第７回地震時保有耐力法に基づく橋梁等構造の
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COMPARING SEISMIC POUNDING EFFECT OF SKEW AND STRAIGHT ELEVATED BRIDGES USING 3D MODELING

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Abstract

Skew bridges are popular structures used in transportation. As support lines of girders on a skew bridge are not perpendicular to the longitudinal direction of the bridge, rotations of girders caused by pounding can be observed under strong ground motion. Comparing with a straight bridge, pounding effect on a skew bridge is more complicated. This paper employs 3D modeling including pounding of bridges to analysis seismic response of a skew bridge comparing with a straight bridge. Discussions are given based on computations.

1. Introduction

Seismic induced pounding between girders and unseating of girders are very harmful to the serviceability of elevated bridges. In skew bridges, as the support lines are skewed to the bridge axis, the seismic pounding effect becomes much more complicated than that of straight-span bridges. The resistance from the transversal direction may cause a rotation of the girder and therefore, as a consequence, may cause unseating as it is illustrated in Figure 1. It has been observed that skewed spans develop larger displacements than that of straight spans.[1] Several skew bridges were suffered from unseating during the 1995 Kobe earthquake as a reason of girder's rotation.[2]

This paper presents detailed 3D modeling of elevated bridges including a 3D model of pounding. A three-span steel elevated bridge is taken as a case study with models of straight and skew spans. Comparisons are given with seismic analyses of pounding effect and countermeasures.

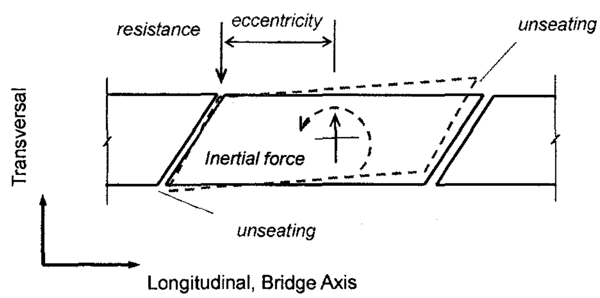


Figure 1. Unseating due to bridge skew

2. Detailed 3D modeling of elevated bridges

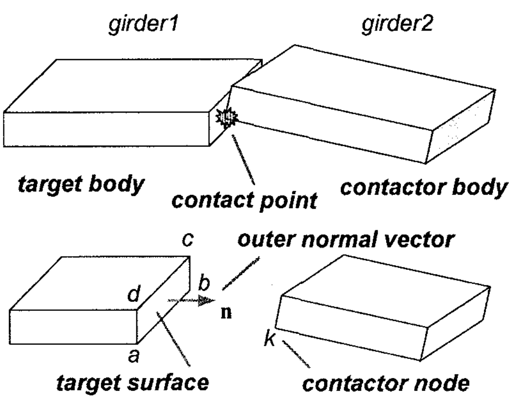
(1) Modeling of each component

Elevated bridges are generally composed of foundations, piers, abutments, girders/decks, bearing supports and expansion joints. To conduct precise analyses, detailed modeling for each of these components is given as follows. In addition, a 3D contact-friction model for pounding between girders/decks and models of restrainers and bumpers are given as well. Models used for each component are listed as follow:

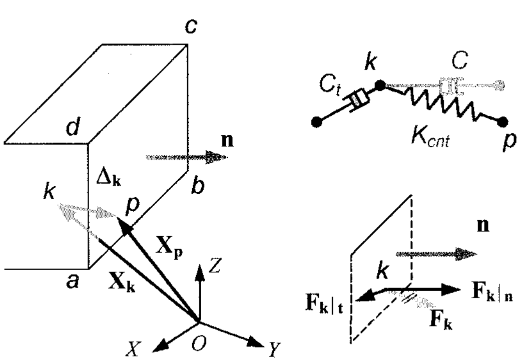
1) Piers – fiber model [3] with bi-linear model of steel fibers,
2) Girders – elastic beam element [4],
3) Foundations – a simplified soil-grouped pile model by Konagai [5],
4) Rubber bearings – a bi-axial model by Yoshida et al [6],
5) Pounding effect between girders – a 3D contact-friction model Zhu et al [7],
6) Restrainers and bumpers – bi-linear model with initial clearance [8].

(2) A brief review of the 3D contact-friction model of pounding[7]

The problem considered herein is a general case of pounding by two bridge girders. As shown in Figure 2(a), two girders contact with each other arbitrarily. They are referred as contactor body and target body where a contact happens between contactor node and target surface. A 3D contact-friction model for the problem is illustrated in Figure 2(b). The target surface, named as *abcd*, is assumed as a rigid plane (The surface has not to be a rectangle). Vector **n** is the outer normal vector of the target surface. Node *k* is the contactor node at the contactor body, which penetrates into the target surface during contact. Point *p* is the physical contact point at the target surface *abcd*.



