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Maximum Directional Earthquake Responses and Its Implication for the Seismic Design

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1. Introduction

In a seismic design, the structural demand of a seismic load is determined by the design response spectrum. And the directional combination method of resultant forces or displacements of structural elements by two horizontal earthquake input is important. For the nuclear facilities, a seismic safety assessment accomplished by the probabilistic approach is also necessary as well as the seismic design. Therefore, the realistic characteristics of bi-directional input ground motion and its spectral acceleration need to be studied for the design response spectrum and the input ground motion. In this study, the spectral acceleration calculation method using the observed ground motion acceleration data was reviewed and its effect on the seismic design was discussed.

2. Seismic Response of Two Orthogonal Horizontal Motions

2.1 Spectral Accelerations of Observed Earthquake Ground Motions

The response spectrum in design codes for bridges or buildings are determined by long period spectral acceleration level and short period one. These design spectral accelerations are calculated by the seismic hazard analysis at the target site. In the hazard analysis, a ground motion attenuation equation which represents the relation between an earthquake moment magnitude, a distance to the site, and a spectral acceleration is used. This equation is estimated by the regression analysis based on the spectral acceleration from the observed seismograms. Therefore, the method of the calculation of a spectral acceleration affects the design response spectrum.

The spectral acceleration of an accelerogram has no uncertainty itself. However, the vibration of ground motion is three-dimensional movement and the horizontal spectral acceleration can be different in every orientation. The ground motion acceleration use to be recorded in two orthogonal horizontal directions. For example, Fig. 1 shows the two horizontal accelerogram observed at the El-Centro station in the 1940 Imperial Valley earthquake. The peak ground acceleration of this motion can be 0.313g or 0.215g which depends on the direction.

Not only the peak acceleration, but also the spectral acceleration is different in a direction. The spectral acceleration is calculated by the displacement response of a single degree of freedom system with the given period. Therefore, it can be drawn by the trace on the horizontal plane. The solid line in Fig. 2 shows the spectral acceleration trace of the El-Centro motion for the period of 2.0 and 5% damping. The spectral acceleration in x-direction is smaller than 0.2 g and that in y-direction is larger than 0.2 g. However these two are almost same. If this ground motion is observed with the rotation angle of 30 degrees, then the trace will be the dotted line in Fig. 2. And then, the spectral acceleration can be 0.094 or 0.235.

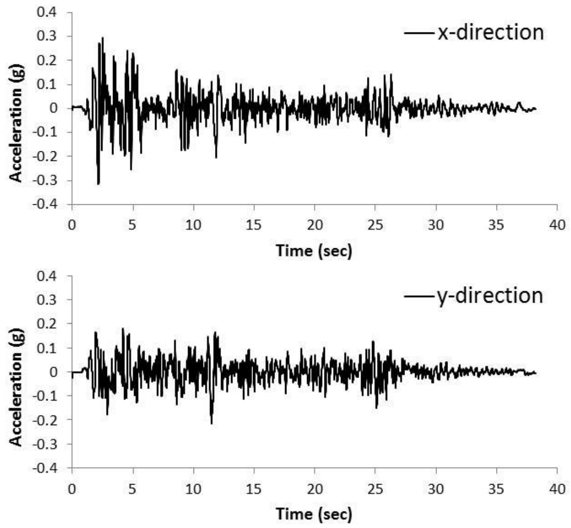

Fig. 1. Two orthogonal horizontal accelerations of the El-Centro motion

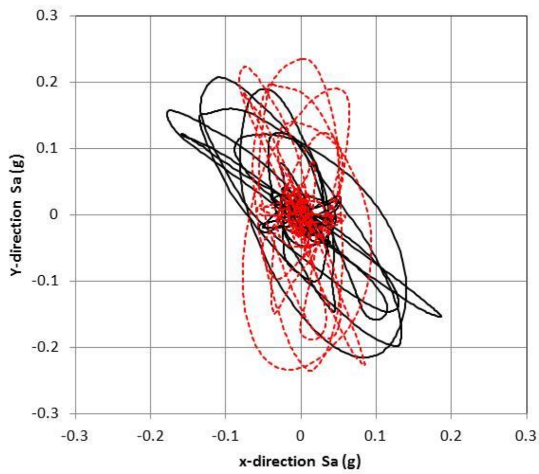

Fig. 1. Spectral acceleration trace of the El-Centro motion for the single degree of freedom system with T=2.0 s and 0.05 damping.

