SEISMIC RESPONSE ANALYSIS OF BASE ISOLATED HIGHWAY BRIDGE : EFFECT OF ISOLATION BEARING'S MODELING

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INTRODUCTION

Prior to the 1995 Hyogo-ken nanbu (H-k-n) earthquake occurrence, highway bridges were regarded as safe against even the extreme earthquake like the Great Kanto earthquake (M7.9) of 1923. It was because a lot of observations and experiences were used in the formulation of the seismic design methods. However, a new experience was achieved after the H-k-n earthquake occurred in 1995 in which destructive damages became apparent mostly in bridge piers. As a consequence, the ductility design method was incorporated in the 1996 revision of JRA seismic design method (JRA, 1996). Although this method is being widely accepted for seismic design of structures, this may not be appropriate for bridge piers since most of failures occurred in bridge piers in the recent earthquake occurrence were found to be shear type rather than flexure type. Moreover, the development of the ductility implies some damages and, therefore, this method is called fail-safe approach. An alternative to this approach is to use seismic isolation approach to virtually separate the superstructure from the substructure. By seismic isolation it is meant that the fundamental frequency of the isolated structure is so reduced that it remains far away from the resonant frequency of the structure. In this regard, use of HDRBs is widely increasing as seismic isolators due to having their inherent damping property along with high flexibility at higher strain levels. The objective of the current study is to evaluate effects of modeling of isolation bearings on the seismic response of the bridge. To this end, a nonlinear dynamic analysis of the highway bridge (Fig.1) isolated by HDRBs is carried out. The isolation bearings are modeled by the bilinear model (JRA, 1996) and the rheology model describing the rate-dependent mechanical behavior of HDRBs (Bhuiyan et al., 2009) for comparison. Numerical algorithms using these two models are developed, which are compatible with Newmark-β method of time integration. The nonlinear hysteresis of the piers is considered in this analysis, which is modeled by the Takeda tri-linear degradation model (Takeda et al., 1970). Finally, a comparative assessment of the bridge responses as obtained using the bilinear model (ibid), and the rheology model (ibid) shows that modeling of isolation bearings has a noticeable effect on the moment-curvature relations of the plastic hinges and the shear stress- strain responses of the bearings.

ANALYTICAL MODEL OF THE BRIDGE

An analytical model of a typical five-span continuous reinforced concrete (RC) girder bridge is schematically shown in Fig.1. The superstructure of the bridge consists of RC slab covered with 8 cm asphalt supported by continuous steel girders; the substructure consists of RC piers supported by pile foundations; and the isolation bearings are located between top of the piers and the steel girders. The superstructure, continuous steel girder, and the pier cap are idealized by linear elastic elements; the body of the pier is modeled by nonlinear beam elements and the plastic hinge located at the bottom is modeled by nonlinear rotational spring; the stiffness of the foundation and soil-structure interaction are idealized by a set of linear translational and rotational springs and finally the isolation bearing is modeled by nonlinear translational spring element. Takeda tri-linear degradation model (Takeda et al., 1970) is used for modeling hysteresis of the body and plastic hinge of the pier. The nonlinear translational spring elements for bearings are modeled by the bilinear model (ibid) and the rheology model (ibid) in order to illustrate effects of modeling of the isolation bearing on the bridge's response. Two types of level-2 earthquake ground motions, applied in the longitudinal direction, are used in the analysis. Subsequently, the nodes of the piers are allowed to displace in the longitudinal direction and rotate about the transverse direction. The vertical displacement of the piers is restrained as no significantly axial shortening is expected.

