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PARAMETRIC STUDY OF A 3D POUNDING MODEL FOR SEISMIC ANALYSIS ON ELEVATED BRIDGES

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Abstract

This paper studies parameters employed in a 3D pounding model which has been developed for seismic analysis on elevated bridges. To verify this 3D model of pounding, parameters, such as restitution coefficients, friction coefficients and stiffness of contact springs, were obtained from experiments and estimated equations. A real elevated bridge, however, is much more complicated and therefore it is not easy to estimate the values of these parameters. Upon reviewing this 3D model of pounding, this paper changes the range of the parameters and studies how much these parameters affect the seismic response of elevated bridges.

1. Introduction

To precisely simulate the seismic response of elevated bridges including pounding between bridge girders/decks, the authors developed a 3D model of pounding which can be applied with common used numerical analysis methods. Pounding is a quite complex physical phenomenon. It is not easy to be simulated precisely in analysis. The authors employed a 3D contact-friction model and several parameters in macro concerns of this physical phenomenon (such as restitution coefficients) to solve the problem. Experiments were conducted to obtain some parameters (restitution coefficients, friction coefficients) and to verify this model. A case study of analyzing a steel elevated bridge with pounding between girders was also conducted to demonstrate the applicability of this pounding model. [1]

The parameters of pounding used for the steel bridge in the case study were adopted based on experiments of small scale steel model girders and estimated equations. As a real elevated bridge is much more complicated, it is not easy to estimate the values of these parameters. Therefore, the sensitiveness of the parameters to seismic response of elevated bridges needs to be studied.

This paper, on reviewing the 3D pounding model, changes the range of the parameters and studies how much the parameters of the pounding model affect the seismic response of elevated bridges with the same model steel bridge studied in Reference 1.

2. A brief review of the 3D pounding model and parameters [1]

Figure 1 shows a general case of pounding by two bridge girders. A 3D contact-friction model for the problem is illustrated in Figure 2.

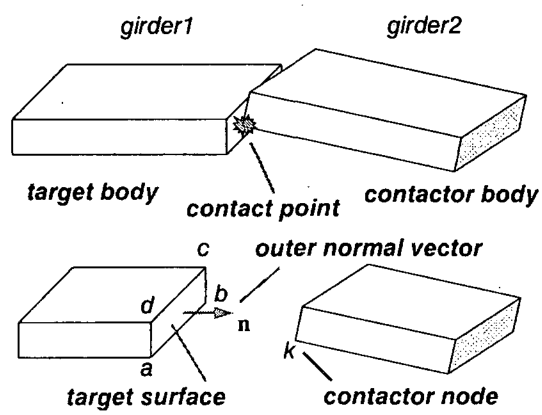


Fig. 1 Bridge girders in arbitrary contact

The model utilizes material penetrations to compute forces during contact. Upon contact, a universal spring K_{cnt} between node k and point p is created to compute the force of contact. Two dashpots, C and C_t, are also applied to node k for simulating energy loss during contact.

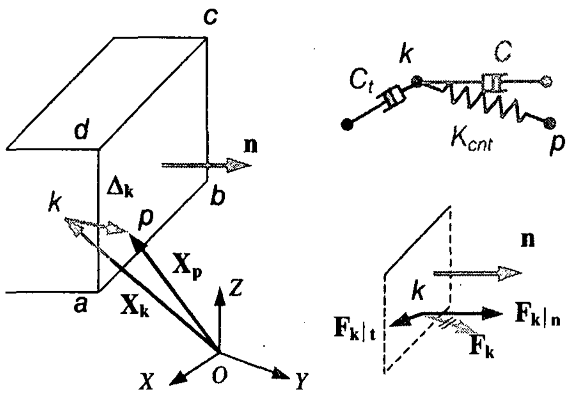


Fig. 2 Illustration of the 3D contact-friction model

Contact forces can be calculated separately for stick and slide conditions. The condition of stick and slide contact is decided by the ratio of tangent component of the contact force $|\mathbf{F}_k|_t|$ to the normal one $|\mathbf{F}_k|_n|$ (eqns. (1a), (1b)). The idea is illustrated by Figure 3. A cone shows the maximum static friction the target surface can supply according to the normal force. If the contact force vector is inside the cone, the relative movement between the node and the surface is prevented due to friction force. Therefore the node sticks to the surface during contact. Otherwise, slide will happen. During slide, the kinetic friction coefficient, μ_k, is used to compute the friction force.

