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Effects of the earthquake-induced pounding upon pier motions in the multi-span simply supported steel girder bridge

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ABSTRACT

The earthquake-induced pounding effects on bridge piers are investigated by analyzing dynamic responses of a three-span simply supported steel girder bridge. Using a simplified and idealized analytical model reflecting random characteristics of seismic excitations, maximum pier responses are evaluated. The nonlinear behaviors of reinforced concrete piers and pounding between adjacent bridge decks are included in the analytical model by utilizing a nonlinear hysteresis model and an impact element (a linear viscoelastic model), respectively. From the results of time history analysis, it is found that pounding between adjacent vibration units reduces the pier forces and displacements by restricting the pier motions. As the peak ground acceleration increases, the results of the case without consideration of pounding shows the impractically large pier displacements in the hysteresis model by ignoring restriction of pier motions due to pounding. The results according to the gap distance between impact elements show that the size of gap distance is heavily correlated to the nonlinear pier behaviors. Therefore, the effects of pounding and nonlinear pier behaviors should be considered together to reflect the bridge responses correctly.

1. Introduction

Surveys of past major earthquakes have revealed that the extensive damage due to the earthquake-induced pounding occurs and the pounding is one of the major reasons causing the collapse of buildings and bridges. For example, in the 1985 Mexico City earthquake, the pounding was observed in the damaged structures of 40% and about 15% of them collapsed due to the pounding [1]. In the 1989 Loma Prieta earthquake, extensive damages and collapses of buildings due to poundings were founded [2]. In 1994 Northridge earthquake and 1995 Kobe earthquake, significant damage and span collapse of bridges due to pounding were reported [3–5]. Moreover, it should be noted that the damage due to pounding is continuously reported in recent earthquakes [6].

Pounding is the impact occurring between adjacent structures when the relative displacement of adjacent structures exceeds the separate distance (gap) due to their out-of-phase movements. The principle reason of occurring pounding is the difference in the natural frequencies of the adjacent structures. Spatial seismic effects and soil–structure interaction (SSI) are also participating in causing poundings [7,8].

In order to reduce the damage of structures under seismic excitations, many researchers have paid attention to pounding-mitigation methods. Obviously, the best solution is to provide sufficient distance between adjacent vibrating structures. In buildings, many seismic codes recommend the minimum distance to prevent pounding based on results of various researches [9,10]. However, in case of bridges, it is studied in a different way since giving sufficient distance to mitigate pounding involves another problem. As the distance between adjacent bridge decks or between an abutment and a bridge deck is increased, the size of expansion joints grows bigger, which disturbs the vehicle moving and increases the pier size in a longitudinal direction. Pounding becomes an inevitable phenomenon for bridges with typical expansion joints and researchers have focused on preventing span collapses through analyzing seismic responses of bridges considering pounding. Representative studies to prevent span collapse of bridges are for restrainers connecting the adjacent bridge decks [11–17].

It is difficult to simulate pounding phenomenon exactly owing to its geometric and material complexity. Pounding process involves the plastic deformation at contact surfaces and local