(a) Girders in arbitrary contact



(b) Illustration of the pounding model

Figure 2. A 3D contact-friction model of pounding

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. The contact force at node k, $\mathbf{F_k}$, can be computed as $\mathbf{F_k} = K_{cnt} \cdot \Delta_k$ and be divided into normal and tangent components ($\mathbf{F_k}|_n$ and $\mathbf{F_k}|_t$ respectively), where vector $\mathbf{n}$ is the outer normal vector of the target surface and vector $\mathbf{t}$ is a projection vector of $\mathbf{F_k}$ to the target surface. During contact, status can be divided into stick contact and slide contact which can be decided by the ratio of tangent component of the contact force $|\mathbf{F_k}|_t|$ to the normal one $|\mathbf{F_k}|_n|$. Contact forces can be calculated separately for stick and slide conditions.

(3) A model bridge with straight and skew spans

A three-span steel elevated bridge (Figure 3) is chosen as a case study, with models of each component as stated in Section 2.1. A skew model bridge (Figure 4) is built by modifying the straight model bridge (Figure 3). The structural model of the skew bridge is the same with the straight model bridge, except a skew angle of 60° at girder's ends.

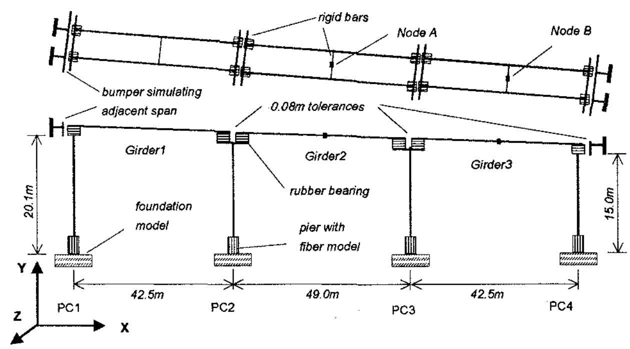


Figure 3. A three-span steel model bridge with straight spans

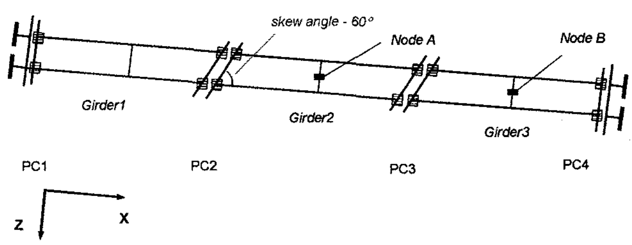
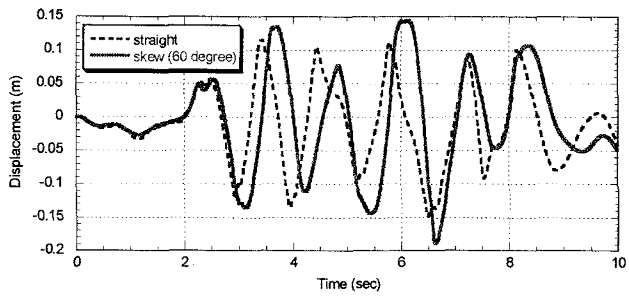


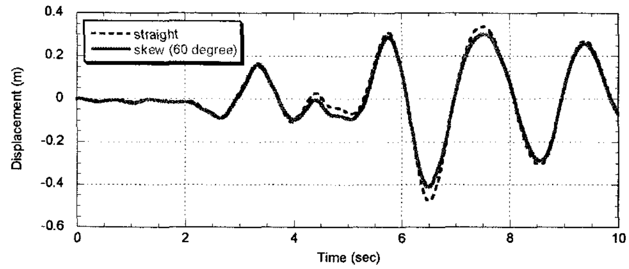
Figure 4. A model bridge of skew spans – top view