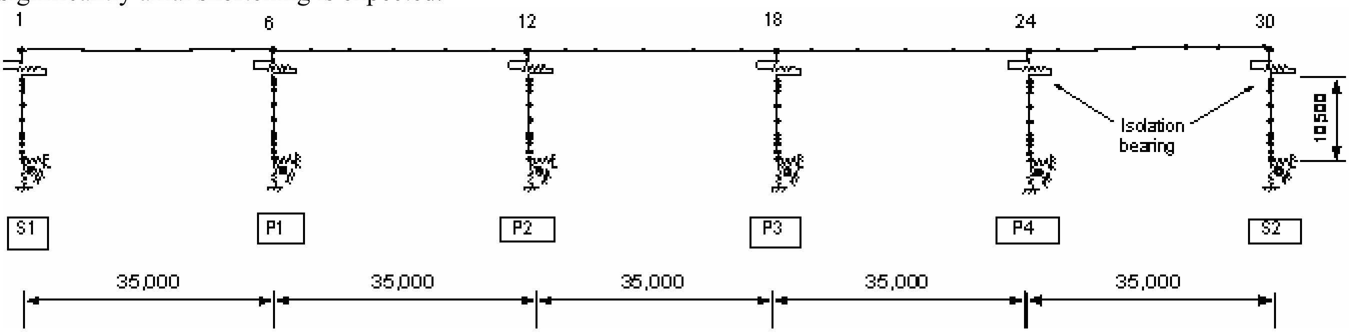

Fig.1. Typical five-span continuous reinforced concrete girder bridge

SOLUTION ALGORITHM

To allow for the time varying tangent stiffness matrix associated with nonlinear modeling of the bridge components, the equation of motion can be written as $[\mathbf{M}]\{\ddot{\mathbf{u}}_{i+1}\}+[\mathbf{C}]\{\dot{\mathbf{u}}_{i+1}\}+\left\{\mathbf{F}_i^{int}\right\}+[\mathbf{K}_i]\{\Delta\mathbf{u}\}=\left\{\mathbf{F}_{i+1}^{ext}\right\}$ (1)

where $[\mathbf{M}]$ is the mass matrix; $[\mathbf{C}]$, the damping matrix; $[\mathbf{K}_i]$, the tangent stiffness matrix; $\{\Delta\mathbf{u}\}$, the vector of displacement increment over the integration time step; $\{\dot{\mathbf{u}}_{i+1}\}$,the vector of the velocity at the end of the time step; $\{\ddot{\mathbf{u}}_{i+1}\}$, the vector of the

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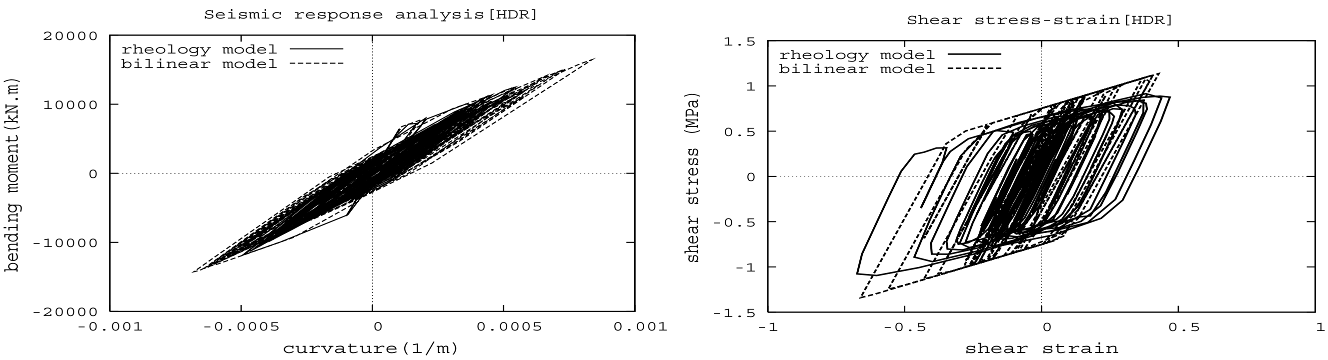
acceleration at the end of time step; $\left\{\mathbf{F}_i^{int}\right\}$, the vector of the internal forces developed in the isolation bearings and the piers at the beginning of the time step, and $\left\{\mathbf{F}_{i+1}^{ext}\right\}$, the vector of the external forces at the end of the time step. The damping matrix $[\mathbf{C}]$ is evaluated using the Rayleigh damping method. The Newmark-β method with constant acceleration approach is employed to solve the equation of motion of the system. The integration time step is taken as 0.0002 sec. Solutions are obtained for the displacement, velocity and acceleration at the end of the time step in terms of the known quantities at the beginning of the time step and the increment of the displacement.

