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Seismic Pounding of Bridges due to Multi-Support Excitation with traveling wave

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Abstract: - Among structural damages, seismic induced pounding has been commonly observed in severalearthquakes. When lateral and transverse movement of a structure occurs during earthquakes, it will hit adjacent structure and bounce back. This back and forth hitting of adjacent structures is known as pounding. The earthquake ground motion is usually assumed as uniform dynamic motion in seismic analysis. This assumption may be inadequate for structures placed at large areas like bridge, dam etc. Pounding in bridges is a result of the relative movement of the adjacent bridge superstructures at the expansion joints. This movement depends on different structural dynamic properties of the adjacent spans and characteristics of ground motions at the pier supports along the bridge. This paper includes a study of effect of pounding between bridge superstructures under the action of earthquake motion having multi-support excitation with traveling effect. The present study is a numerical investigation of pounding effect on a simply supported bridge using finite element method, using the software, OpenSees.

I.　　　INTRODUCTION

　　　Pounding is a damage phenomenon resulting from seismic collision in adjacent structures.Generally, for seismic analysis the earthquake ground motion is assumed as uniform dynamic motion. But for structures placed at large areas, this assumption will not be accurate. Past studies shows that major bridge failures are due to the pounding between superstructures. During Northridge earthquake in 1994, severe collision damage happened in many piers and expansion joints of No.5 intercontinental highway bridge[1]. During the Kobe earthquake in 1995, the collision in bridge made the bearing failure and girder falling. During the Chinese Wenchuan earthquake on12th May 2008, the stoppers in Miao Ziping Bridge were broken, which resulted from longitudinal and transverse movement and collision and resulted into falling of one span approaching bridge[1].

　　　Pounding is a very complicated phenomenon, involves plastic deformations in the materials at the location of pounding, energy dissipation during contact etc[2]. For long Multiplan simply supported bridges the spatial variation acting at the support should be considered since it can induce pounding effect and deck unseating[3]. Recent researches show that these type of bridge structures experiences pounding phenomena between adjacent structural segments ie, between neighboring decks or cap beams and decks with a component of impact force transferred to the piers. This may lead to differential movement between adjacent spans[4]. For such type of bridges to get acceptable approximation we need complex numerical models.

　　　In order to study the pounding effect, many researchers have considered uniform dynamic input for seismic analysis. But the past earthquake studies shows that for long structures like bridges and dams, the assumption of uniform wave excitation is inadequate[5,6]. To get the structural responses including collision by mathematical models, many mathematical models were proposed by foreign researchers. There are two methods to study collision, collision dynamics method and contact element method. Collision dynamics method uses analytical solution technique, so it is difficult for finite element simulation. Contact element method uses numerical solution technique, so easy for finite element formulation. So far, there are four collision element models are developed. (1) The initial model, the relationship between collision force and deformation is

expressed by linear springs, but does not take into account both change of collision and loss of energy.(2) Hertz contact model, in which the relationship is expressed by nonlinear springs. (3) Kelvin model, a linear spring with a damper is used for the relationship between collision force and deformation. (4) Hertz Damper model, a nonlinear relationship between force and deformation including the loss of energy consideration. Some researchers found that the Hertz Damper model is the best one for collision elements[7]. MengQingli developed the 3D contact friction collision model based on open source software OpenSees, furthermore which was realized and validated by numerical simulations of two examples. This collision model can be used on the numerical simulation of seismic collision of building and bridge structures.

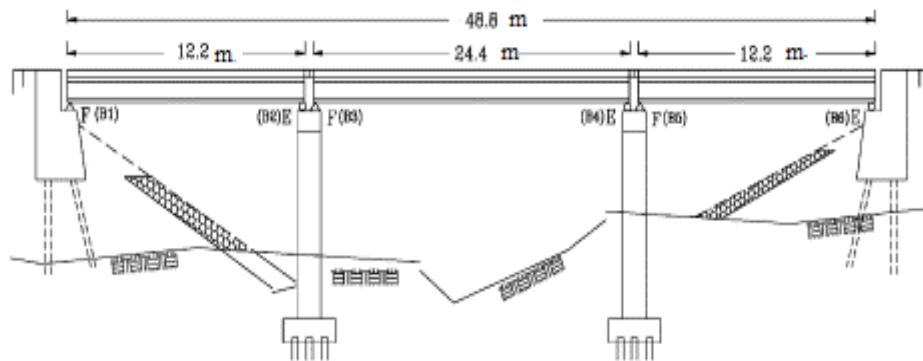## II.   THE ANALYSIS STRUCTURE

Fig. 1 The three span simply supported bridge

The open source software OpenSees is used to model and analyse a simply supported bridge in this paper. As shown in Fig. 1, the structure is a reinforced concrete simply supported bridge having overall length 48.8m and width 8.15m. It has 3 spans in which the two end spans of length n12.2m and mid span of length 24.4m. The piers of the bridge are columns of diameter 900mm. There are 4 expansion joints over the bridge, two of them are steel expansion joints SSFB240, which located on the top of piers of intermediate spans and their width is 17cm. The other two are SSFB80, 10cm wide and lie in abutments.

The finite element model of the bridge is created with open source software OpenSees. While modeling, 3D contact friction pounding elements were used in each expansion joint in left and right side in longitudinal direction. The longitudinal stiffness and damping of the collision element were K= 3.92x108 N/m and Cn = 1.07x107Ns/m, and transverse damping was Ct = 1.07x105Ns/m. The friction coefficient between concrete materials was selected as 0.5.Table 1 shows the first three natural periods of the bridge.

