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Response sensitivity analyses of skewed bridges with and without considering soil–structure interaction

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ABSTRACT

The seismic behavior of skewed bridges has not been well studied compared to straight bridges. Skewed bridges have shown extensive damage, especially due to deck rotation, shear-key failure, abutment unseating, and column-bent drift. This study, therefore, aims to study the behavior of skewed and straight highway overpass bridges both with and without taking into account the effects of Soil–Structure Interaction (SSI) due to near-fault ground motions. A set of nonlinear dynamic analyses was carried out using an intense pulse-like ground motion with two orthogonal components. The effect of the abutment skew angle on various demands was assessed. It was found that most of the demands were very sensitive when there was an increase in the skew angle. Deck rotation showed a higher sensitivity to the increase in skew angle; therefore, it postulated an increasing trend with respect to the increase in the skew angle. Adding SSI elements imposed a decreasing effect on various demands. Furthermore, various sensitivity analyses were carried out with respect to the change in site properties and skew angle and their effects on various demands were investigated. It was concluded that considering a performance-based approach, in which a higher number of ground motions is utilized, would be more useful to capture the sensitivity of various bridge responses with respect to change in different parameters. This would also provide a better intuition regarding any specific trend specifically with respect to the effect of change in skew angle on various demands for different site classes.

1. Introduction

Skewed bridges have been found to respond more severely to earthquakes than straight ones. This type of behavior is due to a number of different reasons such as site condition, construction era, ground motion characteristics, and perhaps most importantly bridge configuration [8]. Damage to skewed bridges is due to different demands such as column drift, abutment unseating, shear-key failure, deck rotation, and bearing pads deformation [10]. Several instances of damage to various components of skewed bridges have been reported in past earthquakes. For instance, Painter Street Overcrossing [7] underwent a significant deck rotation about its vertical axis perpendicular to the traffic line during the main shock of the 1992 Cape Mendocino/Petrolia earthquake. Meng and Lui [14] reported severe damage to intermediate piers of the Foothill Boulevard Undercrossing after the 1971 San Fernando earthquake. Failure of the Gavin Canyon Undercrossing in the 1994 Northridge earthquake was reported due to abutment unseating in which the relative displacement of the deck with respect to abutment exceeded the seating length [8]. Shear-key failure was reported in the 2010 Chile earthquake (Kawashima et al. and [20]). This might have been due to deck rotation causing the deck to undergo excessive transverse displacement, which imposed extra pressure on the shear keys. Several instances of damage to various bridge components have also been reported in the 2008 China earthquake [16].

For these reasons, it is vital to assess the seismic behavior of skewed bridges to detect their weaknesses and come up with enhanced design criteria. There has been a wealth of research on skewed bridges. Shamsabadi et al. [17] studied the seismic behavior of skewed bridges considering soil–abutment–foundation interaction subjected to near-fault ground motions. They first simulated the bridge abutment in PLAXIS to study the behavior of the backfill behind the abutment backwall. They derived the force–deformation relationship for the backfill in order to use that to determine the prosperities of the abutment nonlinear springs in their bridge model. They found that skewed bridges are very susceptible to deck rotation and deck rotation is sensitive to the skew angle. Apirakvorapinit et al. [1] performed a number of time-history and pushover analyses to capture the behavior of the superstructure of skewed bridges using the Northridge ground motion. Their study showed an increase in critical stresses due to the increase of skew angle. Zakeri et al. [21] studied the seismic behavior of skewed bridges using a probabilistic approach. Hence, they studied the effect of skew angle on bridge fragility for bridges with single- and two-column bents and integral or seat-type abutments. They found that older bridges are not as