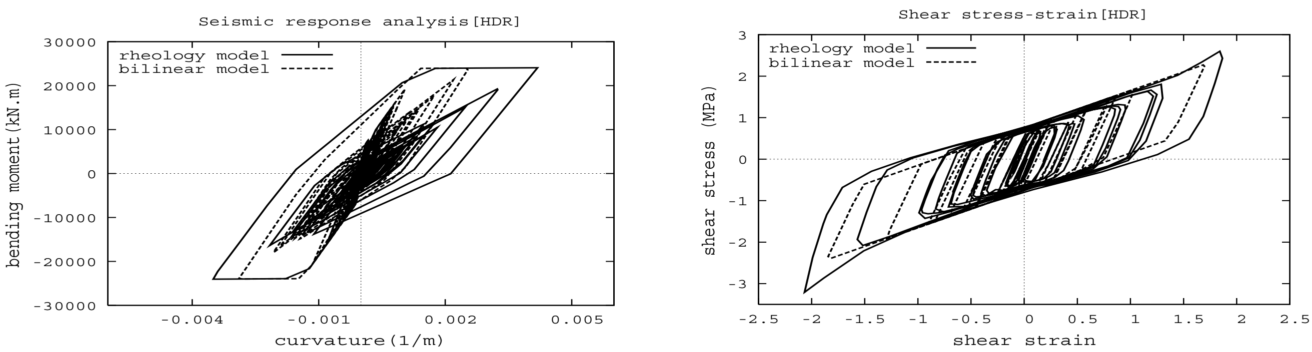
SEISMIC RESPONSES OF BRIDGE

The seismic responses of interest of the isolated bridge system are the moment-curvature relations of the plastic hinges and the shear stress-strain relations of the isolation bearings. In order to compute these responses, numerical algorithms compatible with the Newmark-β method are developed in the study. These algorithms along with the analytical model of the bridge system are implemented in commercially available software named Resp-T (Resp-T, 2006). Due to space limitations and the symmetry of the bridge system, the results of only one pier (P1) are presented and discussed herein. Figs.2 (a) and 3(a) represent the moment-curvature relations of the plastic hinges of the pier for level-2 type-I and type-II earthquakes, respectively. As shown in these Figs., the effect of modeling the isolation bearings on the hysteresis of the plastic hinges is evident. The similar trend of the responses is obtained from the shear stress-strain relations of the HDRB as shown in Figs.2 (b) and 3(b).



(a) (b)

Fig.2. Seismic responses of the bridge for type-I earthquake (a) moment-curvature relations of the plastic hinge (b) shear stress-strain relation of HDRBs.



(a) (b)

Fig.3. Seismic responses of the bridge for type-II earthquake (a) moment-curvature relations of the plastic hinge (b) shear stress-strain relation of HDRBs.

CONCLUDING REMARKS

Effect of modeling of HDRBs on the seismic responses of the isolated bridge is evaluated by conducting a nonlinear dynamic analysis. Two nonlinear hysteretic models are used for HDRBs: the bilinear model (ibid) which parameters are estimated using the Japanese standard seismic design method and the rheology model developed by Bhuiyan et al. (2009). It is noted that the same loading condition (sinusoidal loading with 1.75 strain and 0.5 Hz) is used to determine the parameters of the two models. In this paper, the bridge responses are discussed in terms of the moment-curvature relations of the plastic hinges and the shear stress-strain relations of the bearings since these responses are very crucial for seismic design of the bridge system. Figs.2 and 3 show the responses of the bridge for two types of earthquake ground motions. The effect of modeling the bearings is significantly observed in the responses indicating that a careful selection of the models of isolation bearings is very important for seismic design of an isolated bridge system.

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