Influence of directionality of bi-directional ground motions on seismic response of bridge bearings

X. He[1], A. Igarashi[2]

[1] *Department of Urban Management, Kyoto University, Japan.*
E-mail: he.xinhao.25u@st.kyoto-u.ac.jp

[2] *Disaster Prevention Research Institute, Kyoto University, Japan.*
E-mail: igarashi.akira.7m@kyoto-u.ac.jp

ABSTRACT

This study focuses on the directionality effect of bi-directional ground motions on the seismic response of bridge bearings of two types, namely the high damping rubber (HDR) bearing and the functionally discrete bearing (FDB) in their bi-directional application. Artificially generated spectrum compatible bi-directional ground motions are used as the input to specify the directionality effect in terms of the degree of the elliptic property. With a special interest in the seismic displacement response, the numerical results indicate a notable difference between the two seismic bearings to the directionality effect, even though they have almost the same level of response as in the unidirectional condition. A method of assessing the directionality effect is proposed based on a simple stochastic approximation.

KEYWORDS: *High damping rubber bearings, functionally discrete bearings, bi-directional ground motion, directionality effect, seismic performance assessment.*

INTRODUCTION

In the present practice of seismic design based on the Japanese Specifications for Highway Bridges, unidirectional seismic loads are applied in various concerned directions of bridge systems for seismic performance assessment. This concept is based on the idea that the maximum rotated elastic spectral [1] (or bi-axial spectrum) which measures the maximum value of the response spectra for the axes of input in various directions rotated on the horizontal plane is considered as an appropriate representative of bi-directional seismic demand.

On the other hand, since the response of a single-degree-of-freedom (SDOF) oscillator to the rotated ground motion can be expressed as a function of the rotation angle and time, the directionality effect of bi-directional ground motion is defined as the ratio of the minimum value to the maximum value of this function for a given period of oscillator. The fact that structural behavior can be significantly affected by the directionality effect of bi-directional loading has been reported by a previous study [2]. It is of great importance to investigate whether the unidirectional design of bridge systems with seismic bearings satisfies the requirement of the seismic demand under bi-directional input with various degrees of directionality effect.

The spectrum compatible bi-directional accelerograms with the specified elliptical component of polarization proposed in Ref. [3] is proposed to be an appropriate solution for this purpose, since the bi-axial spectrum of the generated bi-directional input consisting of the standard and complementary ground motions is almost the same as that of the unidirectional input of the standard ground motion. In the present study, the directionality effect of the bi-directional ground motion is investigated in two types of seismic bridge bearings in their bi-directional application: the high damping rubber (HDR) bearings and the functionally discrete bearings (FDB). A method for assessment of the directionality effect is proposed based on a simple stochastic approximation.

BI-DIRECTIONAL INPUT AND MODELLING

For a given target spectrum and a spectrum-compatible unidirectional input a_x, the bi-directional accelerograms that match the target spectrum with a specified degree of directionality effect can be synthesized by the following equation proposed in Ref. [3]:

$$\begin{Bmatrix} a'_x(t) \\ a'_y(t) \end{Bmatrix} = \begin{bmatrix} \cos\theta & -\sin\theta \\ \sin\theta & \cos\theta \end{bmatrix} \begin{bmatrix} \cos\theta & \sin\theta \\ -\alpha\sin\theta & \alpha\cos\theta \end{bmatrix} \begin{Bmatrix} a_x(t) \\ a_y(t) \end{Bmatrix} \tag{1}$$

where $a_y(t) = H[a_x(t)]$ is the complementary orthogonal component corresponding to $a_x(t)$, by applying Hilbert transform. The constant α represents the elliptical component, which implies the degree of directionality effect ranging from zero to unity, and θ is the major direction angle. When α is equal to unity, it is a non-directivity case with uniform contribution over all directions, while a smaller value indicates a greater fluctuation of intensity among various direction. The standard design ground motions in the Japanese Specifications for Highway Bridges, are used as original components considering different ground condition and intensities: II-I-1, II-II-2, II-III-3, II-I-1, II-II-2, II-II-3, II-III-3.

The dynamic response of a straight girders bridge supported by single columns with the HDR or FDB in their bi-directional application is investigated. The system is simplified as a lumped mass type with two translational DOFs in the horizontal plane in a single span. The assumed weight of the superstructure is 900 tons.

The FDB system consists of the pure friction bearings and linear elastomeric bearings set in parallel. The linear spring representing the behavior of elastomeric bearings are independently applied in the longitudinal and transverse directions. The Coulomb model with a circular interaction surface is used to represent the bi-directional coupled effect of the friction force in the pure friction bearings. The magnitude of the friction force is proportional to the friction coefficient and the self-weight of the girder. Two cases of linear spring stiffness with natural periods of 1.0 and 2.0 sec are assumed. The friction coefficient is 0.15.