3. Analyses and comparisons

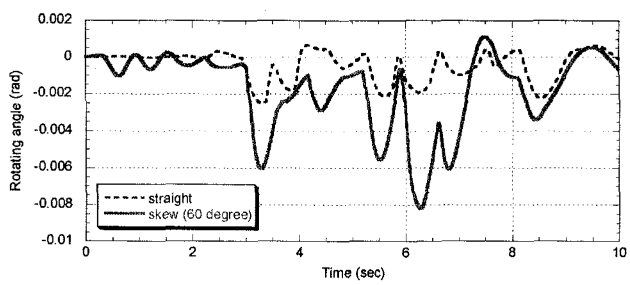
Computing parameters are set to the same with these two model bridges. A general-purpose dynamic analysis program for bridges, DABS (Dynamic Analysis of Bridge Systems), developed by Zhu et al [8] and implements 3D models of bridge structures listed in Section 2.1, is used in analyses. Responses of center points at the center girder and a side girder are monitored. Comparisons of displacements and accelerations at these center points under Takatori ground motion (1995 Kobe earthquake) are given in Figures 5 and 6. It can be seen that displacement responses in longitudinal and transversal directions for the skew bridge have similar trends to its counterpart, while longitudinal response of the skew bridge is larger. Big differences of responses in rotating direction can be observed for these two kinds of bridges. Responses of the skew bridge are stronger than that the responses of the straight-span bridge. The maximum rotating angle of the skew bridge is about four times comparing with the straight-span bridge.



(a) Longitudinal displacements

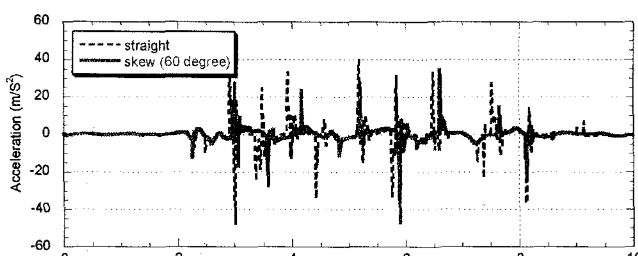


(b) Transversal displacements

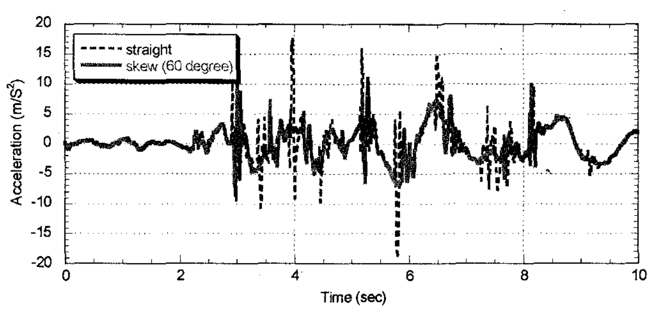


(c) Rotating angles

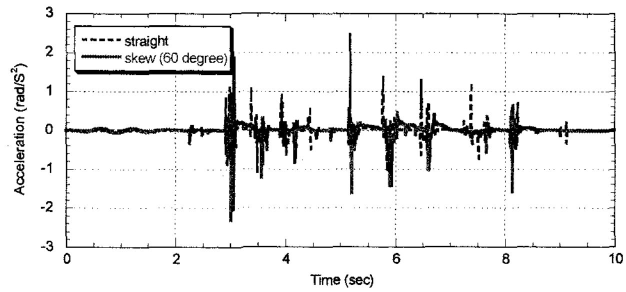
Figure 5. Displacement comparisons of the mid span at Node A



(a) Longitudinal accelerations



(b) Transversal accelerations



(c) Accelerations at rotating direction

Figure 6. Acceleration comparisons of the mid span at Node A

4. Analysis with pounding mitigation

Figure 7 shows the skew model bridge used for analysis with pounding mitigation measures. Restrainers are installed along the longitudinal direction of the bridge. Computing conditions are the same with the analysis of the skew bridge in the previous chapter. Responses at Node A under Takatori ground motion with cases of without and with pounding mitigation are given in Figures 8 and 9. The results show that mitigating devices can reduce displacements of girders in longitudinal and rotating directions. Generally speaking, the results indicate that for skew bridges, to apply restrainers and bumpers only along the longitudinal direction is less effective in pounding mitigations comparing with the cases of the straight bridge.

