Launch of a Seismic Risk Assessment Service for Buried Linear Structures

— Visualization of the Risks and Values of Invisible Structures Underground —

September 1, 2021

Tokyo Electric Power Services Co., Ltd.

Tokyo Electric Power Services Co., Ltd., (in Koto-ku, Tokyo: President Yasuhiro Kubo) has developed a seismic risk assessment for buried linear structures and launch this service today. Through the assessment we have developed this time, a seismic risk analysis of buried linear structures can be carried out to break down and visualize not only the entire structures but also the areas in the structures having a high risk of breakage. Therefore, we believe that the owners of the structures can obtain information on the risk level and amount of loss, which makes it possible to develop an optimum renewal plan within the framework of a limited budget and time. This assessment method was developed under the commission of Tokyo Electric Power Company Holdings, Incorporated.

1. Background

The PML (*) is used as an indicator of the damage to a building caused by an earthquake. However, needless to say, not only buildings but also underground structures are at seismic risk, and such underground structures are below ground. Therefore, it has been very difficult to perform risk assessment, in particular, of linear underground installations, which are subject to this assessment. For example, headrace channels used at hydraulic power plants and water intake pipes used at thermal power plants are installed linearly as long as some hundreds of meters to several kilometers. If even a part of such structure breaks due to an earthquake, it not only causes water leakage but also affects power generation. In addition, it requires a long time and huge costs to renew such long-range structures at one time. Thus, the assessment of seismic risk for such linear underground structures has been a major issue for their owners.

* PML: Probable Maximum Loss
How much a building will be damaged in the event of the largest credible earthquake is expressed in the ratio (%) to the replacement cost of the building (the cost required if the entire building is reconstructed). The estimated size of an earthquake is based on the largest ground motion that is generally predicted to have a more than 10 percent chance of occurring in 50 years (a great earthquake that occurs once in approximately 475 years).

2. Outline of the Seismic Risk Assessment

First, this assessment is also carried out based on the PML that is used for the assessment of the building. As the material, structure, and ground characteristics of the surrounding area vary depending on the section even in one structure, the entire structure is broken down into elements at an interval of 1–3 meters, and the assessment is carried out for each element to assess the PML of the entire structure from the sum. The procedure is as follows:

(1) A fragility curve is set for each element
(2) The rate and amount of loss are calculated for each element
(3) The amounts of loss of all elements are totalized to calculate the amount of loss of the entire facility
(4) The amount of loss of the entire facility is divided by the total amount of loss to calculate the rate of loss of the entire facility
(5) The steps (1)–(4) are carried out in both total and effective stress analyses (*2) to calculate each rate of loss and PML value

*2 Total stress analysis and effective stress analysis
Total stress analysis is a method of analysis in which the earth area and the pore water are handled together, concerning the stress generated in the ground. Effective stress analysis is an analysis method in which the earth and the pore water are handled separately, concerning the stress generated in the ground. Effective stress analysis enables to represent the liquefaction phenomenon of the ground.

The details of each procedure are as follows:

(1) A fragility curve is set for each element

A seismic response analysis of a structure is carried out to figure out the damage probability of each element divided at an interval of 1–3 m. In addition, concerning the method of vibration, trial calculation is carried out 100 times in the Monte Carlo simulation (*3, hereinafter referred to as "MCS") at each seismic movement acceleration level to represent the result using a fragility curve.

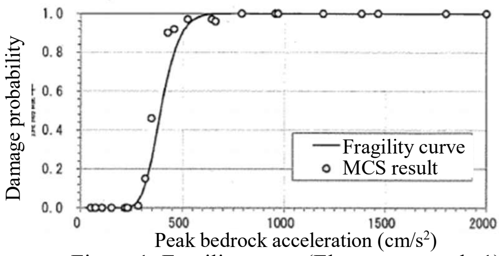

Figure 1: Fragility curve (Element example 1)

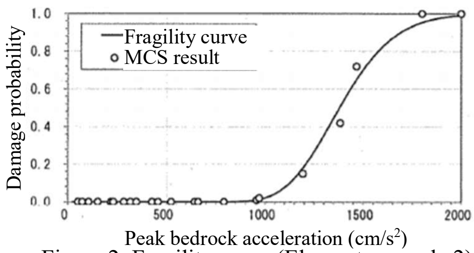

Figure 2: Fragility curve (Element example 2)

*3 Monte Carlo simulation (MCS)

A method for determining how a model reacts to a variable number entered randomly. In this assessment, MCS is carried out to determine what the damage probability will be when a physical property of rock mass is set randomly at each peak ground acceleration level. The symbols as shown in the figures can be obtained by carrying out trial calculation many times, and applying the lognormal distribution function to them creates fragility curves (the solid lines in the figures).