The modified Park-Wen model [4] to represent the bi-directional behavior of HDR is used. The effect of bi-directional shear strain components at high strain levels involving increased hysteretic energy dissipation is included with the use of the modified Park-Wen model. The planar dimensions of each layer of sample rubber are 160mm×160mm, with a total thickness of 10mm in 4 layers. The size scale factor is selected as 3.38, and five bearings are set in parallel in this study.

NUMRICAL RESULTS AND ASSESSMENT

The relationship between the maximum absolute response of the bearings and the level of elliptical component compared with the maximum response in the unidirectional input case is shown in Figure 1. It is observed that the effect of the elliptical component value on the maximum response is different depending on the bearing type. Despite some variation due to the ground motion characteristics, the maximum response of HDR tends to decrease with a higher elliptical component, while the opposite tendency is shown for FDB. As indicated in the hysteresis loops of the two seismic bearings in Figure 1, the energy dissipation of these devices subjected to bi-directional displacement loading are considerably affected by the directionality effect. The different tendencies of the maximum response can be reasonably explained by this mechanism.

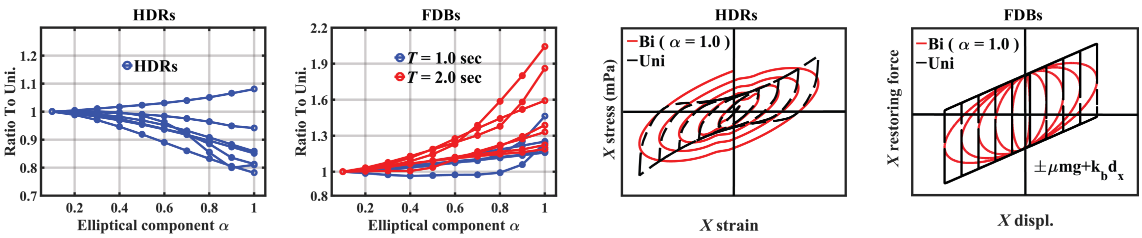

Figure 1: Directionality effect of bi-directional loadings on maximum response and the hysteresis loops

In order to estimate the statistical variance of the response under bi-directional loading to that under unidirectional loading, application of a simple stochastic dynamic approximation with white-noise excitation to a SDOF system is investigated. The equivalent stiffness and damping ratio are evaluated by applying bi-directional displacement loading with various amplitudes and specified elliptical component on the original bi-directional model. The ratio of statistical variance of the response under bi-directional loading to that under unidirectional loading is obtained in Figure 2. It is noted that the results for FDB are almost similar for two natural period cases.

The ratio of the statistical mean of the maximum response for the bi-directional case to that of the unidirectional case are shown in Figure 3. A good agreement with Figure 2 can be seen.

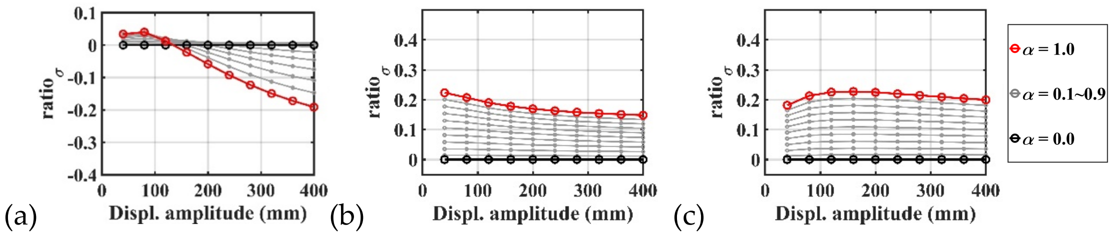

Figure 2: Response variance ratio with various elliptical components (a) HDRs, (b) FDB, $T = 1.0$ sec, and (c) FDB, $T = 2.0$ sec

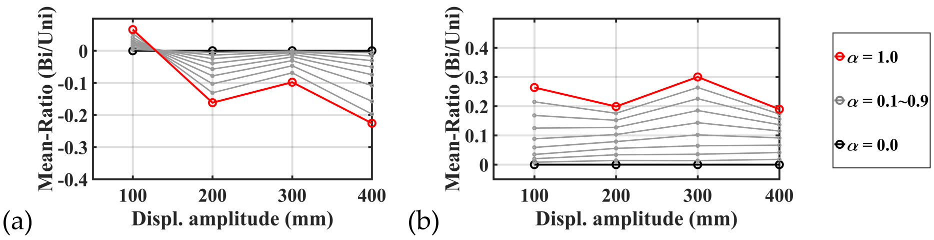

Figure 3: Response mean ratio of maximum response with various elliptical components (a) HDRs, (b) FDBs

CONCLUSIONS

The influence of the directionality effect of spectrum compatible bi-directional input on the maximum response of bi-directional seismic bearings of two types is investigated. The maximum response of HDR tends to decrease with a higher elliptical component, while the opposite tendency is shown for FDB. It is observed that the equivalent stiffness and damping ratio of restoring force in the two bearings undergo significant change under the bi-directional loading with specified directionality effect due to the bearing's path-dependence feature. A method of assessing the directionality effect is proposed based on a simple stochastic approximation.

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