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Bumpers for reducing the effect of pounding between bridge decks

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The study addresses the influence of bumpers as reduction measures at the bridge decks. The considered devices are steel spring, steel spring with additional viscous damper or steel spring with additional friction element. Gap between bridge decks remains. The reduction measure is placed at one end of the neighbouring girders. The considered earthquakes are the 1994 Northridge earthquake and the 1995 Kobe earthquake. For the nonlinear analysis a finite element method is used. The investigation shows that compared to the other measures the best reduction of the pounding force can be achieved with a friction device.

Key words: reduction measure, earthquake response, bridge girder, pounding, viscous damping, friction device

1 INTRODUCTION

Bridge damages during strong earthquakes can be caused by pounding between the girders when the gap is not sufficient. The larger the relative displacements between the neighbouring bridge decks, the stronger the damage can be. Pounding damage of a bridge can have severe consequences as it has been observed in many major earthquakes, such as the 1994 Northridge earthquake (Hall 1994), the 1995 Kobe earthquake (Park et al. (1995), and the 1999 Chi-Chi earthquake (Hamada et al. (1999)). Since bridges belong to one of the important lifeline systems, their proper function is significant, especially after the earthquake for the rescue work and for a quick earthquake recovery. Therefore it is significant that bridges should survive strong earthquakes without severe damages.

In the past many investigations on pounding between adjacent bridge girders have been performed. Most of the works focus on how to determine the appropriate separation distance for avoiding the pounding (e.g. Jeng and Tzeng 2000) and how to mitigate the pounding effect by using possible reduction measure (Goerguelue 2003). Since the distance between the neighbouring bridge piers can be large, the ground motions at two different locations may not the same, especially when the ground is soft. Investigations on the influence of the spatially non-uniform ground excitation in relation to the dynamic characteristics of the bridge are performed for a better understanding of the relationship between the near-source ground motion characteristics and pounding behavior of the bridge girders (Chouw and Hao 2003)).

In order to reduce the influence of poundings on the girder damage potential, bumpers consisting of a steel spring, a steel spring with additional viscous damper, and a steel spring with additional friction element are considered in this study. The bumper is installed at one end of the bridge girder. Gap between the adjacent girders remains. This means the reduction devices can only be activated when poundings take place. In order to study one of the characteristics of near-source earthquakes, ground motions with long-period pulses are considered. For modeling the bridge structure and the reduction devices a finite element method is used.

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2 POUNDING ANALYSIS

2.1 CONSIDERED SYSTEM

Each of the adjacent multiple-pier bridge frames in Fig.1 is simplified as a Single-Degree-of-Freedom (SDOF) system indicated in Fig. 2. The material data are given in Table 1. It is assumed that the bridge structure is fixed at its base. No soil-structure interaction is taken into account in this investigation. It is also assumed that both bridge frames experience the same ground excitation $a_g(t)$.

In the numerical model the reduction measure can comprise of elastic steel spring, a gap, a friction device and viscous damper. If the initial gap, damping constant and one of the stiffness of the springs are zero, the device have both tension and compression capability. If the gap is not zero initially, the device responds as follow: when the spring force is negative (compression), the gap remains closed and the device behaves like a spring. If the spring force becomes positive (tension), the gap opens and no force is transmitted. The friction device consists of a friction element and a spring, if the activated force is larger than the pre-defined friction force, the friction device will slide, and the friction element dissipates the energy at the sliding surface. In Fig. 2 all considered reduction devices are shown together. They are attached at the girder of the left bridge frame. If the device has only a spring, impact force is determined by Hertz Impact Rule:

$$F = k\,u_{rel}, \tag{1}$$

where F is the pounding force, k is the spring stiffness, u_{rel} is the relative displacement of the structures.

In order to investigate the frequency ratio of the adjacent bridge frames, three models are considered.

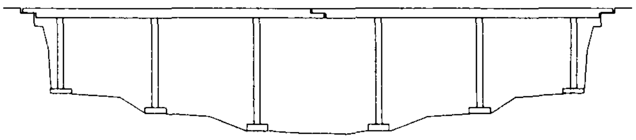

Fig. 1. Multiple-pier bridge model

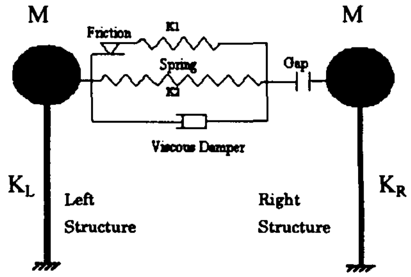

Fig. 2. Two SDOF model

While the fundamental frequency of the left bridge frame is kept at 1Hz, the right bridge frame can have the frequency of 0.7Hz, 0.8Hz, and 0.9Hz (see Table 1). For each model three cases are considered: the case with steel spring, the case with steel spring and viscous damper, and the case with steel spring and friction damper as bumper. The influence of pounding and separation of the adjacent bridge girders is considered iteratively by using the Newtow-Raphson algorithm (Cook et al. (2002)).

