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Soil-structure interaction of seismically isolated bridge structure during very strong ground motion

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ABSTRACT: Soil-structure-interaction (SSI) has a significant effect on seismically isolated bridge structure during very strong ground motion. Bearing pads in between pier and girder can rotate more than allowable design rotation during extremely strong ground motion which has really a detrimental effect on the total displacement of bridge deck. The total response of the superstructure could be more dangerous in case of very large girder section. Here, in this research a simplified model is constructed to present the whole bridge system considering soil-structure interaction. The model consists five degree of freedoms: translation and rotation of foundation, translation of pier and translation and rotation of isolation mass. The equations of motion for the whole bridge system are derived in frequency domain by assuming soil stiffness and damping constants. The simplified model is run under finite element environment in ABAQUS. Parametric studies are per-formed based on the constructed ABAQUS model. The focus of the research is to find out the contributing modes of the model due to SSI effect on bridge structure.

1 NOTATIONS

m_G, m_p	:	Girder and pier mass respectively
k_G, k_p, k_h, k_r and k_{rG}	:	Girder, pier, foundation translational, foundation rotational and bearing pad rotational stiffness coefficient respectively
c_G, c_p, c_h, c_r and c_{rG}	:	Girder, pier, foundation translational, foundation rotational and bearing pad rotational damping coefficient respectively
h	:	Height of pier
h_G	:	Height of girder
u_G, u_p, u_h, ϕ_{rG} and ϕ_r	:	Girder, pier, foundation translational, girder rotational and foundation rotational degree of freedom respectively
u^t_p, u^t_G	:	Total displacement of the pier mass and girder
u_g	:	Displacement due to ground motion

2 INTRODUCTION

The seismic impact on the structures with large height is always vigorously dominant issue in the field of earthquake engineering. In the bridge engineering, the rotation due to large girder web in presence of soil structure interaction is normally overlooked by the bridge engineers. This rotation in girder due to some seismic activity could be an imperative issue in global stability of bridge. Studies involving dynamic soil–structure interaction (SSI) are rather complex because of the non-homogeneity, nonlinearity and semi-infinite extent of the soil, as well as several difficulties in coupling the soil and the supported structure. The literature is rather extensive on the topic. A comprehensive review of the literature on soil–foundation interaction can be found in the papers by Gazetas [1], Antes and Spyrakos [2] and Spyrakos [3].

The bridge-soil system adopted in the analysis is shown in Fig. 1. The bridge deck is considerably stiffer than the isolation bearings, which are used for the seismic isolation of the superstructure, and the piers are founded on a semi-infinite soil medium through massless, surface foundations. The span lengths are quite short so that the whole system is vibrating in the same way. Further, the mass m, of the piers is significantly smaller than the mass ma of the tributary bridge deck. Complying also with the concept of seismic isolation design, all the bridge components, other than the isolation bearings that are characterized by elasto-plastic behavior, are assumed to remain elastic during an earthquake event in this paper. The system is excited by a seismic ground motion acting along the transverse axis of the bridge. The possible rotation is the girder is shown in Fig. 2. It should be noted that the scope of this study is limited to the regular bridges [AASHTO, 19831. Bridges with abrupt changes of stiffness or mass distribution are not compatible with the purpose of this paper and so are excluded.

