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Development of Earthquake Assessment Technology

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Abstract:
The recent earthquake disasters have highlighted the importance of seismic design and attracted the attention of societies. In response to these market demands, we have developed the earthquake assessment technologies, i.e., PSHA (Probabilistic Seismic Hazard Assessment), SRA (Site Response Analysis), SSI (Soil Structure Interaction) and LA (Liquefaction Assessment). From among these, this report discusses the PSHA and SRA.

１. Background

Amid continuous earthquake disasters, seismic design codes are becoming more stringent and complicated following the strengthening of American design codes, e.g., ASCE 7, and are attracting the attention of societies. According to an existing earthquake hazard map, countries such as the Philippines, Indonesia, Mozambique and the US west coast are recognized as high seismic zones. The structures and foundations have to be designed against strong earthquake motions and this results in the need to increase the design quantities and also to conduct ground improvement to prevent the potential hazards of soil liquefaction or slope failure. The earthquake assessment technologies will enable the accurate design outcomes to be obtained through the detailed evaluation processes and the countermeasures to be optimized. Therefore, it will contribute to optimize the plant costs as well as enhance the design reliabilities. With these backgrounds, we have developed the earthquake assessment technologies.

２. Schematic Flow of Seismic Assessment

The schematic flow of seismic assessment is described in Fig.1.

(1) PSHA : Probabilistic Seismic Hazard Assessment

Based on the past earthquake records, a response spectrum at bedrock level is evaluated at the specific site location by the probabilistic analysis approach.

A response spectrum is the physical property of the earthquake and presents the strength of structural vibrations, i.e., accelerations of structures, responding to fundamental periods of superstructures as described in Fig.2.

(2) SRA : Site Response Analysis
From the response spectrum at bedrock, the response spectrum at ground surface is evaluated taking into account the site-specific ground stiffness and strength. As described in Fig.2, the response spectrum at ground surface is typically amplified from that of bedrock.

(3) SSI : Soil Structure Interaction
As a structure is found on ground, there is an interaction of forces and energies between the structure and ground when a structure vibrates during earthquake. This is called soil-structure interaction (SSI). In the conventional design, a simplified rigid-base design model is used, ignoring the SSI effects. However, in the case of heavy masses such as large tanks, the SSI effects become significant and therefore should not be ignored.

(4) LA : Liquefaction Assessment
The liquefaction potential of ground is evaluated based on the seismic accelerations at the ground surface. For liquefiable ground condition, some countermeasures such as ground improvement or pile foundations will be required depending on the performance requirements of the facilities.

A different seismic assessment technology is required for the above 4 assessments. From among these, this report discusses (1) PSHA and (2) SRA.

