Failure Mechanism of a Skew Bridge Damaged in Wenchuan Earthquake

Graduate School of Engineering, Kyushu Institute of Technology Student Member Heng GAO
Kyushu Institute of Technology Member Kenji KOSA
Nippon Engineering Consultants Co., Ltd. Member Tatsuo SASAKI
Graduate School of Engineering, Kyushu Institute of Technology Student Member Zhongqi SHI

1. Introduction

The Wenchuan Earthquake, occurred on May 12th, 2008, had a magnitude of 8.0 by CEA. Maweihe Bridge, which is a 3-span skew bridge, was damaged in this earthquake. Shown as Fig.1, it has a length of 39 m, width of 10 m, and a skewed angle of 50˚. The deck of each span consists of 8 hollow reinforced concrete slabs. Each slab is supported by four bearings. So the deck is supported by 96 rubber bearings totally, among which 32 bearings is with Teflon coating on abutments and the others are the ordinary rubber bearing on bents. Nonlinear dynamic analysis is conducted to make clear seismic response and failure mechanism of this bridge during the earthquake.

2. Damage Condition

From field survey, damage condition was summarized as Fig.2 briefly. Relatively large residual displacements and in-plane rotation happened on the deck. Poundings between deck and abutment caused the damage of abutments. As the Fig.2 illustrated, the end of the slab on abutment A2 is raised from the roadbed in the actual damage. The guardrail at corner C suffers serious damage. On the other side of abutment, there is a great crack occurring between parapet and substructure of A1 at the obtuse corner, and it seems to have some dislocation between them. Shown as Fig.2, the deformation of deck center reached 315mm in X direction and 75mm in Y direction. Also the rotational angle of actual damage reached 1.32° clockwise.

3. Analytical Condition

Model in analysis was established based on the bridge structure and damage condition. A frame model is established for slab shown as Fig. 3 (a). Pounding and bearing spring is set for the abutment and bearing separately.

Shown as Fig.3 (b), 8 pounding springs is set at each side as each span consists of 8 reinforced concrete slabs. The direction of pounding spring is set as perpendicular to the parapet, and the stiffness is set as 1.3 MN/mm based on punching shear experiment on RC member. Bearing spring is used to model the two types of bearing. Stiffness of bearing spring is set as 0.54kN/mm. With the different interface, the critical point of sliding is set as 1.13kN and 19.02kN separately for the Teflon and ordinary rubber bearing. Wave data was measured by the Bajiao Station, which is the nearest station away from bridge. During the analysis, the wave is input in both X and Y direction in the same time. Since the wave was weak at start and end, data of 30 seconds in the middle of wave is used for the analysis.

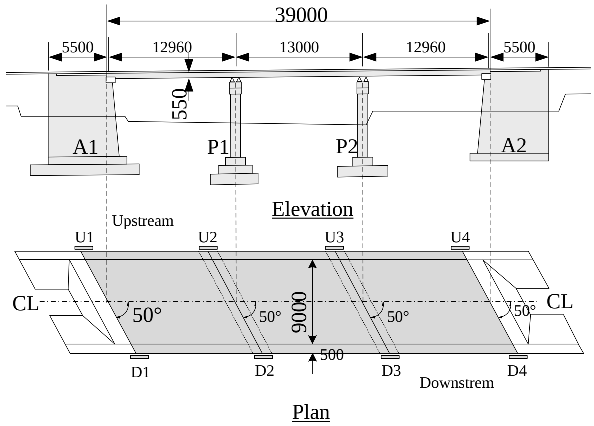


Fig. 1 Objective Bridge: Maweihe Bridge

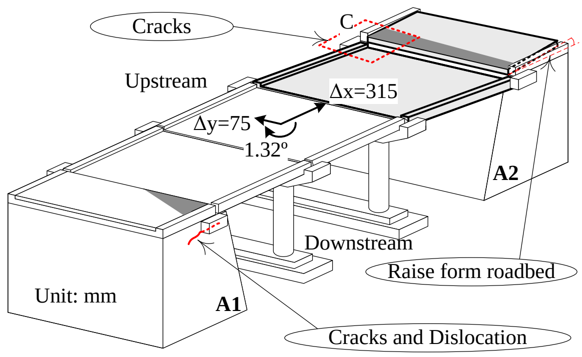


Fig. 2 View of Damage Condition

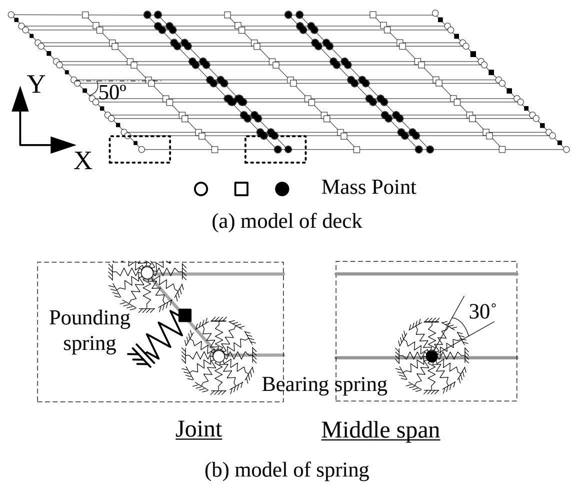


Fig.3 Analytical Model

4. Analytical Result and Evaluation on Failure Mechanism

Poundings happened between superstructure and abutment during the procedure of analysis. The pounding force history can be shown as Fig.4. Three poundings happened in analysis which twice at abutment A2 and once at abutment A1. Also the max value of pounding force gets 24.5MN at the 2nd pounding.