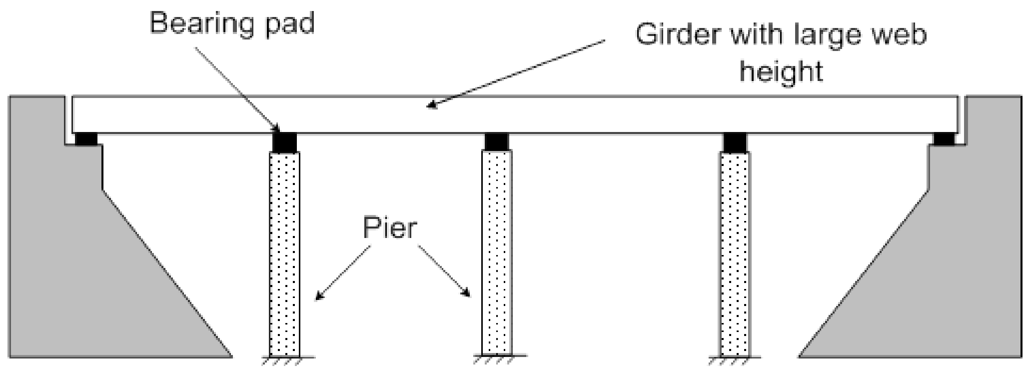

Figure 1. Steel girder bridge with deep web size

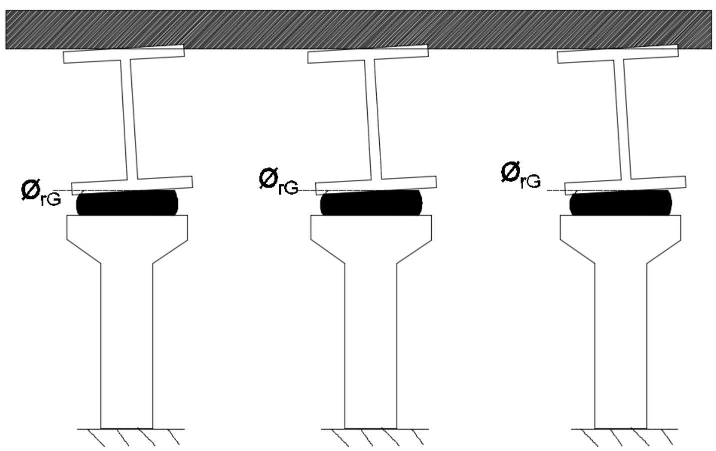

Figure 2. Possible rotation in bearing pad during very strong ground motion

3 PREVIOUS SSI MODEL FOR BRIDGE STRUCTURE

In the past research, rotation of bearing pad was not considered which can reduce the maximum displacement in large girder [4]. This reduction in maximum displacement may cause some problem to bridge engineering in estimating the total girder displacement during very strong ground motion. The previous SSI model for bridge structure and its displacement pattern are shown in Fig. 3 and Fig. 4.

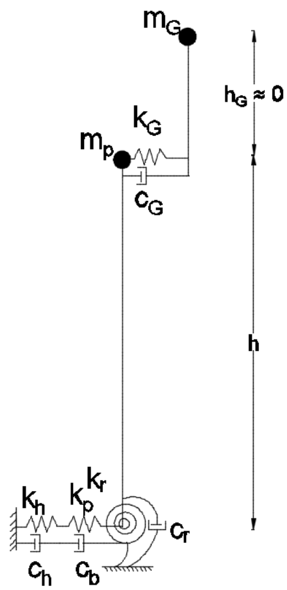

Figure 3. Spyrakos et al. model for SSI

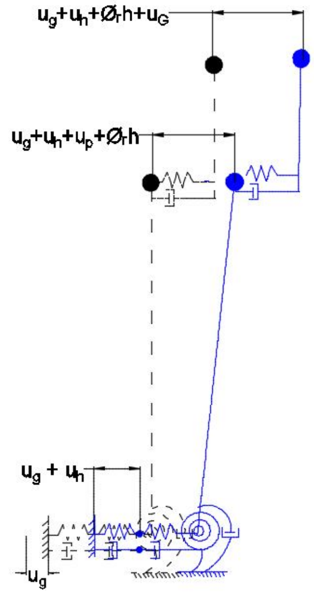

Figure 4. Displacement of Spyrakos et al. model during ground motion

Based on the Fig. 4, the equation of motion can be derived in matrix as Eq. 1.

$$
\begin{bmatrix} m_p & 0 & m_p & m_p h \\ 0 & m_G & m_G & m_G h \\ m_b & m_G & m_p + m_G & m_p h + m_G h \\ m_p h & m_G h & m_p h + m_G h & m_p h^2 + m_G h^2 \end{bmatrix} . \begin{Bmatrix} \ddot{u}_p \\ \ddot{u}_G \\ \ddot{u}_h \\ \ddot{\varphi}_r \end{Bmatrix} + \begin{bmatrix} c_p & -c_p & 0 & 0 \\ -c_p & c_p + c_G & 0 & 0 \\ 0 & 0 & c_h & 0 \\ 0 & 0 & 0 & c_r \end{bmatrix} . \begin{Bmatrix} \dot{u}_p \\ \dot{u}_G \\ \dot{u}_h \\ \dot{\varphi}_r \end{Bmatrix}
$$

$$
+ \begin{bmatrix} k_p & -k_p & 0 & 0 \\ -k_p & k_p + k_G & 0 & 0 \\ 0 & 0 & k_h & 0 \\ 0 & 0 & 0 & k_r \end{bmatrix} . \begin{Bmatrix} u_p \\ u_G \\ u_h \\ \varphi_r \end{Bmatrix} = - \begin{Bmatrix} m_p \\ m_G \\ m_p + m_G \\ m_p h + m_G h \end{Bmatrix} . \ddot{u}_g \qquad (1)
$$