(2) The rate and amount of loss are calculated for each element

To figure out the rate and amount of loss, a probabilistic seismic hazard analysis needs to be carried out. The analysis is carried out to determine how much the peak bedrock acceleration will be in the structure when an earthquake occurred and to show it graphically.

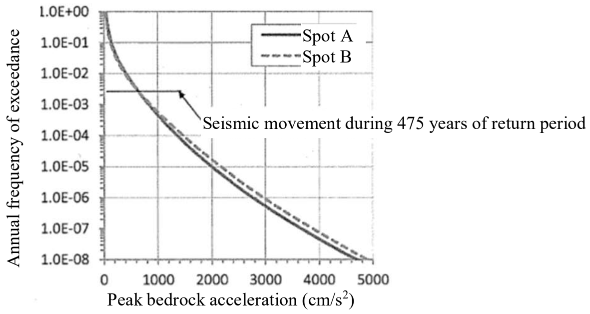

Figure 3: Probabilistic seismic hazard curve (Example)

As the final objective of this assessment is to determine the PML value, the peak acceleration during 475 years of the return period is read graphically. Figure 3 shows the seismic hazard curves of two specific spots, and the peak bedrock acceleration during 475 years is 686 cm/S^2 at the spot A and 688 cm/S^2 at the spot B.

Next, the rate of loss (damage probability) is calculated. If the calculation is carried out for the above spot A (686 cm/S^2), taking the above figures 1 and 2 for example, the damage probability of the element in Figure 1 becomes 0.98 and that in Figure 2 becomes 0. Assuming that each member costs one million yen, the amount of loss of the element in Figure 1 becomes one million yen x 0.98 = 980,000 yen, and that in Figure 2 becomes 0 yen. In this way, the amount of loss of each element can be figured out by checking the peak bedrock acceleration of the spot against the fragility curve of each element and multiplying the member cost of each element by the damage probability.

(3) The elements obtained in step (2) are totalized to calculate the amount of loss of the entire facility

(4) The amount of loss of the entire facility obtained in step (3) is divided by the amount of cost required if the entire facility is renewed at a time to calculate the rate of loss of the entire facility

This is the rate of loss of the entire structure at the peak bedrock acceleration and the PML value.

(5) The steps (1)–(4) are carried out in both total and effective stress analyses to calculate each rate of loss (= PML value)

The above steps (1)–(4) are carried out in both total and effective stress analyses to calculate the PML value in each case. Although the assessed risk generally tends to be larger in the effective stress analysis than in the total stress analysis, in some cases, the PML value calculated was confirmed to be higher in the total stress analysis depending on the element. Therefore, just to be sure, we decided to use two types of analyses for this assessment.

(6) The PML values are assessed

In general, the PML values calculated are compared with the table below for building damages.

PML value	Degree of risk	Extent of building damage
0–10 %	Very low	Minor
10–20 %	Low	Local damage
20–30 %	Medium	Medium damage
30–60 %	High	Major damage
Higher than 60 %	Very high	Collapse

Table 1: The relationship between PML value and seismic damage (in the case of buildings)

Also in this assessment, smaller PML value means smaller risk of seismic damage to the structure. As the PML values of the buildings, which were designed according to the Building Standards Act (Revised Seismic Design Method) in 1981 and later are generally approximately 10–20 %, we consider that 20 % is one of the standards also in this assessment. Furthermore, it is also possible to determine to renew only a certain part, focusing on the rate of loss of the respective elements.

For all of these reasons, we consider that this assessment enables the owners of underground structures to establish, design, and implement an optimum renewal plan in light of the budget and timing. In addition, it can also be utilized for maintenance, such as by evaluating the effect of aseismic reinforcement based on the difference in the PML value, which can be determined through comparison between before and after the aseismic reinforcement.

Although we originally started to develop this method for assessing buried linear structures for electric power, we confirmed that it could be applied to underground linear structures for purposes other than electric power, such as utility conduits and cable tunnels. Therefore, we expect that this assessment method can be utilized by many customers, such as gas companies and telephone carriers who own and manage similar buried objects.

This assessment method won the Takahashi Prize from the Japan Electric Power Civil Engineering Association in FY 2020. This prize is given for the development, research, invention, etc. of technology related to hydraulic power for electricity generation and other civil engineering technology related to power plants, which are found to have especially contributed to the advancement and improvement of such technology.

《Inquiries》

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