2.2 Representative Spectral Accelerations of Two Orthogonal Horizontal Ground Motions

There has been effort to reduce this orientation induced uncertainty. Generally, the geometric mean of two orthogonal spectral accelerations is used. The geometric mean of the spectral acceleration of El-Centro motions in as-recorded direction is $\sqrt{0.187 \times 0.215} = 0.201$ g. However if the measuring instrument was installed with the rotation angle of 30 degree, then the geometric mean spectral acceleration can be $\sqrt{0.094 \times 0.235} = 0.146$ g. Therefore it has also large uncertainty.

To reduce this uncertainty of the geometric mean method, the 50%-ile of geometric means of all possible rotated angles was introduced. This method can calculate only single value for the spectral acceleration of the given period. However the rotated angle in accordance with 50%-tile geometric mean can be different in every period. To find independent rotated angle of the geometric mean for all period range, the error minimized angle for the all period range interested was determined. This is called GMRotI50 spectral acceleration [1]. The GMRotI50 of the spectral acceleration of the El-Centro motion in previous example is 0.186 g.

Recently, another definition, in which the representative spectral acceleration is calculated as the maximum value of all possible direction, was introduced [2]. The maximum spectral acceleration of the El-Centro motion in previous example is 0.235 g

The response spectrum of the El-Centro motion can be calculated as in Fig. 3. In this figure, the dotted line is the GMRotI50 response spectrum and the solid line is the maximum directional response spectrum. The ratio of the maximum directional response spectrum to the GMRotI50 response spectrum is depicted in Fig 4. The ratio is around 1.3.

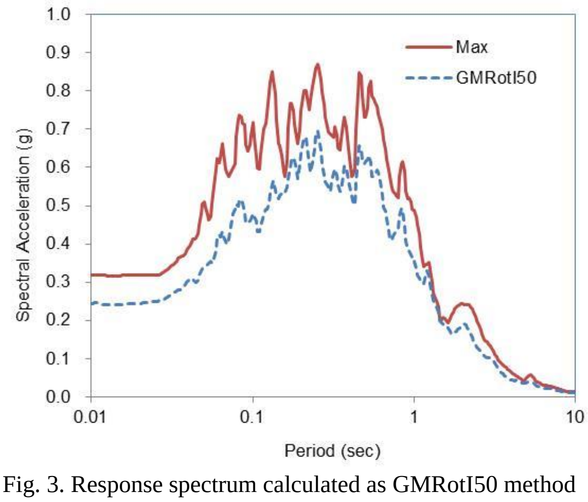

Fig. 3. Response spectrum calculated as GMRotI50 method and the maximum directional method.

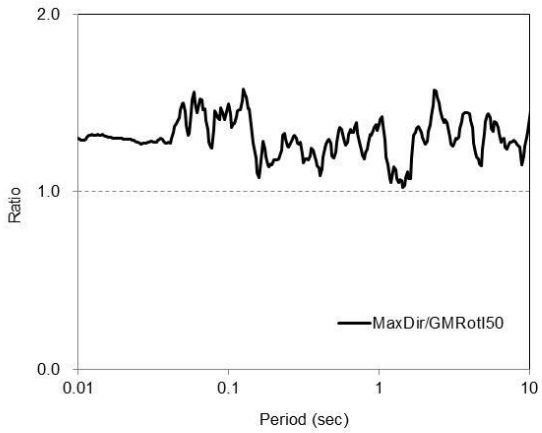

Fig. 4. The ratio of the maximum directional response spectrum to the GMRotI50 response spectrum.

3. Discussion for the Seismic Design

The response spectrum in design codes, the geometric mean method has been used for the seismic hazard analysis. However if the maximum directional spectral acceleration is used for the attenuation equation, the design spectrum can increase. The directional effect in design codes is considered by the combination methods of responses in each direction such as the SRSS method or 100%-30%-30% rule. However, the directional combination in design codes cannot produce appropriate response for the azimuth independent pole type structures. In this case, the maximum directional response is apparently reasonable.

For the probabilistic seismic safety assessment, all the possible uncertainty needs to be considered. In this case, the geometric mean spectrum can be separated as the maximum direction spectrum and its orthogonal direction spectrum to consider existing uncertainty

4. Conclusions

In this study, the spectral acceleration definition with two horizontal directions is reviewed. These definitions should be properly adjusted in design codes. The detailed effect on the result of a structural design need to be investigated in further study

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