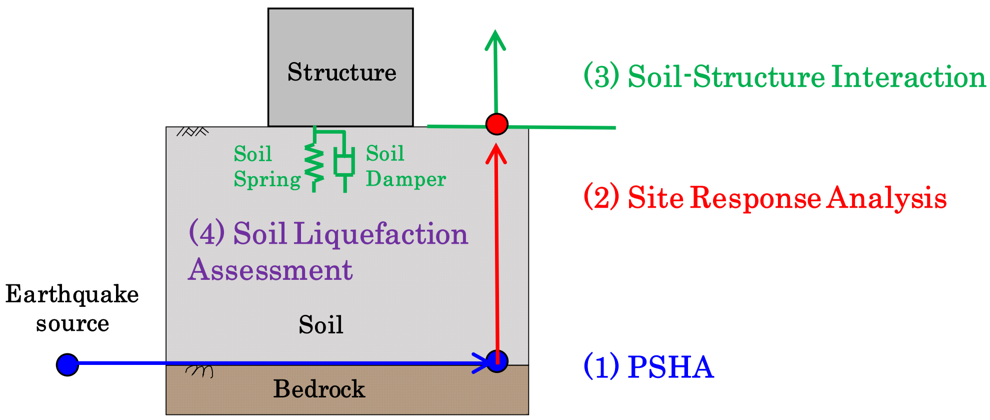

Fig.1 Schematic Flow of Seismic Assessment

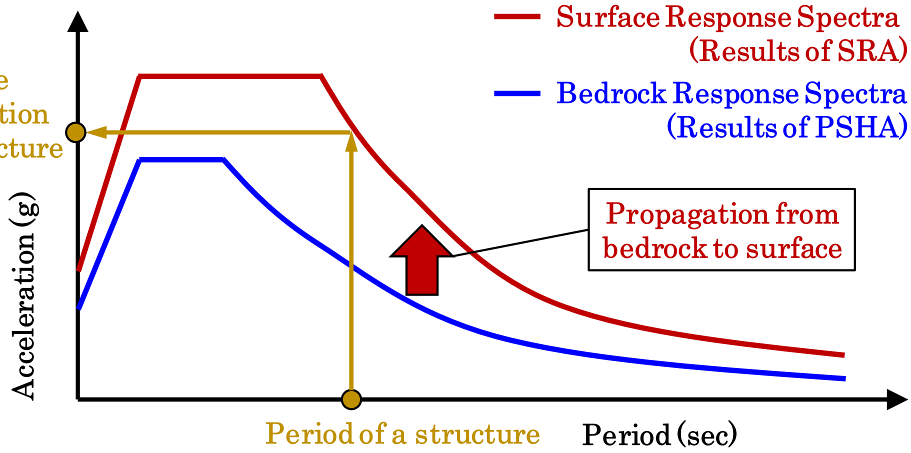

Fig.2 Sample Response Spectra

3. Probabilistic Seismic Hazard Assessment (PSHA)

The seismic hazard assessment (SHA) is the process to analyze the seismic waves traveling in the crust from the earthquake source and to evaluate the response spectrum at deep bedrock level of a site-specific location.

The SHA used to be the owner's scope to provide the seismic design basis of the plant facility. However, in recent years, there are increasing needs for contractors to undertake the SHA in Pre-FEED and FEED on behalf of the owner. In response to the needs, JGC has developed the ability to perform the SHA on its own. The strength of our SHA is to seek not only the rationality based on the scientific and engineering perspectives, but also that of the business profitability and execution, which provides great added value to the owners.

The SHA consists of two forms, the deterministic and probabilistic. The deterministic SHA (DSHA) assesses the largest hazard from a particular earthquake source. The probabilistic SHA (PSHA) assesses the hazards from all the earthquake sources and magnitudes that affect the site-specific location. It can be said that the PSHA includes the DSHA or that the DSHA is one of the forms of the PSHA. The PSHA is more objective than DSHA and therefore, makes it possible to provide more accountable and appropriate seismic design basis.

The PSHA procedure is shown as follows:

(1) Literature reviews on the seismic intensity, geology and surface soil properties around the site of interest

This is the work to collect and analyze the existing research papers. The results of the literature reviews will be used to verify our PSHA process and to be accountable to the owner and the third party. It is important to adopt our option for our specific project carefully from multiple views in the research papers, because there are a wide variety of views depending on the researchers. It is also important to trace the state-of-the-art knowledge of the technology.

(2) Obtaining and analyzing the numerical seismic information

This work starts with obtaining the earthquake catalogue data from the seismic data information services provided by sources such as the United States Geological Survey (USGS), International Seismological Centre (ISC), Japan Meteorological Agency (JMA), etc. Then the obtained data is analyzed by using the open source software, OpenQuake Hazard Modeler's Toolkit to establish the seismic source model.

(3) Modeling of seismic model

This is the work to establish the seismic model by using the open source software, OpenQuake Engine. The seismic model including earthquake source, seismic wave propagation, uncertainty, etc. is created in the OpenQuake Engine based on the obtained data and the literature survey.

We always keep in mind the fact that the assessment result is significantly affected by our adopted option from multiple views, and hence we always seek rationality, accountability for both the engineering point of view and the business point of view when we select our option.

(4) Calculation of the seismic intensity at the site of interest

This is the work to calculate the seismic intensity at the site of interest while considering all the earthquake sources and magnitudes and the associated uncertainty. One of the output forms is the acceleration response spectrum shown in Fig.3.