Stick condition: $$\left|\mathbf{F}_k\big|_t\right| < \mu_s \left|\mathbf{F}_k\big|_n\right| \qquad (1a)$$

Slide condition: $$\left|\mathbf{F}_k\big|_t\right| \geq \mu_s \left|\mathbf{F}_k\big|_n\right| \qquad (1b)$$

μ_s - static friction coeff.

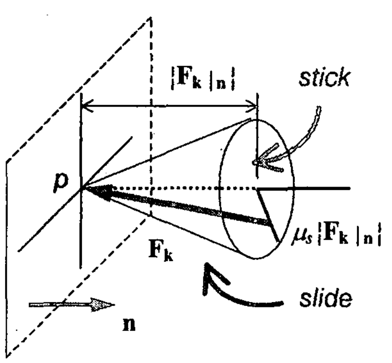


Fig. 3 Condition to decide status of stick and slide

Parameters of the model are chosen as follow:

The axial stiffness of the contactor body can be used as the stiffness of the universal spring K_{cnt}. As presented in eqn. (2):

$$K_{cnt} = \frac{EA}{L} \qquad (2)$$

where E, A and L are modulus of elasticity, cross section area and length of the contactor element respectively.

The damping ratio C and C_t can be determined according to the restitution coefficient at normal and tangent directions by eqns. (3) and (4).

$$C = 2\xi\sqrt{K_{cnt}\frac{M_1M_2}{M_1+M_2}} \qquad (3)$$

$$\xi = \frac{-\ln e}{\sqrt{\pi^2 + (\ln e)^2}} \qquad (4)$$

where,

M_1, M_2 – masses of the two bodies in contact

K_{cnt} – stiffness of the universal spring

e – restitution coefficient

ξ – damping ratio according to restitution coefficient e

The range of restitution coefficient is between 1 and 0, which represents the pounding from elastic to plastic. The corresponding range of ξ is between 0 and 1.

In a brief, parameters employed in this pounding model include restitution coefficients (e in normal direction and e_t in tangent direction, which are used to compute C and C_t), static and kinetic friction coefficients (μ_s and μ_k) and the stiffness of the contact spring K_{cnt}.

3. Parametric study of the 3D pounding model

A typical three-span steel bridge[1] is used to study the parameters of the pound model. As shown in Figure 4, fiber model is adopted at the first segment of each pier from foundation. Base-isolation rubber bearings are applied for each pier. For computation of pounding, a simple supported girder in each span is assumed. Takatori waves from the 1995 Kobe earthquake are used as earthquake excitations in three-dimensional.

Restitution coefficients and friction coefficients are not easy to be estimated in real situation. The following computations change the range of these parameters. Seismic response of displacement at the center of the middle span (*Node A*) is observed for parametric study of the pounding model.

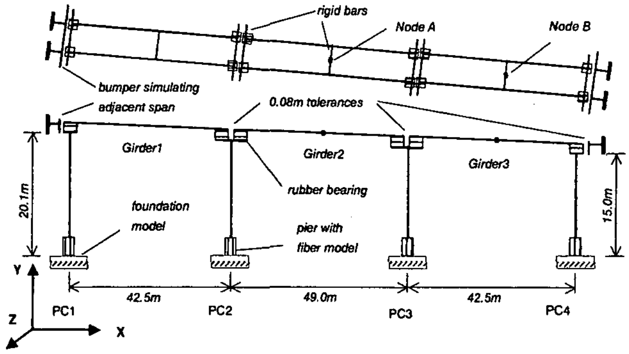
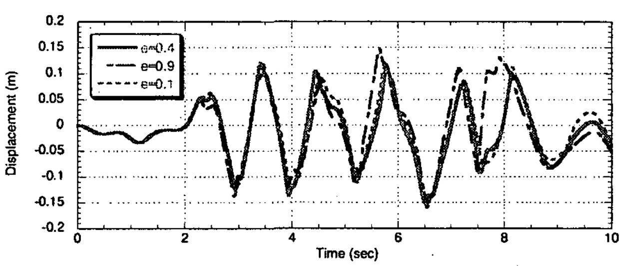