2.2 GROUND MOTIONS

The considered ground motions are the acceleration of the 1994 Northridge earthquake and the 1995 Kobe earthquake. Figs. 3(a) and (c) show the selected Northridge earthquake at the Sylmar station and Kobe earthquake at Japan Meteorological Agency (JMA) station. Their corresponding response spectrum with a damping ratio of 5% is displayed in Figs.3 (b) and (d), respectively.

Table.1 Properties of SDOF Model

Model	Mass (t)	Stiffness (kN/m)		Natural frequency (Hz)	
		Left	Right	Left	Right
1	1377	54382	26650	1	0.7
2			34800		0.8
3			44000		0.9

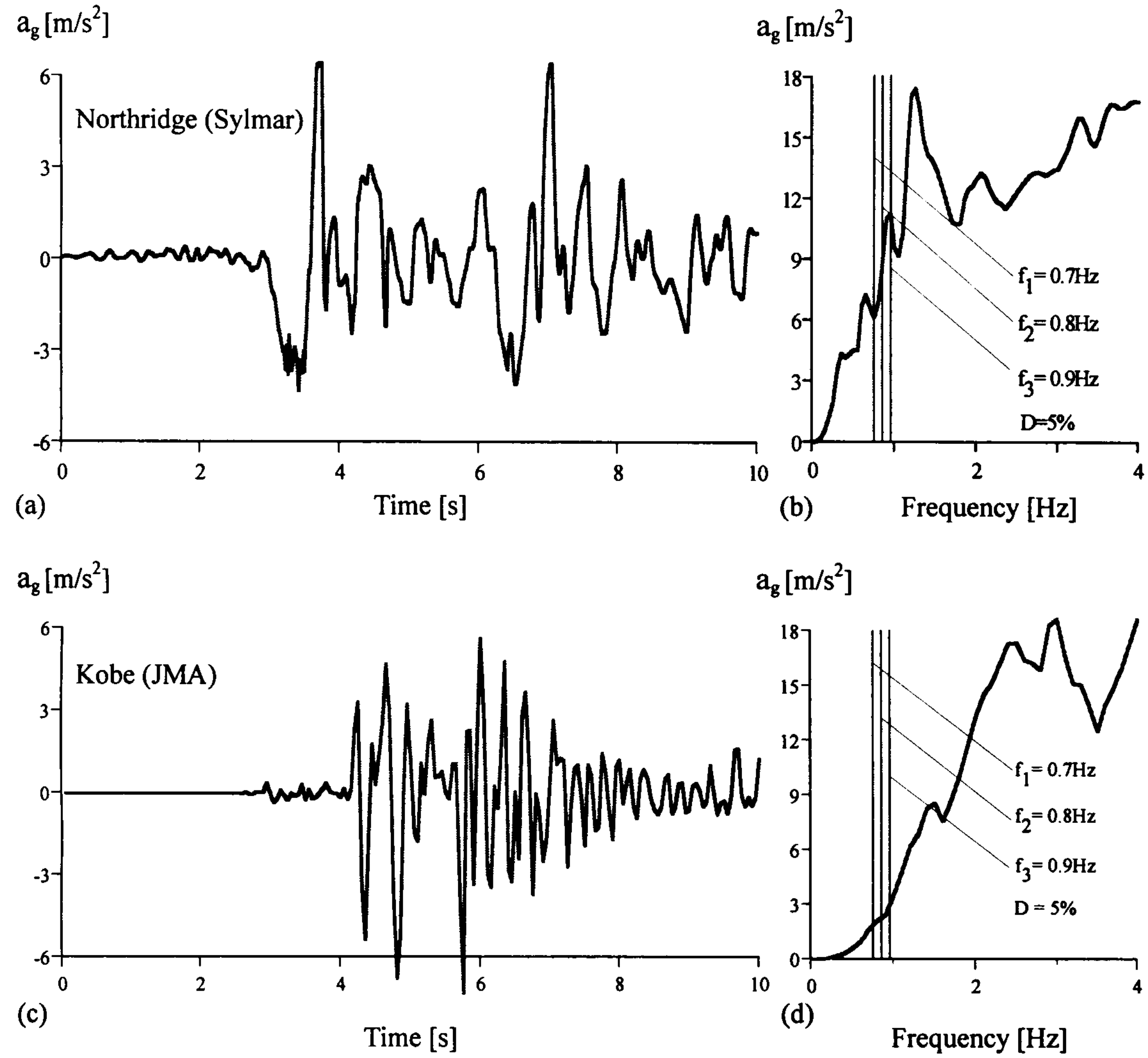

Fig. 3 (a)-(d). Ground motions, (a) Northridge earthquake at Sylmar station, (c) Kobe earthquake at station JMA, (b) and (d) corresponding response spectrum with a damping ration of 5%.

