exceed the ones by the response spectrum method, the time history of the earthquake ground motion by the fault model is adopted as the standard seismic motion S_s for the earthquake-resistant design.

2.4 Assessment of Earthquake Ground Motion Without Identifying the Seismic Source

It is generally difficult to identify all of the inland crustal earthquakes that may occur in the area surrounding the site in advance, even by detailed geological surveys and precise active fault investigations. Therefore, in addition to the

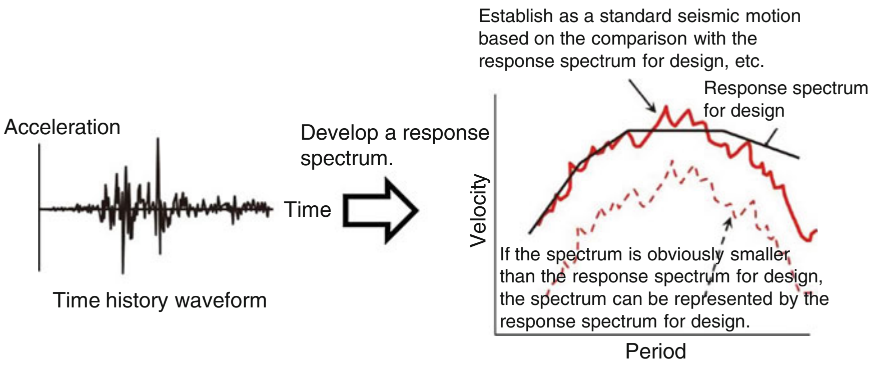

Fig. 2.12 Comparison of response spectrum of earthquake ground motion for the seismic design

earthquake ground motion based on the identified active faults, the earthquake ground motion will be estimated without identifying the seismic sources. To assess this type of earthquake ground motion, ground motions observed in the neighborhood of the epicenter of past inland crustal earthquakes, for which seismic sources and active faults had not be identified in advance, are collected. Based on the observed earthquake ground motions, the response spectra for the design are then derived by considering the amplification characteristics of the subsurface ground at the site, and the time histories of the earthquake ground motion to fit with the response spectra are developed.

2.5 Assessment of the Standard Seismic Motion S_s

The standard seismic motion S_s on the hypothetical free surface of the bedrock is determined based on the seismic motion assessed by both identifying and not identifying the seismic source.

Examples of the tripartite response spectra and the time histories of the standard seismic motion S_s are shown in Figs. 2.13 and 2.14, respectively. The tripartite response spectra (refer to Part II, Chap. 14) are a type of graph in which the response spectrum for each displacement, velocity, and acceleration is presented in one figure. The vertical axis is the velocity response, and the horizontal axis is the periods of seismic motion, while the 45° axis increasing towards the left and the 45° axis increasing towards the right are the acceleration and displacement responses, respectively.

The standard seismic motion S_s is used to verify the safety-related functions of the plant. The seismic motion for the elastic design S_d are developed from the standard seismic motion.