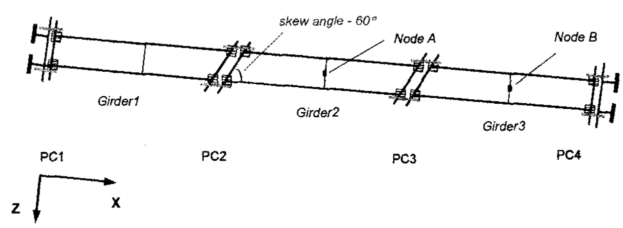
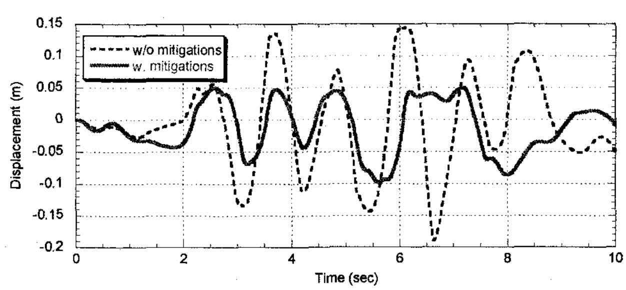
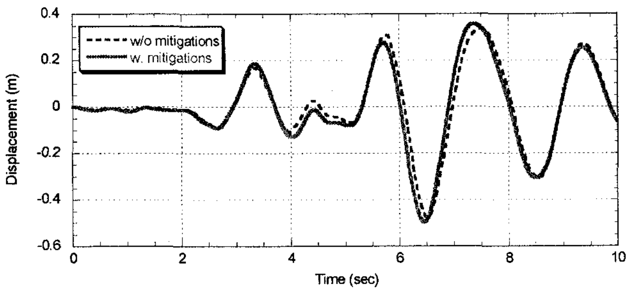


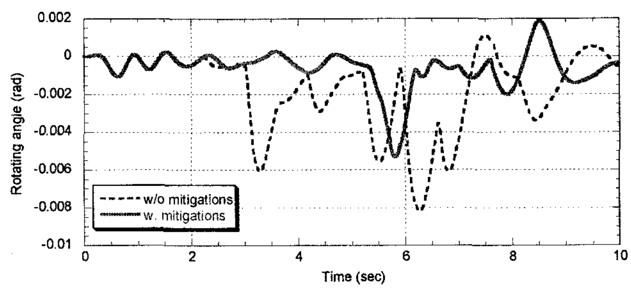
Figure 7. Modeling of the skew bridge with pounding mitigations – top view



(a) Longitudinal displacements

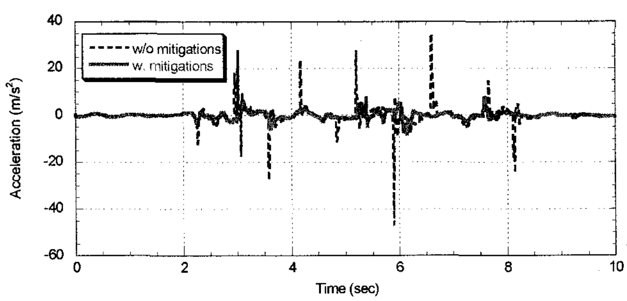


(b) Transversal displacements

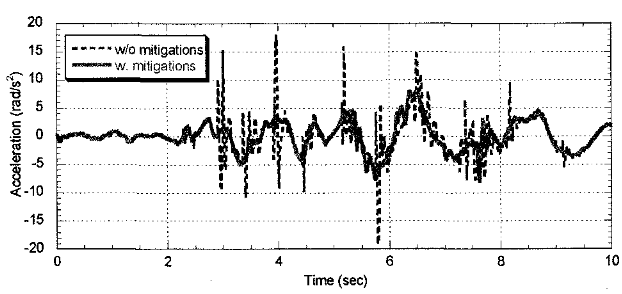


(c) Rotating angles

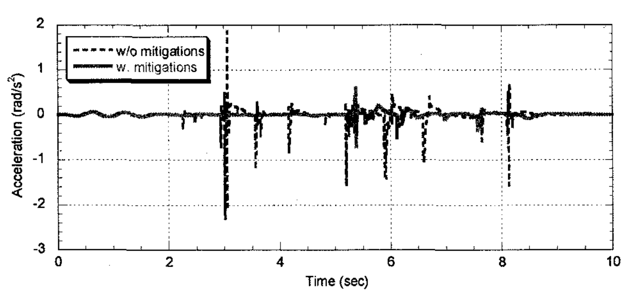
Figure 8. Displacements at Node A – the skew bridge with/without mitigation



(a) Longitudinal accelerations



(b) Transversal accelerations



(c) Accelerations at rotating direction

Figure 9. Accelerations at Node A – the skew bridge with/without mitigation

5. Conclusions

This paper analyzed and compared a skew-span model bridge against a straight-span model bridge using detailed 3D modeling including a 3D pounding model for arbitrary contact of bridge girders under strong ground motion. Results showed that seismic responses of the skew bridge have a similar trend to the straight one, but displacements of the former one in longitudinal and rotating directions are higher. Pounding mitigation measures have effects in both types, though in case of the skew bridge, the countermeasure is less effective.

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