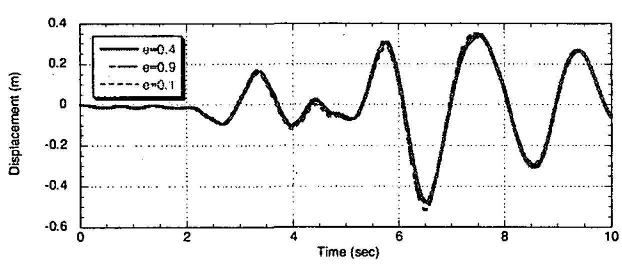
Fig. 4 Modeling of a three-span steel bridge

(1) Restitution coefficient

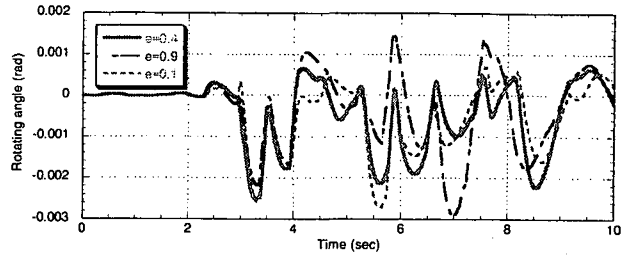
Restitution coefficient (in normal direction), e, represents the behavior of pounding as an elastic or plastic one, where the range of e is from 1 (elastic) to 0 (plastic). For the computation results shown in Figure 5, in additional to the value of restitution coefficient (e=0.4) obtained from experiments, two more values for nearly elastic impact (e=0.9) and nearly plastic impact (e=0.1) were also used for computations. Results show that responses in longitudinal and transversal displacements do not change much in accordance with the change of restitution coefficient. In rotating angle, the change is insignificant while the restitution coefficient moves to the plastic part. But some changes can be observed when an elastic impact is assumed.



(a) Longitudinal displacements



(b) Transversal displacements

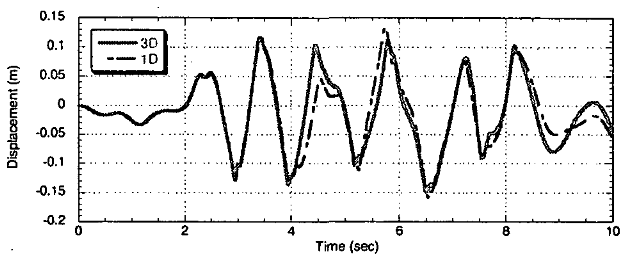


(c) Rotating angles

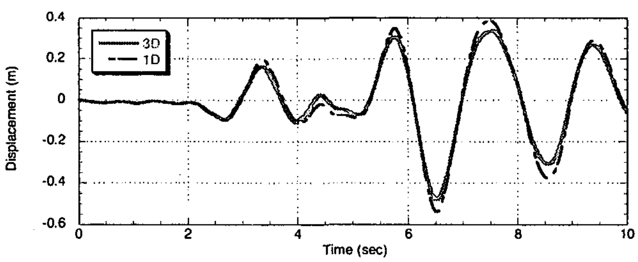
Fig. 5 Displacement comparisons - different restitution coefficients