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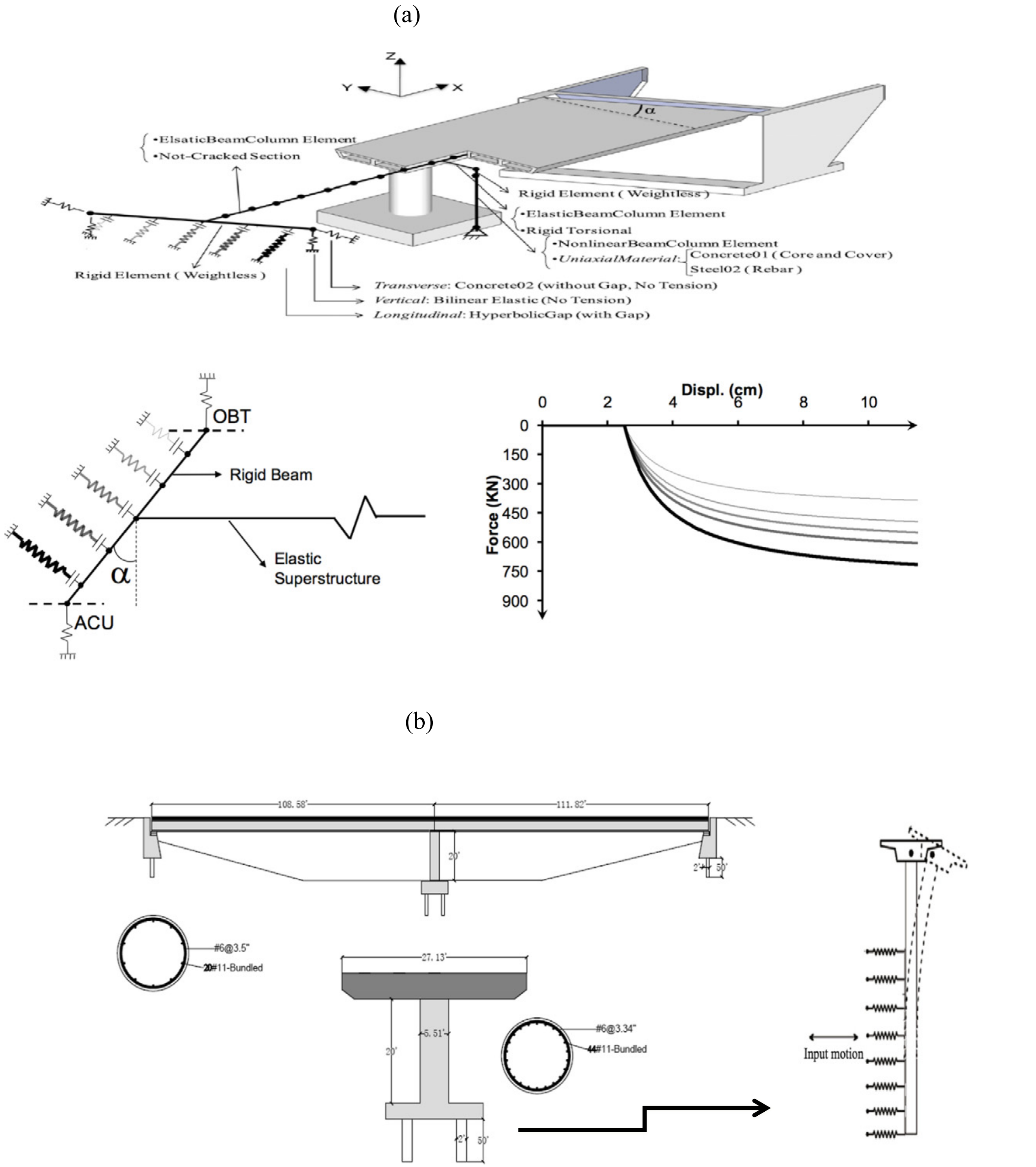

Fig. 1. (a) Bridge analytical model including the abutment properties (after [9]). (b) Bridge configuration including the column cross section (next to the column) and pile cross section (underneath the left abutment's pile) (after [23–25] and [26]) (figures not to scale).

susceptible to skew angle. They also found that the presence of integral abutments in newer bridges decreases the impact of skew angle on the bridge fragility.

Furthermore, Meng and Lui [14] studied the seismic response of a skewed concrete box girder bridge. They considered the effects of superstructure flexibility, boundary conditions, structural skewness, and stiffness eccentricity on the behavior of the bridge using spectral analysis. Their study showed the bridge was susceptible to the variations of skew angle. Dimitrakopoulos [6] studied the seismic response of short skewed bridges with deck-abutment pounding. He showed that the tendency of skewed bridges to rotate and undergo transverse displacements, after the deck was pounded into the abutment was not only the function of skew angle, but also depends on the plane geometry and friction. Maleki [15] compared the seismic response of skewed and straight bridges with and without considering the gap for the bearing pad retainers. The stiffness of end diaphragms and elastomeric bearings were included in the model. His study showed a significant amount of nonlinearity in the dynamic response of the bridge.

In the present research, it is aimed to consider the entire bridge system once assuming the bridge without pile foundations as a fixed base