Table 1 The first three natural periods of the bridge

No.	Longitudinal Direction	Transverse Direction
1	0.6	1.2
2	1.1	2.0
3	1.5	2.4

III.   DETERMINATION OF INPUT EARTHQUAKE MOTION

In the numerical simulation of seismic pounding effect on bridges one typical input ground motion isconsidered: Parkfield wave, whose predominant period is larger and closer to the natural period of the bridge. The uniform wave excitation and multi-support excitation with travelling effect were considered for the case. The characteristic of the earthquake wave is listed in Table 2.

Table 2 The main characteristics of the selected earthquake acceleration motion

Earthquake Motion	Direction	Amplitude	Predominant Period(s)
Park Field wave	E-W	216.5	0.533
	N-S	239.2	0.263
	V	90.0	0.320

IV.   SEISMIC POUNDING EFFECT ANALYSIS OF THE BRIDGE

For the study of seismic pounding effect on the bridge, the analysis was carried out under uniform seismic excitations and multi-support excitation with travelling effect. Throughout the paper "Uniform" denotes uniform seismic excitations and "Traveling" denotes multi-support excitation with travelling effect.

V.   CONTACT FRICTION POUNDING RESPONSE

Table 3 shows the number of pounding at different locations of the bridge under uniform and travelling waves. By comparing the pounding number we can see that numberof pounding is smaller under travelling effect, and intermediate supports.

Table 3 The number of Pounding

LOCATION	Left abutment		Left inte.pier		Right inte.pier		Right abutment	
	Left	Right	Left	Right	Left	Right	Left	Right
Uniform	5	5	6	6	6	7	3	2
Traveling	2	4	2	3	5	6	3	2

From Table 4 it is clear that, the pounding force is more for travelling effect as compared touniform excitation. At middle spans, the pounding force is more like number of pounding, whichshows that the intermediate supports are the peak pounding points.

Table 4 Peak pounding force (x 10^7 N)

LOCATION	Left abutment		Left inte.pier		Right inte.pier		Right abutment	
	Left	Right	Left	Right	Left	Right	Left	Right
Uniform	0.60(6)	0.23(5s)	0.57(6)	0.63(6s)	1.10(5)	1.05(5)	1.11(8)	0.92(4s)
Traveling	0.80(6)	0.70(12s)	0.62(6s)	0.73(11s)	1.50(6s)	1.15(6s)	1.60(9s)	1.40(4.5s)

VI.   DECK BEAM RESPONSE

When we compare the axial forces under different conditions listed in Table 5 we can see that, the axial force is more for earthquake wave with travelling effect like pounding force. That is larger pounding force will result in larger axial force in beams. But the axial force is more in end spans compared to the middle span.

Table 5 Peak axial force in deck beams (x10^7N)

LOCATION	Left Abutment	Middle Span	Right Abutment
Uniform	1.98	0.35	2.05
Traveling	2.36	0.75	2.40

VII.   THE BEARING DISTORTION

Table 6 shows that for all cases, distortion of bearing is more at interior piers, so it is clear that the intermediatesupports are the main pounding positions.

Table 6 The peak distortion of bearings

Direction	Longitudinal				Transverse			
Location	Left Abutment	Left int. Pier	Right int.	Right abutment	Left Abutment	Left int.	Right int.	Right abutment
Uniform	0.19	0.25	0.27	0.13	0.02	0.03	0.04	0.03
Travelling	0.17	0.24	0.26	0.14	0.03	0.04	0.06	0.04

VIII.   DRIFT OF PIER

From the numerical study, it is observed that for travelling wave effect, the longitudinal and transverse drift of approach span piers is larger. Longitudinal drift of middle span piers become smaller and its transverse drift become larger. In Table 7 the drift of piers at different locations are listed.

Table 7 Drift of Piers (m)

Direction	Longitudinal Drift				Transverse Drift			
PIER NO.	1	2	3	4	1	2	3	4
Uniform	0.42	0.41	0.40	0.45	0.14	0.12	0.12	0.15
Travelling	0.52	0.41	0.42	0.50	0.18	0.13	0.13	0.18

IX.   BENDING MOMENT OF PIERS

From Table 8 and Table 9, it is clear that for travelling effect, the longitudinal bending moment of the pier of approach span is larger & for interior piers, the longitudinal moment is smaller for travelling wave. But the transverse moment for all piers is larger for travelling wave effect.

Table 8 Maximum bending moment in longitudinal direction (kNm)

LOCATION	PIER BOTTOM				PIER TOP			
PIER NO.	1	2	3	4	1	2	3	4
Uniform	19.90	112.03	110.40	20.271	36.67	164.30	165.23	35.11
Travelling	21.30	115.11	113.20	22.12	38.00	168.25	168.14	36.32

Table 9 Maximum bending moments in transverse direction (kNm)

LOCATION	PIER BOTTOM				PIER TOP			
PIER NO.	1	2	3	4	1	2	3	4
Uniform	13.45	82.41	83.24	14.00	10.14	50.28	51.23	12.32
Travelling	15.14	85.66	86.58	15.32	12.65	53.22	55.25	14.22

X.   CONCLUSION

The comparison between under uniform excitation or under multi-support excitation with travelling effect shows that, the number of pounding is less when considering travelling wave effect but the pounding force at pounding locations are larger. Also, the axial force under travelling wave effect is more. The approach span's response is changing more compared to the main span's response under travelling wave effect. Under travelling wave effect the drift and bending moment of approach span found to be more.

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