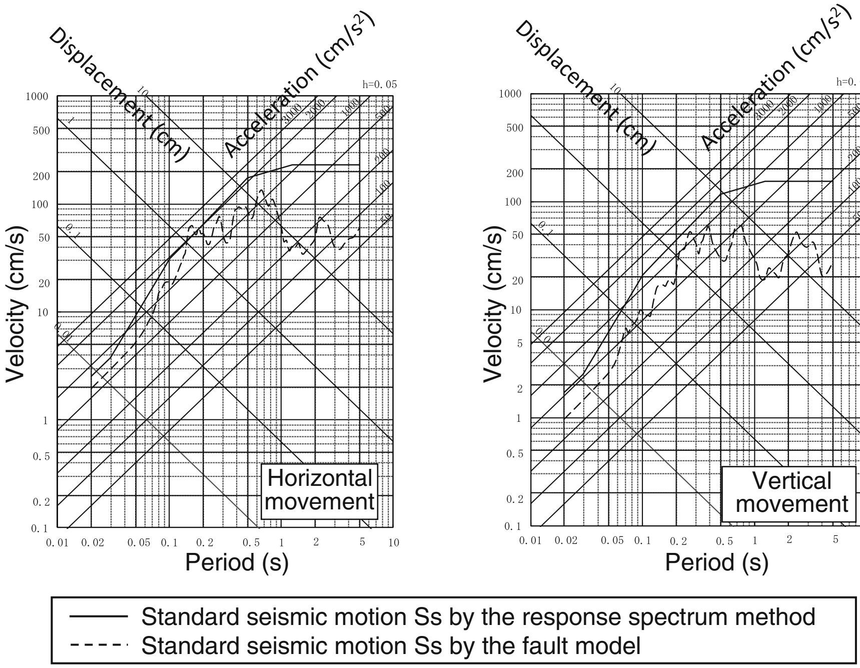

Fig. 2.13 Tripartite response spectra of the standard seismic motion S_s

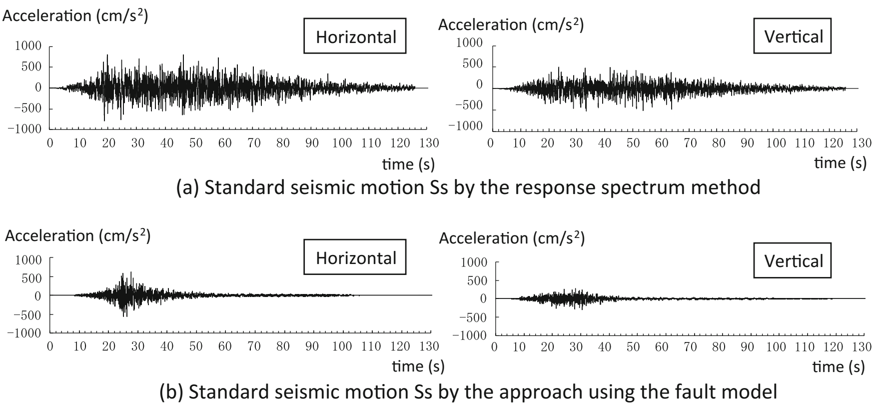

Fig. 2.14 Standard seismic motion S_s (time histories)

Appendix 2.1: Active Fault for Earthquake-Resistant Design

Besides the active faults that may cause earthquakes, faults that may cause permanent displacement, such as slippage in the plant's foundation during earthquakes should be taken into consideration for earthquake-resistant design. Additionally, faults that cannot be proven to have been inactive since the Late Pleistocene period (approximately 120,000–130,000 years ago) should be considered for the design. If the activeness of faults cannot be clearly determined, it must be assessed by carrying out comprehensive studies on the landscape, geological conditions and structures, and stress condition of the crust after the Middle Pleistocene (approximately 400,000 years ago) (Fig. 2.15).