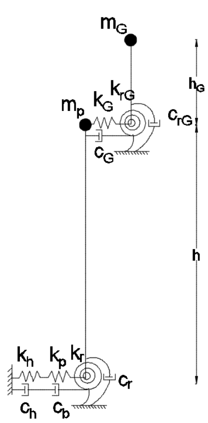

Figure 5. Proposed SSI model large girder bridge

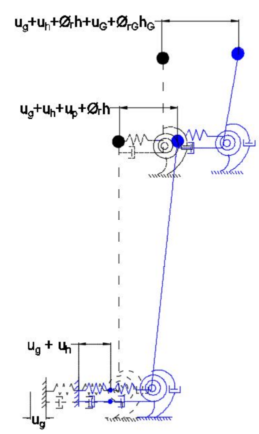

Figure 6. Displacement of proposed SSI model during ground motion

4 PROPOSED SSI MODEL FOR BRIDGE STRUCTURE

In the proposed SSI model for bridge structure, the rotation of bearing pad was taken into account in estimating the total maximum displacement in girder during very strong ground motion. The proposed simplified model of soil-structure interaction for bridge structure is shown in Fig. 5. The displacement behavior of the simplified model is shown in Fig. 6.

The equations of motion were derived based upon the Fig. 6. The equation of motion is reformatted in matrix form shown in Eq. 2.

$$\begin{bmatrix} m_p & m_G & m_p + m_G & m_p h + (h+h_G)m_G & m_G h_G \\ m_p h & (h+h_G)m_G & m_p h + (h+h_G)m_G & m_p h^2 + (h+h_G)^2 m_G & h_G(h+h_G)m_G \\ 0 & m_G & m_G & (h+h_G)m_G & h_G m_G \\ 0 & h_G m_G & h_G m_G & h_G(h+h_G)m_G & h_G{}^2 m_G \\ m_p & 0 & m_p & m_p h & 0 \end{bmatrix} . \begin{Bmatrix} \ddot{u}_p \\ \ddot{u}_G \\ \ddot{u}_h \\ \ddot{\varphi}_r \\ \ddot{\varphi}_{rG} \end{Bmatrix}$$

$$+ \begin{bmatrix} 0 & 0 & c_h & 0 & 0 \\ 0 & 0 & 0 & c_r & 0 \\ -c_p & c_p & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & c_{rG} \\ c_p + c_G & -c_G & 0 & 0 & 0 \end{bmatrix} . \begin{Bmatrix} \dot{u}_p \\ \dot{u}_G \\ \dot{u}_h \\ \dot{\varphi}_r \\ \dot{\varphi}_{rG} \end{Bmatrix} + \begin{bmatrix} 0 & 0 & k_h & 0 & 0 \\ 0 & 0 & 0 & k_r & 0 \\ -k_p & k_p & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & k_{rG} \\ k_p + k_G & -k_G & 0 & 0 & 0 \end{bmatrix} . \begin{Bmatrix} u_p \\ u_G \\ u_h \\ \varphi_r \\ \varphi_{rG} \end{Bmatrix} \qquad (2)$$

$$= - \begin{Bmatrix} m_p + m_G \\ m_p h + (h+h_G)m_G \\ m_G \\ h_G m_G \\ m_p \end{Bmatrix} . \ddot{u}_g$$

5 COMPARISON BETWEEN PROPOSED AND PREVIOUS MODEL

5.1 *Updates in Proposed Model*

Large girder displacement is the major concern during major earthquake ground motion. To define large girder displacement, the rotation in bearing pad was considered into account. The rotation in bearing pad can bring global instability in the whole structure. In this study, deep girder is considered to consider the rotational inertia of the girder.