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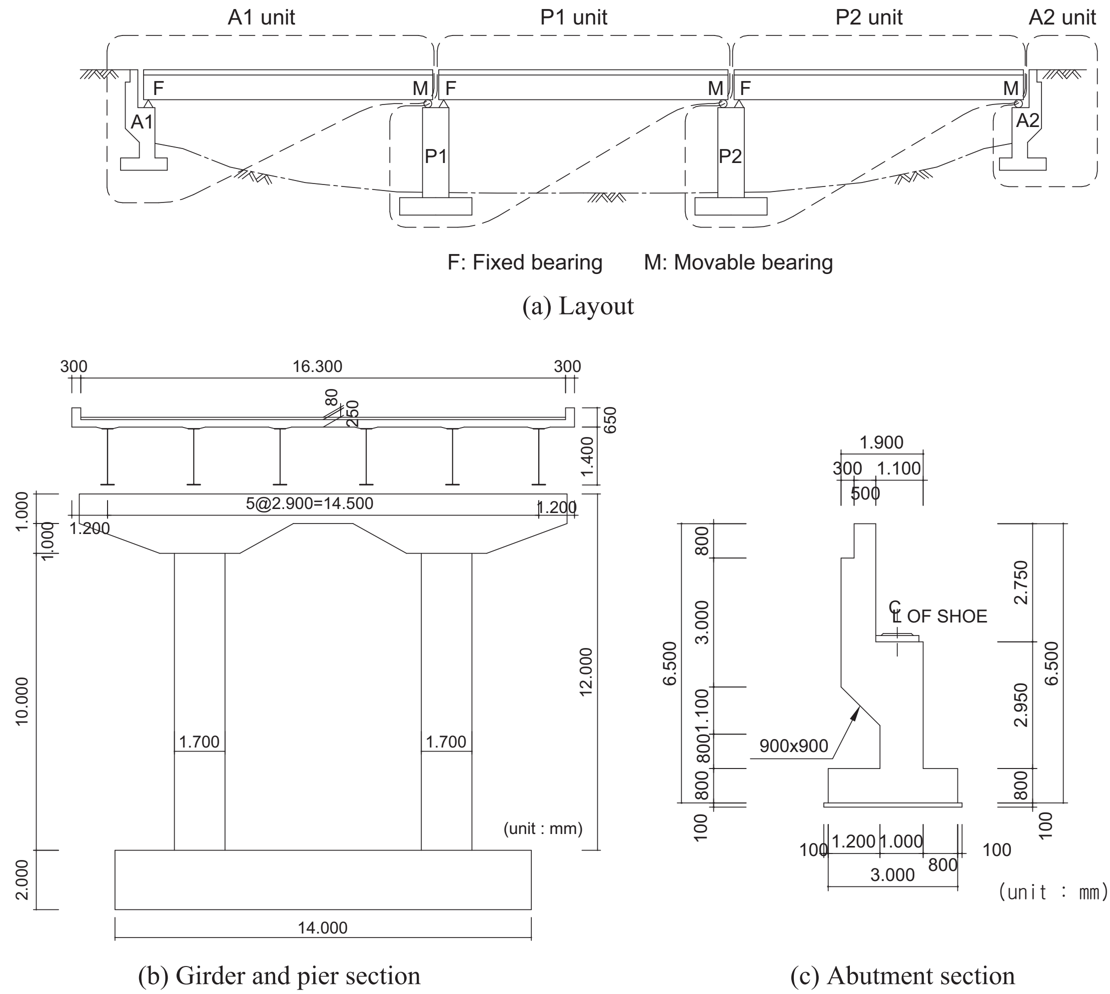

Fig. 1. Example bridge.

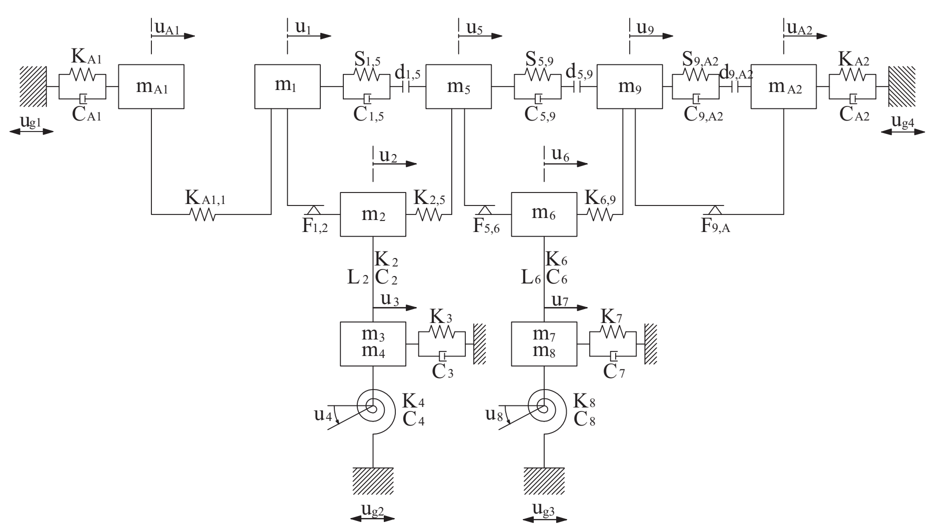

Fig. 2. Simplified mechanical model of an example bridge.

cracking or crushing due to impact. Moreover, impact forces are applied and removed during a short time and the process of energy transfer is highly complicated [18]. Even though a precise simulation of pounding is difficult, various researches have been analytically studied based on two techniques. One is a stereo mechanical approach and the other is force-based approach. The stereo mechanical approach uses the principle of momentum conservation and the coefficient of restitution to modify the velocities of colliding structures after impact. The forced-based approach utilizes contact elements consisting of a spring and a damper, which