Table. 2 Parameters of the considered cases and pounding response

Case	Mode 1	Gap (m)	Spring stiffness (kN/m)	Damping constant (kNs/m)	Friction Force (kN)	Response Reduction (%)	Ground motion
1	1	0.2	1372131	0	0	--	Kobe (JMA)
2				864.756	0	17.57	
3				0	10000	17.49	
4	2	0.3		0	0	--	Northridge (Sylmar)
5				864.756	0	0	
6				0	10000	24.36	
7	3	0.4		0	0	--	Kobe (JMA)
8				864.756	0	2.9	
9				0	10000	36.06	

The damping constant corresponds to a damping ratio of 5% of the left structure. The magnitude of the stiffness of the friction device is 1000MN/m, and the pre-defined friction force is 10MN. This means when the lateral displacement of the spring of the friction device is larger than the 0.01m, the friction device starts to slide, and the pounding force will be reduced.

3 NUMERICAL RESULTS

3. 1 SEPARATION DISTANCE AND EFFECT OF STEEL SPRING AS BUMPER

Figs. 4(a), 5(a) and 6(a) show the displacement time history U(t) of the both left and right structure due to JMA ground excitation in the case 1, 4 and 7. The results clearly show that poundings cannot be prevented if the gap size between left and right structure is less than 0.4m. Since the purpose of this study is not to investigate the minimum separation distance between the adjacent structures, but the effect of bumper on the reduction of pounding forces, the size of the gap is assumed.

Figs. 4(b) and 6(b) show the pounding force time history F(t) of the SDOF model due to JMA ground excitation. The results show that if the gap size between left and right structure is small, the pounding causes a large response as a comparison between the case 1 and the case 7 shows. In Table 2 in the case 1, 4 and 7 with only steel spring as bumper the activated maximum pounding force is 77496kN, 77101kN and 47537kN, respectively. They are used as a reference for the case 2 and 3, the case 4 and 5, as well as the case 8 and 9 correspondingly. As the gap size become smaller, larger pounding force can be expected, therefore the possibility of damage of bridge decks becomes high. In the design, if it is possible, a small gap should be avoided.

3. 2 EFFECT OF STEEL SPRING AND VISCOUS DAMPER AS BUMPER

In Table 2 for each case the response reduction (%) is

$$\frac{F_p - F_b}{F_p} . 100, \qquad (2)$$

where F_p is the maximum pounding force in the case of steel spring alone used as the reference case, and F_b is the maximum pounding force in the case with additional viscous damper or friction device.

Figs. 4(c) and (d) show the displacement time history U(t) and the pounding force time history F(t) in the case 2 due to JMA ground excitation. The results show that compared to the result with steel spring alone as bumper the maximum pounding force decreases. The reduction ratio is 17.57%. In this case the viscous damper can be used to reduce the effect of pounding. As we see from Table. 2 in the case 5 the viscous damper cannot contribute to mitigate the pounding due to the Sylmar ground excitation. The response spectrum value in the range of the considered system at 0.7 Hz to 0.9Hz in Fig. 3 increases. The case 5 represents the case in the middle of the considered range. The result shows that steel spring and viscous damper is not the best solution. The reason is that the bumper effect will be activated

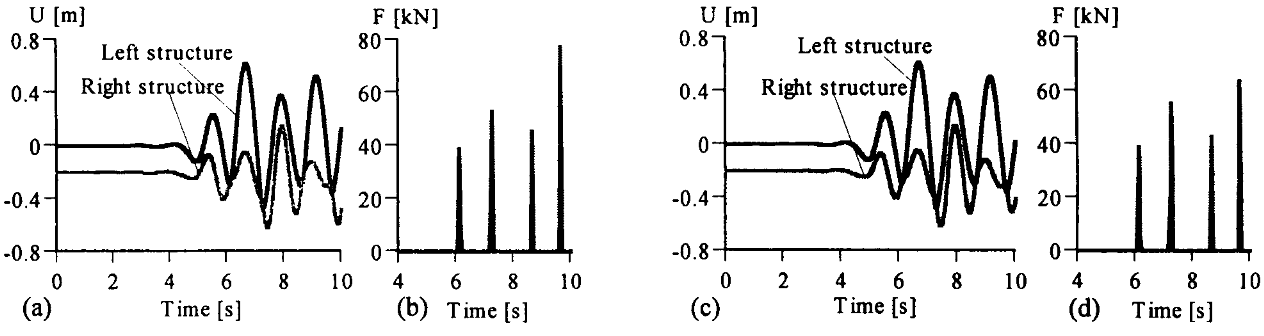

Fig. 4. Displacement time history and pounding force time history of the model 1 for gap size is 0.2 m due to JMA excitation, (a), (b) with spring alone, and (c), (d) with additional viscous damper

when pounding occurs, and its effect lasts only when contact between the adjacent girders exists. In general this period is very short. Since the bumper does not vibrate long enough, viscous damper cannot be activated properly.