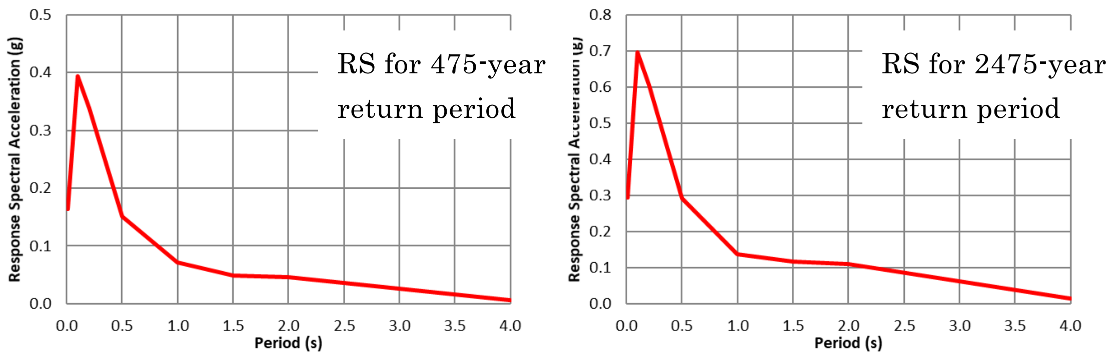

Fig.3 Bedrock Response Spectra at Project Site

(5) Deaggregation of the impact degree of the earthquake source

This is the last step of the PSHA. The contribution of each earthquake source to the seismic intensity at the site of interest is evaluated. Fig.4 shows examples of deaggregation for peak ground acceleration (PGA) for two of return periods (475 years and 2475 years). The examples indicate that the medium-scale earthquake (M5.0 to M6.5) at a short distance (less than 50 km) are the major contributors for the PGA.

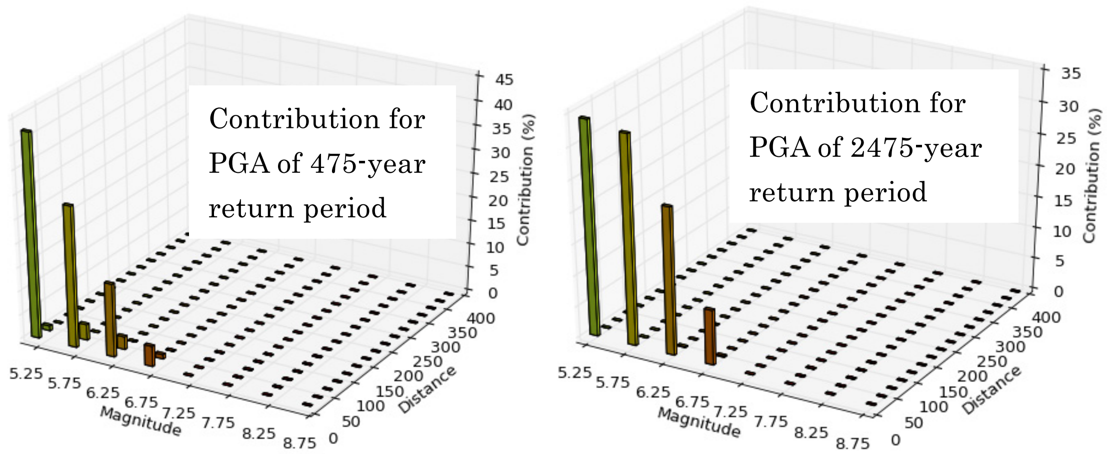

Fig.4 Deaggregation Plot

4. Site Response Analysis (SRA)

SRA is a methodology to evaluate the seismic intensity at ground surface, which analyses how the seismic wave travels from the bedrock to the ground surface through the soil layers. Although the PSHA used to be carried out by owner, the evaluation of seismic amplification has been performed by the contractor using the conventional amplification factors which are simply correlated with soil stiffness and strength in accordance with ASCE 7. SRA can evaluate the seismic wave propagation from the bedrock to the ground surface more precisely than the conventional method. The analysis results can be used for the derivation of design earthquake forces for structures and also liquefaction assessment and slope stability.

A flow chart of SRA is shown in Fig.5. Further details are described as below. Design conditions and interpretations of the analysis shall comply with the requirements in Chapter 21 of ACSE 7.

(1) Based on PSHA results, appropriate seven earthquake time histories are selected from the database for use in SRA. And the spectral matching is performed to modify the time histories to be compatible with a specified target response spectrum. The modified time histories are defined as an outcrop motion in ASCE 7.

(2) A horizontal layered soil model is prepared with the dynamic soil properties of each

layer i.e., the shear strain dependence of shear modulus and damping. Soil material property is illustrated in Fig.6.

(3) The modified time histories are input for the bedrock layer and the resulted time histories at ground surface are obtained. There are two methodologies to carry out site response analysis as follows:

- Frequency-domain method based on the equivalent-linear soil model (SHAKE)
- Time-domain method based on the non-linear soil model

SHAKE is known as a simple and fast method with comparison to the time-domain method. However, the time-domain method is recommended if the shear strain in the soil exceeds a certain level, because the accuracy of the equivalent-linear method may be impaired.

