Relation of Biaxial Nonlinear Response and Mechanical Properties of Structures

Hisato HOTTA
Associate Professor
Tokyo Institute of Technology
Tokyo, Japan
hotta@arch.titech.ac.jp

Hisato Hotta, born 1962, received his building engineering degree from Tokyo Institute of Technology, Japan.

Yoshina TAKAHASHI
Graduate Student
Tokyo Institute of Technology
Tokyo, Japan
takahashi.y.az@m.titech.ac.jp

Yoshina Takahashi, born 1989, received her building engineering degree from Tokyo Institute of Technology, Japan.

Summary

The effect of horizontal biaxial seismic input is not considered in the equivalent linearizing method, while the cases of investigation in terms of biaxial response displacement of structures are not sufficient to grasp the characteristics of biaxial elasto-plastic response comprehensively. The objective of this paper is to comprehend the relation between mechanical properties of structures and biaxial response displacement. With an analytical model of single-mass two degree of freedom system, we conducted examination with parameters of mechanical properties; oblateness of yield surface, biaxial restoring force characteristics, and yield strength to uniaxial input. As a result, it was verified that response to biaxial input was often much greater than the response to uniaxial input, and oblateness of elastic response displacement to biaxial input was concerned with the characteristics of biaxial elasto-plastic response.

Keywords: elasto-plastic response, horizontal biaxial seismic input, response displacement, mechanical properties of structures, plasticity theory.

1. Introduction

In the design method of equivalent linearizing method with response spectrum, the effect of horizontal bi-directional seismic response is not taken into account. In terms of the nonlinear response of structures to horizontal biaxial seismic input, although several papers have shown analysis results that the response displacement to biaxial input exceeds the response to uniaxial input, the examination cases are not enough to grasp the relation between response displacement to biaxial input and mechanical properties of structures comprehensively. The objective of this paper is to comprehend the effect of biaxial input, and we conducted parametric investigation of the relation between mechanical properties of structures and bi-directional response displacement.

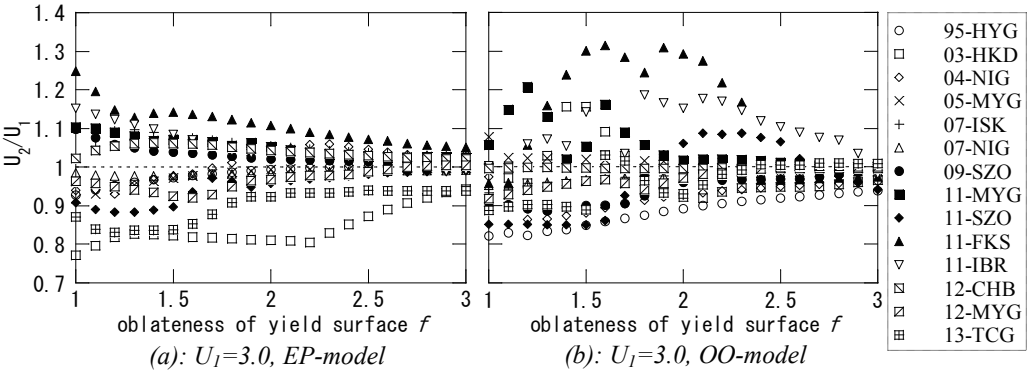
2. Outline of Analysis

Analytical model for time history response analysis is single-mass system with two degrees of freedom. Stiffness for x-axis and y-axis of horizontal coordinate system are set so that the natural periods are 1.0 second. Bilinear elastic-perfectly plastic type and origin-oriented type are adopted for uniaxial restoring force characteristics, and are expanded respectively to two axes on the basis of the theory of plasticity. The biaxial restoring force model of elastic-perfectly plastic type is abbreviated as EP-model, and the one of origin-oriented type is abbreviated as OO-model. The Newmark-β method (β=1/4) is applied to numerical integration of equation of motion, and damping coefficient is 5% for each axis. Fourteen earthquakes whose maximum ground acceleration are more than 200 gal are chosen for input seismic motions. To unify input condition, they are reconstituted to Mj wave and Mn wave. Mj wave is in the direction with the maximum ground acceleration, and the direction of Mn wave is perpendicular to the direction of Mj wave.

3. Examination of Response Displacement to Bi-directional Input

The effect of biaxial input on displacement response is examined by comparison with the response to uniaxial input. Considering the directionality of seismic motions, response ductility factor to uniaxial input U_1 is unified to 3.0 or 4.0 for each earthquake and restoring force model by adjusting yield resistance. The response to biaxial input U_2 is also calculated considering the directionality of earthquake. We used three parameters which indicated mechanical properties of structures. The first is the biaxial restoring force characteristics (EP-model and OO-model), the second is U_1 which indicates the yield strength, and the third is the oblateness of ellipse of yield surface. The oblateness of yield surface, abbreviated as f, is the ratio of the yield resistance in y-axis to the one in x-axis, and is varied from 1.0 to 3.0.

As a part of the analysis results, the relations between U_2/U_1 and f in the case of U_1=3.0 and EP-model and the case of U_1=3.0 and OO-model are given in Fig. 1.



(a): U_1=3.0, EP-model *(b): U_1=3.0, OO-model*

Fig. 1: Relation between U_2/U_1 and f

4. Conclusions

To investigate the characteristics of displacement response to biaxial input, we concluded the examination using analytical model of single-mass two-degree of freedom system and parameters of mechanical properties; oblateness of yield surface f, biaxial restoring force model (elasto-perfectly plastic model [EP-model] and origin-oriented model [OO-model]) and response ductility factor to uniaxial input U_1 which indicates yield strength. We reached the following conclusions.

1) When we input earthquake bi-directionally to the analytical model, yielding occurs on the part of yield surface other than the point where the axis for response evaluation intersects with the yield surface, and the model yields before reaching yield resistance in that axis. Therefore difference of response state from the case of uniaxial input is caused.

2) With respect to the oblateness of yield surface f, it is verified that the ratio of response displacement to biaxial input to the one to uniaxial input, U_2/U_1, is dispersed according to diminishment of f, and converges to 1.0 with increase of f (which is shown in Fig. 1). Obtained maximum ratio of the response displacement to biaxial input and the one to uniaxial input U_2/U_1 is 1.37 (11-IBR, U_1=4.0, OO-model, f=3.0).

3) It is found that in the case of OO-model the convergence of U_2/U_1 to 1.0 according to the increase of f is delayed than the case of EP-model to some extent within the results obtained from this examination.

4) As for the response ductility factor to uniaxial input U_1, in the case of EP-model the convergence of U_2/U_1 with increase of f is not so different between the cases of U_1=3.0 and U_1=4.0. On the other hand, in the case of OO-model it is found that the convergence of U_2/U_1 caused by the larger U_1 is delayed than the one by the smaller U_1.

5) From the aspect of oblateness of biaxial elastic response displacement, it is verified that the response displacement to biaxial input is often relatively much greater than uniaxial response when the oblateness of elastic response is larger than about 0.4 and bi-directionality of response is strong.