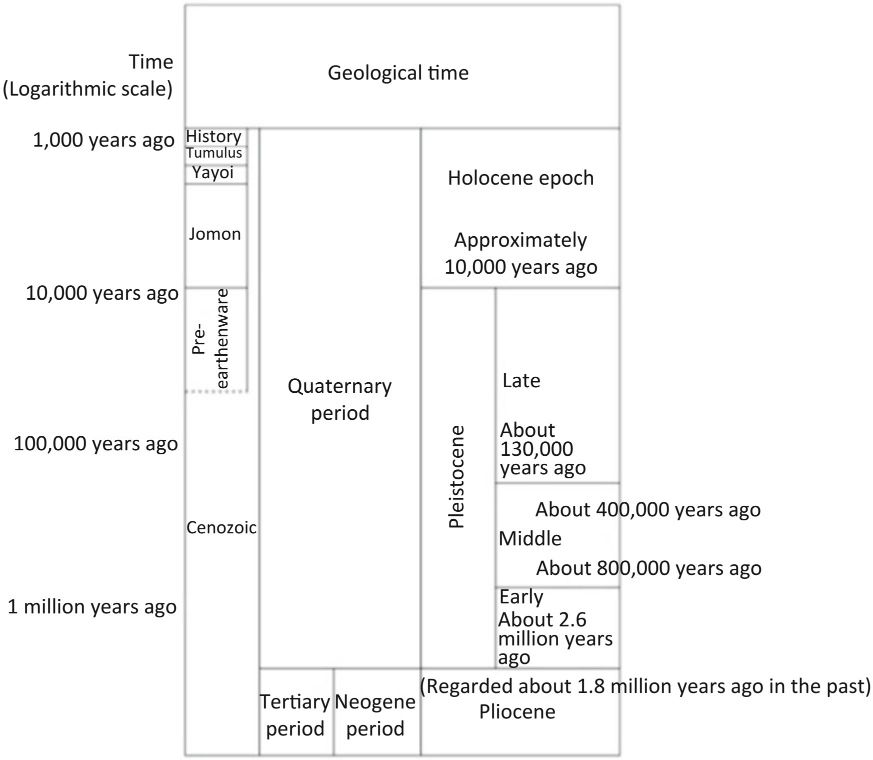

Fig. 2.15 Geological age [5–7]

Appendix 2.2: Assessment of Standard Seismic Motion S_s by Response Spectrum Method: Guidelines for the Seismic Design of Nuclear Power Plants (JEAG 4601-2008)

This method was developed for deriving response spectra on the bedrock based on statistical analysis of ground motions observed during past earthquakes (214 horizontal components and 107 vertical components) on bedrock in the Kanto and Tohoku regions, Japan.

JMA (Japan Meteorological Agency) magnitudes, hypocentral depths, and epicentral distances of the observed seismic motions were >5.5, <60, and <200 km, respectively. The applicability of this method was verified by comparing the seismic motion records observed at 23 locations in Japan, as well as 14 overseas locations with those calculated by this method. The parameters for the seismic motion assessment include earthquake magnitude M_J (JMA), equivalent hypocenter distance X_{eq}, and the S wave velocities of the bedrock.

As Fig. 2.16 shows, the equivalent hypocentral distance is defined by taking into account the effects of the area of the fault plane, and the distribution of the strong ground motion generation areas. The equivalent hypocentral distance is the distance at which the seismic wave energy released from each segment of the seismic source fault becomes equivalent to the energy released from a single specific point.

Response spectra in the horizontal and vertical directions on the virtual free surface of the bedrock are calculated by considering the effects of the site amplification of the ground. The effects of seismic wave amplification characteristics at the site are evaluated by analyzing existing earthquake ground motion records.

To develop the time histories of the earthquake ground motion, the envelope curves E (T), as shown in Fig. 2.17, are applied. The periods for the changing points of the curves, T_b and T_c, can be defined by the magnitude (M_J) and the equivalent hypocentral distance X_{eq}. Figure 2.18 shows an example of the time histories and the response spectrum of the earthquake ground motion development.

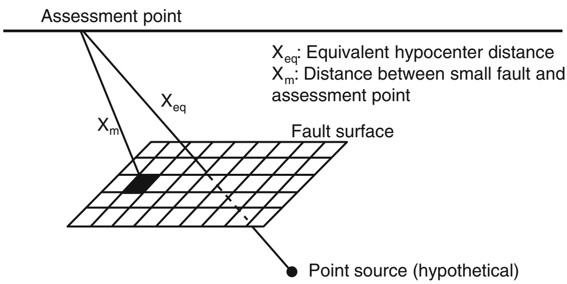

Fig. 2.16 Concept of equivalent hypocenter distance [8]