(4) A response spectrum is created from the resulted time histories at ground surface. The SRA results shall be checked to satisfy the design requirements specified in ASCE 7. Design earthquake forces for structures can be determined by plotting the fundamental periods of structures on the design response spectrum.

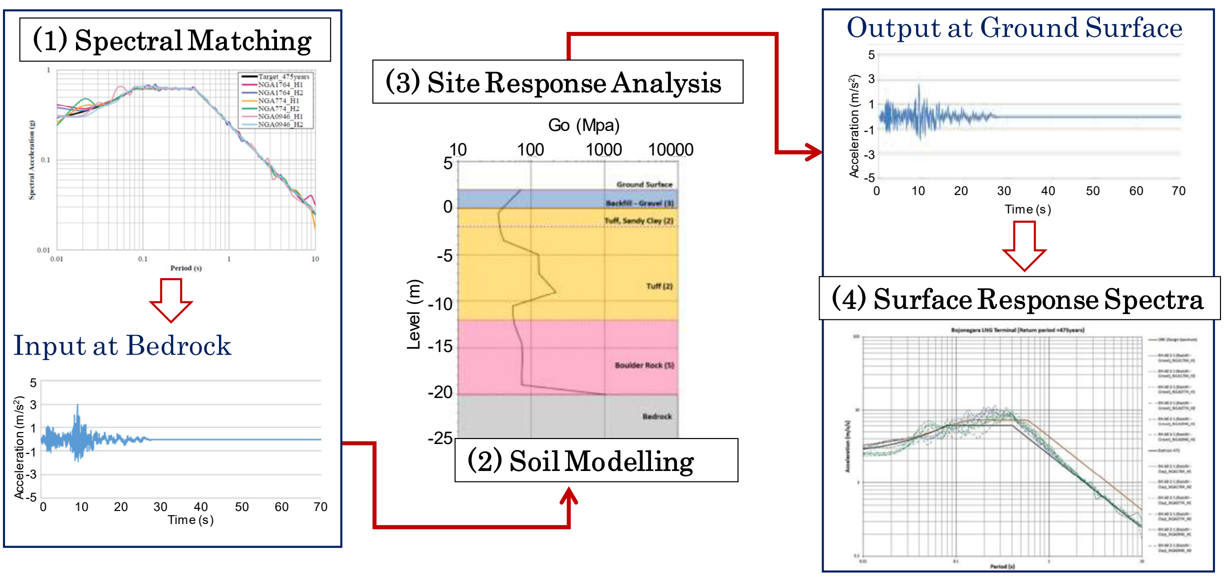

Fig.5 Schematic Flow of Site Response Analysis

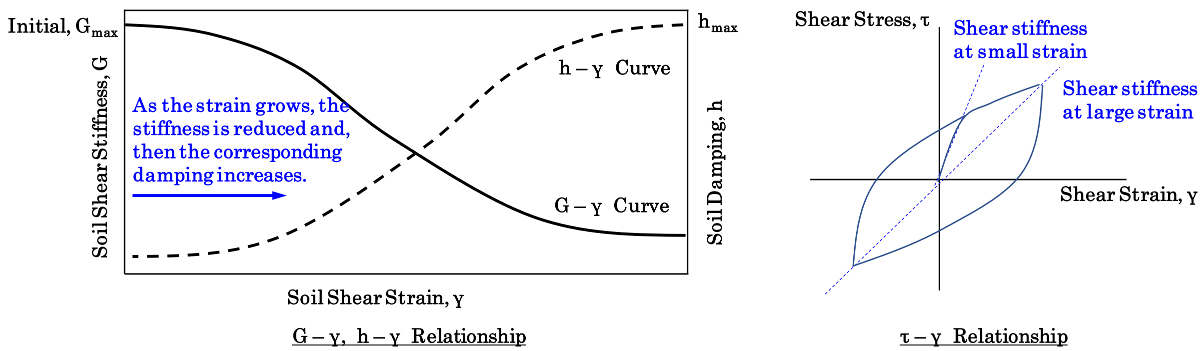

Fig.6 Soil Material Property

5． Closing

In this report, the brief procedures of PSHA and SRA are introduced from among four earthquake assessment technologies. We take into account the EPC execution as well as scientific and engineering rationality, which enable the most efficient seismic assessment to be achieved.

ASCE 7： Minimum Design Loads and Associated Criteria for Buildings and Other Structures, American Society of Civil Engineers