(2) Friction at transversal direction

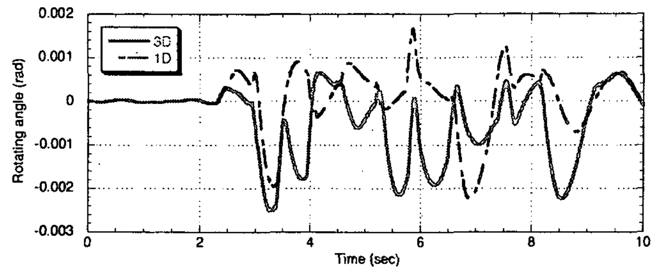
To indicate the effect of involving frictions into the pound model, a case of 1D pounding has been conducted. This case contains spring-dashpot elements working only in the normal direction against contact surfaces and no friction is assumed along the target surface, which is the case of $\mu_s=\mu_k=0$. The 1D pounding case was conducted to show the effect of involving friction into the proposed model of pounding. Results are given in Figure 6. Compare the 3D pounding case where μ_s=0.2 and μ_k=0.15, the responses of the 1D pounding case are very similar in longitudinal and transversal directions. But a big difference of the responses can be observed in rotating direction. These results indicate that the friction in transversal direction, which is adopted by the proposed pounding model, can dramatically affect the displacement responses of girders in rotating direction.



(a) Longitudinal displacements



(b) Transversal displacements

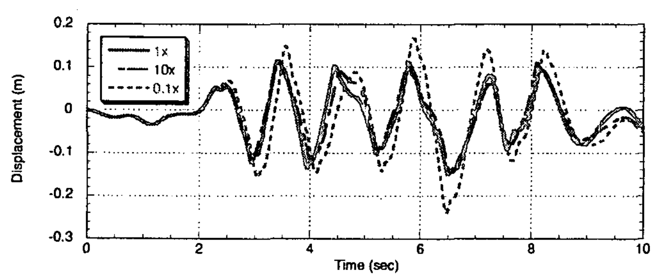


(c) Rotating angles

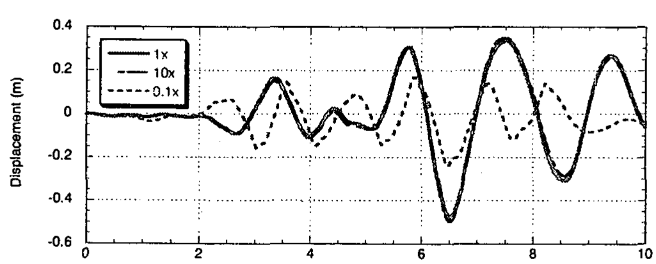
Fig. 6 Displacement comparisons – 3D and 1D poundings

(3) Stiffness of contact spring

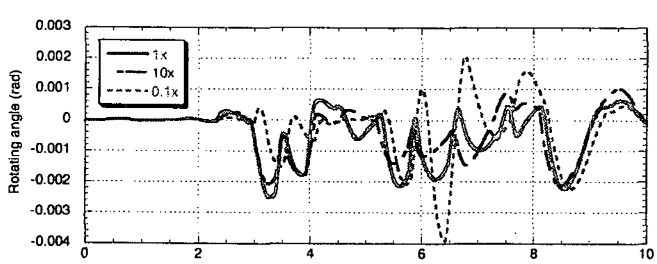
The stiffness of contact spring is determined by axial stiffness of girders. The following computations take the values of the stiffness as 10 times and 0.1 times of the adopted value of stiffness according to the axial stiffness of girders. In the 10x's case, a time interval of 0.0005 sec is adopted, while the other two case use 0.001 sec. Results in Figure 7 show responses by assuming harder contact springs (10x's case) are quite similar to the standard case (1x). While in the case of adopting softer contact springs, changes of responses can be observed. This is mainly caused by large penetrations among contact pairs.



(a) Longitudinal displacements



(b) Transversal displacements



(c) Rotating angles

Fig. 7 Displacement comparisons – different contact springs

4. Conclusions

This paper conducted a parametric study of a 3D pounding model developed by the authors. Computations were undertaken with different values of pounding parameters, which include restitution coefficient, friction coefficients and stiffness of contact spring. Results show that within a reasonable range, changes of these parameters do not result dramatic changes of major responses of the elevated bridge modeled for this study.

Reference

1) Zhu P., Abe M. and Fujino Y., Modeling Three Dimensional Non-linear Seismic Performance of Elevated Bridges with Emphasis on Pounding of Girders. *Earthquake Engineering and Structural Dynamics*, Vol. 31, pp.1891-1913, 2002