Evaluation of seismic behaviors of a bridge crossing a fault subject to fling-step displacement

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1. Introduction

The effects of near-fault ground motions with and without considering the fling-step displacement on the seismic behaviors of a bridge are very important and can cause serious damage or collapse of bridge due to both ground acceleration and fault ruptures (permanent displacement). However, little has been done to evaluate the effects of focal mechanism on the seismic response of a fault-rupture crossing bridge. In order to explore these effects, parametric study was conducted based on various strike-, dip-, and rake- angles. The evaluation was focused on the maximum curvature and maximum strain of the piers in this research.

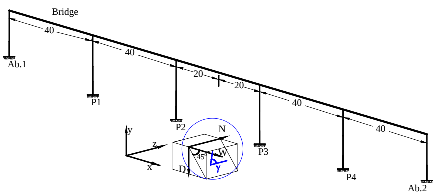
2. Methodology

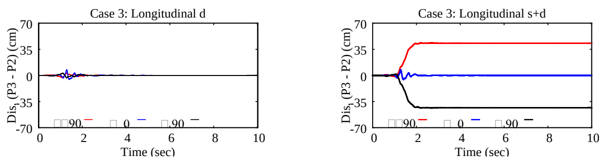
In this paper, aimed at investigating the effects of the focal mechanism of fault rutprue on the seismic response of a 5-span simple isolated bridge (the image of the bridge is shown in Table 1), the near-fault seismic displacement waveforms were obtained based on a hybrid synthesis method [1], which combined a corrected stochastic Green's function method [2][3] with a theoretical method [4]. Then, based on the multiple-support excitation method by Chopra [5], the nonlinear time history analysis was conducted by the OpenSees [6].

3. Cases for numerical calculation

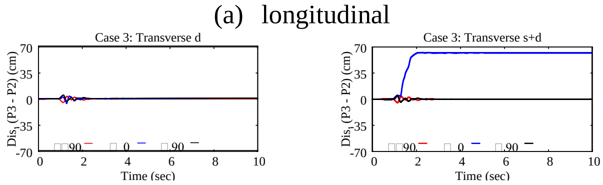
The parametric study was performed for various strike- (Case 1), dip- (Case 2) and rake-angles (Case 3). Due to the limited space, only Case 3 will be presented here (**Table 1**). Relative displacement between P3 and P2 for Case 3 with and without permanent displacements are plotted in **Fig. 1**. It well illustrates that the relative displacements of the piers were much larger for the case with both the static and dynamic displacements than for the case with only the dynamic term.

Table 1 Different rake angles for case study

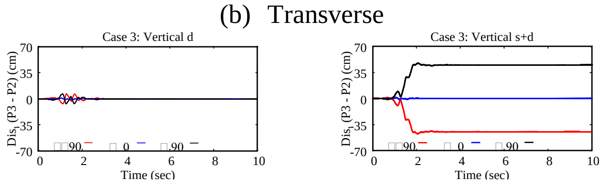
Case No.	Angle (°)	Image of fault-rupture crossing bridge
Case 3-1	-90	
Case 3-2	-60	
Case 3-3	-30	
Case 3-4	00	
Case 3-5	+30	
Case 3-6	+60	
Case 3-7	+90	



(a) longitudinal



(b) Transverse



(c) Vertical

Fig. 1 Relative displacement of P3 and P2 under various γ (left: dynamic term; right: static and dynamic terms)

4. Results of numerical calculation

The nonlinear behavior of the piers could be significantly dependent on the dynamic axial force during earthquakes. This effect is considered in the numerical calculation, while the curvatures corresponding to the limit states, which are calculated by the push-over analysis and the displacements corresponding to the limit states [7], do not necessarily represent these effects. On the other hand, if we consider the strain or the normalized strain (the ratio to the yield strain) corresponding to the limit states [8], more rational comparison can be made between the calculated response

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and the limit states. The results will be presented for P2 and P3, which are located very near the fault plane. **Fig. 2** shows the maximum curvature in Case 3. The limit states 2 and 3 were obtained by the push-over analysis and the displacements corresponding to the limit states [7]. It illustrates that, all the piers under different rake angles are within the limit state 2, and with some cases within the yield level. The effects of the rake angle are greater on the maximum Cz in **Fig. 2 (a)** (curvature along the longitudinal directions) than on the maximum Cx in **Fig. 2 (b)** (along the transverse directions) mainly due to the relatively large stiffness along the transverse directions. The maximum normalized strain at the monitor points on the cross section of P2 and P3 shown in **Fig. 3 (a)** under various rake angles are compared with the normalized strain corresponding to the limit states [8] in **Fig. 3 (b) ~ (e)**. Compared with the evaluation results for the maximum curvature above, there are significantly different behaviors. The maximum normalized strain under the rake angle -60^{o} with fling-step displacement for P3 is beyond the limit state 3 as shown in **Fig. 3 (d)**. Additionally, there are several cases exceeding the limit state 2 as highlighted in **Fig. 3 (d)**. The comparison made in **Fig. 3** is more reasonable than that in **Fig. 2,** because the effect of axial force is appropriately included.