3.3 EFFECT OF STEEL SPRING AND FRICTION DEVICE AS BUMPER

Figs. 5(c) and (d) show the displacement time history U(t) and pounding force time history F(t) in the case 6 due to Sylmar ground excitation. Figs. 6(c) and (d) show the displacement time history U(t) and pounding force time history F(t) in the case 9 due to JMA ground excitation. The results show that the friction device can reduce the pounding force, and the friction device works in different earthquakes. It does not depend on the frequency content of ground excitation. As we can also see from Table.2, the reduction ratio is high in the case 3, 6 and 9, which indicates that the reduction can be achieved using friction device.

4 CONCLUSIONS

The investigation reveals:

In order to reduce the pounding effect an adequate gap size is necessary. However, it is difficult to provide this necessary practically.

Steel spring together with viscous damper can be used to reduce pounding effects. However, this device is sensitive to the ground motions. In some cases it is not effective.

Friction device is more effective compare to viscous damper. It is also less sensitive to different ground excitation.

Bumper is not the best solution for reducing the effect of pounding between bridge girders. Even though the immediate damage might be avoided, the activated pounding force cannot be reduced significantly. Further investigations are necessary.

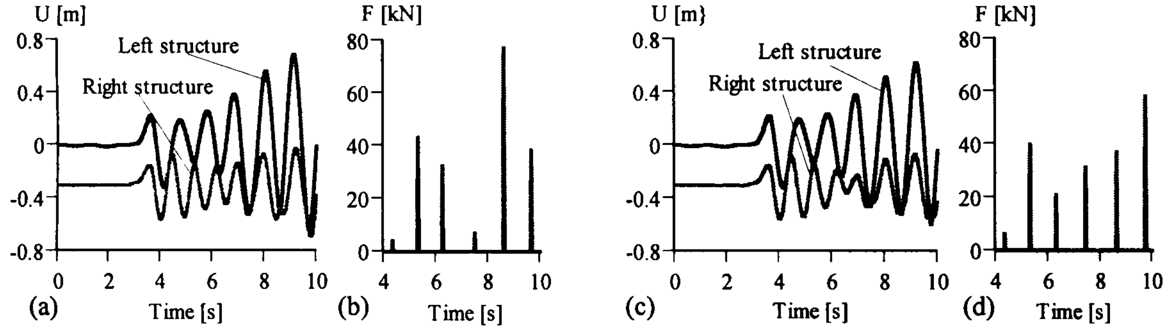

Fig. 5 Displacement time history and pounding force time history of the model 2 for gap size is 0.3 m due to Sylmar excitation, (a), (b) with spring alone, and (c), (d) with an additional friction device.

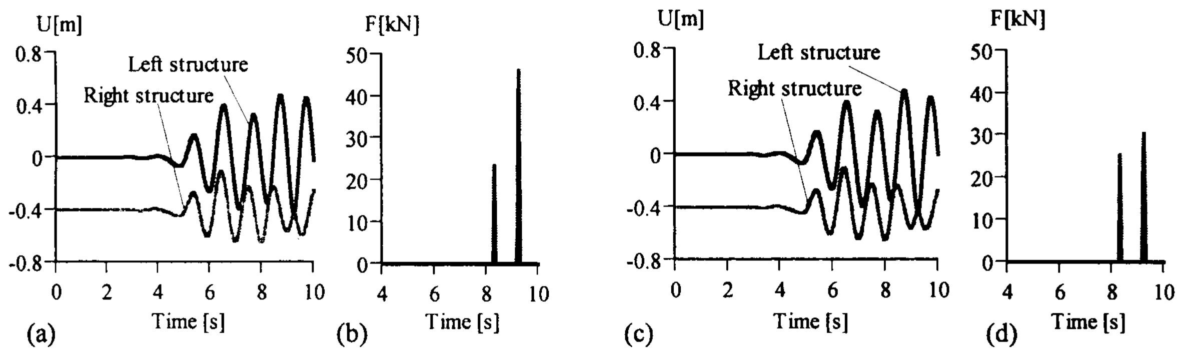

Fig. 6 Displacement time history and pounding force time history of the model 3 for gap size is 0.4 m due to JMA excitation, (a), (b) with spring alone, and (c), (d) with an additional friction device.

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