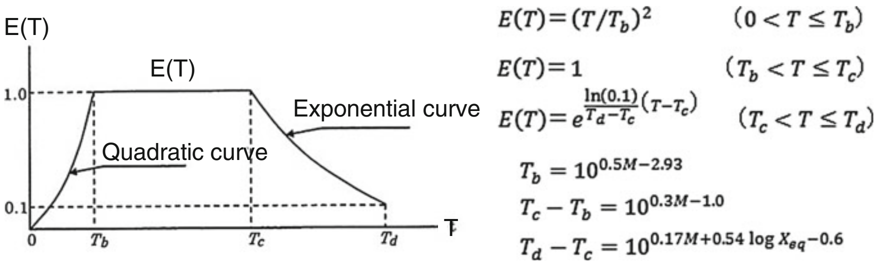

Fig. 2.17 Temporal changes in the amplification envelope [8]

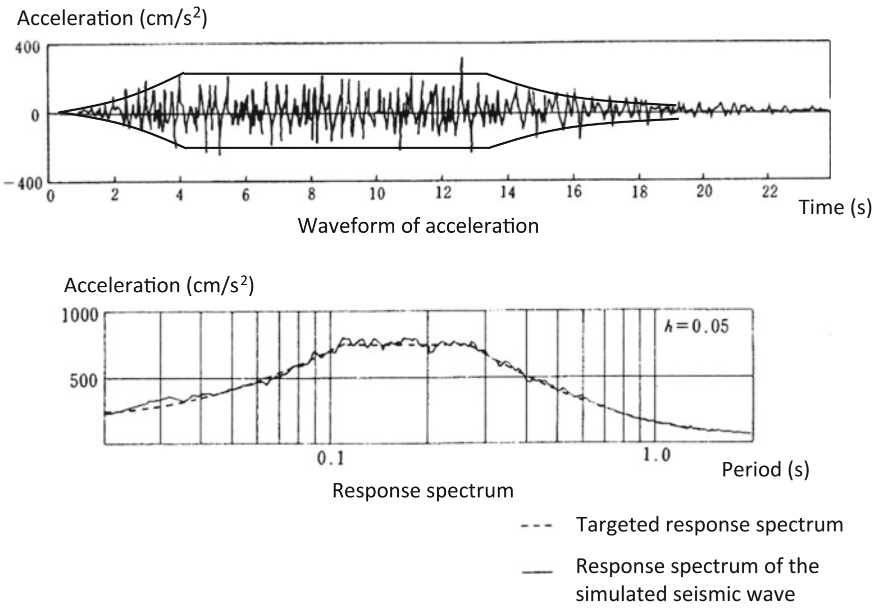

Fig. 2.18 Example of earthquake ground motion development [8]

References

1. "*Nihon no Jishin Bosai, Katsudanso* (Japan's Seismic Disaster Prevention; Active faults)", Ministry of Education of Japan, Culture, Sports, Science and Technology, 2004
2. The Headquarters for Earthquake Research Promotion, Japan website
3. "*Nankai Torafu no Kyodai Jishin Moderu Kentoukai* (The investigation committee of the Nankai Trough mega-thrust earthquake)", Cabinet Office, Government of Japan, 2012
4. "Characteristics of Observed Peak Amplitude for Strong Ground Motion from the 1995 Hyogoken Nanbu (Kobe) Earthquake", Yoshimitsu Fukushima, Kojiro Irikura, Tomiichi

Uetake, and Hisashi Matsumoto, Bulletin of the Seismological Society of America, 90, 3, pp. 545–565, June 2000
5. "*Nihon no Chikei* (Geographical Features of Japan)", Sohei Kaizuka, Iwanami Paperbacks, 1977
6. "*Nihon-rettou no Tanjou* (Birth of the Japanese Archipelago)", Asahiko Taira, Iwanami Paperbacks, 1990
7. Japan Association for Quaternary Research website
8. "Technical Guidelines for Seismic Design of Nuclear Power Plants (JEAG4601-2008)", The Japan Electric Association, 2008

Further Readings

9. "Shinpen, Nihon no Katsudansou (New Edition of Active Faults in Japan); Active Fault Research", University of Tokyo Press, 1991
10. "Kijun-jihindou oyobi Tiashin-sekkei Houshin ni kakaru Shinsa Gaido (Review Guide for Design Basis Ground Motion and Seismic Design Policy)", Nuclear Regulation Authority, 2013

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