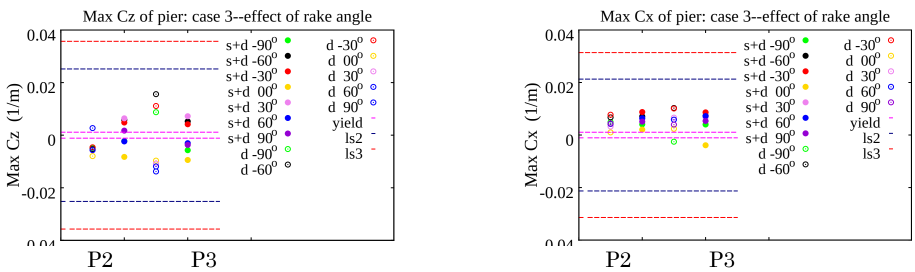

Fig. 2: Maximum curvature under various γ
(left: Cz along longitudinal directions; right: Cx along transverse direction)

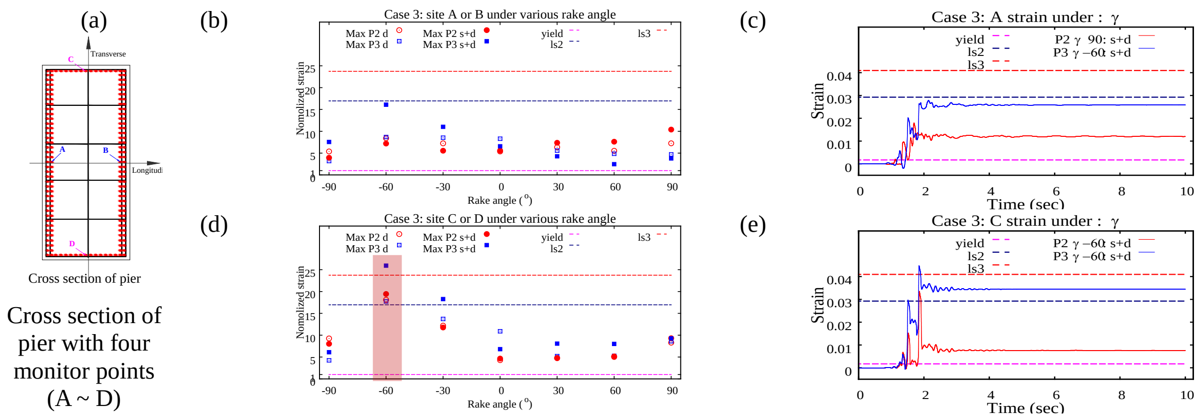

Fig. 3 Case 3: (b) (d): Maximum normalized strain distribution of Pier 2 and Pier 3
(c) (e): the related time history of the maximum strain

Note: *s: static, d: dynamic, ls: limit state.*

5. Conclusions

The effects of focal mechanism on the seismic behaviors of a fault-rupture crossing bridge were evaluated in this paper. The results indicated the importance of considering fling-step displacements. In addition, the limit states should be specified by the normalized strain.

References

[1] Shuanglan, W. et al. (2016), *Front. Built Environ*. 2:24, pp. 1-16. doi: 10.3389/fbuil.2016.00024. [2] Kagawa, T. (2004), J. Japan Assoc. Earthq. Eng., 4(2), pp. 21–32. [3] Nozu, A. and Y. Nagasaka (2017), http://www.pari.go.jp/bsh/jbn-kzo/jbn-bsi/taisin/research_jpn/research_jpn_2017/jr_51.pdf. [4] Hisada, Y, and J. Bielak (2003), *Bull. Seism. Soc. Am*, 93(3), pp.1154-1168. [5] Chopra, A.(2012), Dynamics of structures: theory and applications to earthquake engineering, 4th ed. Upper Saddle River, N.J. : Prentice Hall. [6] Mazzoni, B. et al. (2001), http://opensees.berkeley.edu/. [7] J. R. Association (2012), Specifications for highway bridges: Part V seismic design, p.169. [8] J. R. Association (2012), Specifications for highway bridges: Part V seismic design, pp.180-181.