5.2 *Example Problem*

Considering height of the pier = 15 m; height of the pier = 8 m; pier mass, = 1500000 kg; girder mass, =9071847 kg; pier spring coefficient, =1.4e11 N/m; bearing pad spring coefficient, = 5.0e7 N/m; foundation horizontal spring coefficient, = 4.8e9 N/m; foundation rotational spring coefficient, = 1.3e8 N.m; bearing pad rocking spring coefficient, = 1.3e9 N.m; pier damping coefficient, = 2.2e8 N-s/m; bearing pad damping coefficient, = 5.8e6 N-s/m; foundation horizontal damping coefficient, = 4e6 N-s/m; foundation rotational damping coefficient, = 4.8e6 N-s-m; bearing pad rocking damping coefficient, = 4.8e5. As the maximum structure response is the main concern in this stage of research, response at the structural mass is determined due to earthquake excitations El Centro.

6 RESULTS AND CONCLUSIONS

Based on the finite element analysis in ABAQUS, the responses in girder from simplified SSI model are shown in Fig. 7 to Fig. 9.

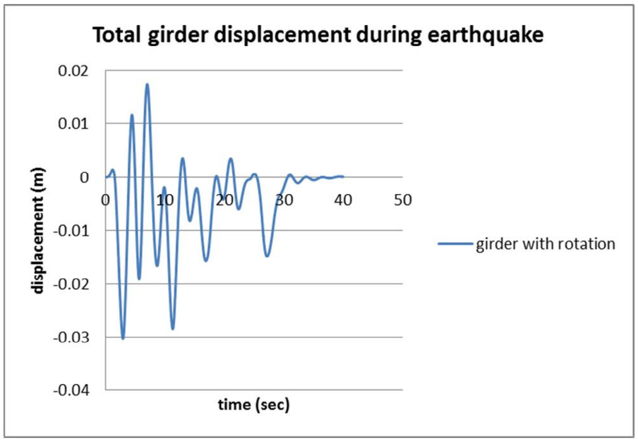

Figure 7. Total girder displacement from ABAQUS

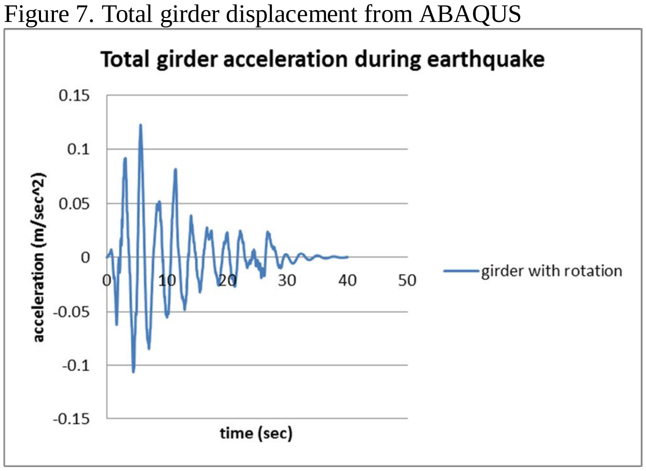

Figure 8. Total girder acceleration from ABAQUS

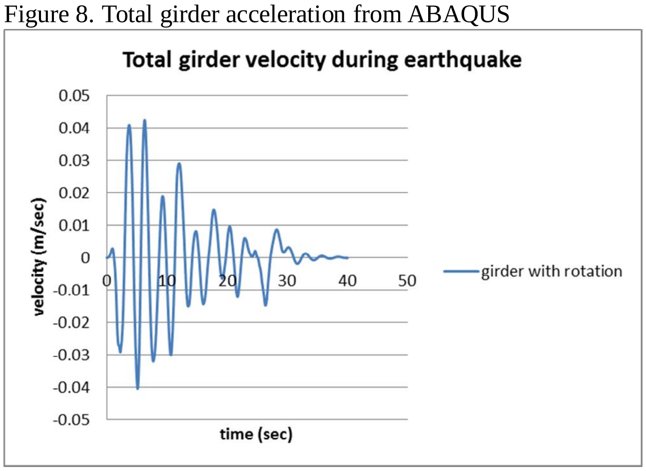

Figure 9. Total girder velocity from ABAQUS

It can be easily seen that the rotation in bearing is an important factor to get large rotation in the super structure.

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