During the 1st pounding, the deck collides to the abutment with all joint area, which can be shown as Fig.5 (a). The author thinks that damage degree of members may be related to the stress members suffer. During the 1st pounding the pounding area is the whole joint area of 8.84m^2. The average stress by the 1st pounding is calculated as 1.85MPa (=16.4MN/8.84m^2) which just reaches 9.2% of the compressive strength of deck (C30 concrete, fc'=20.1MPa). Also the corner C (obtuse corner of deck at A2 side) gets the max value of stress of 2.18MPa (=2.4MN/1.1m^2), which is 10.8% of the compressive strength. Stress by 1st pounding is just about 10% of compressive strength. The actual damage of A2 is plotted shown as Fig.5 (b). The end of the slab on abutment is raised from the roadbed by about 185mm almost evenly in the actual damage. It can be confirmed that the even-raising of slab end is strongly related to the 1st pounding with all joint area, and its evenly distributed stress.

Similarly, the 2nd pounding is evaluated as Fig.6 shows. Five springs (in total 8 springs) provide resistance referenced Fig.6 (a). The max force of pounding reaches 9.5MN at corner C so that the stress at this part is calculated as 8.5MPa (=9.5MN/1.1m^2). Also with the total pounding of 24.5MN, the average stress reaches 5.6MPa (=24.5MN/5.5m^2). The guardrail (C25 concrete) at corner C may be damaged serious, shown as Fig.6 (b), as the stress (8.5MPa) it suffers reaches 51% of its compressive strength (C25 concrete, fc'=16.7MPa). The guardrail at corner C suffers concrete crushing and dropping, and there are some cracks on it. Also the 3rd pounding got the max-value of stress 15.4 MPa, and it caused the most serious damage of A1 obtuse corner. All of these can confirm the damage mechanism that the greater stress bridge members suffer, the more serious damage will occur.

5. Conclusions

(1) Large residual displacements and in-plane rotation happened on the deck. Deformation of deck center reached 315mm and 75mm in axial and transverse. The rotational angle of actual damage reached 1.32° clockwise. Both of the abutments have been damaged to different degree due to poundings.

(2) Based on the analysis, the 1st pounding, with whole joint area, giving the slab on A2 a trend to be raised from the roadbed. The 2nd pounding aggravates this damage, including concrete crushing of guardrail at obtuse corner, with its great stress which is 51% of the compressive strength of guardrail.

(3) Based on the evaluation on the failure mechanism, damage degree is related to pounding stress. Greater pounding stress will cause more serious damage of local member.

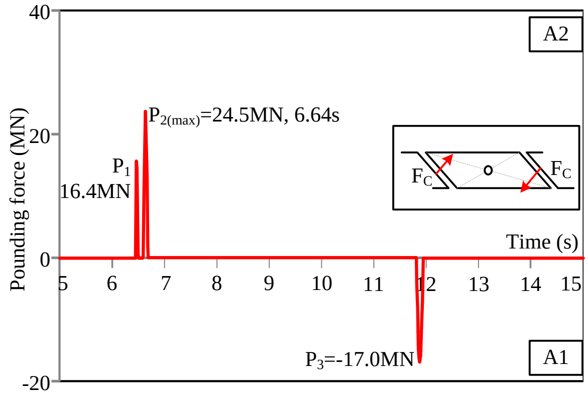
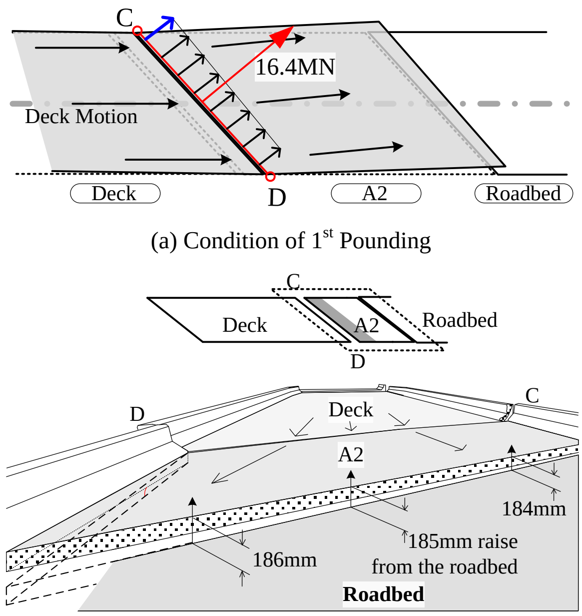


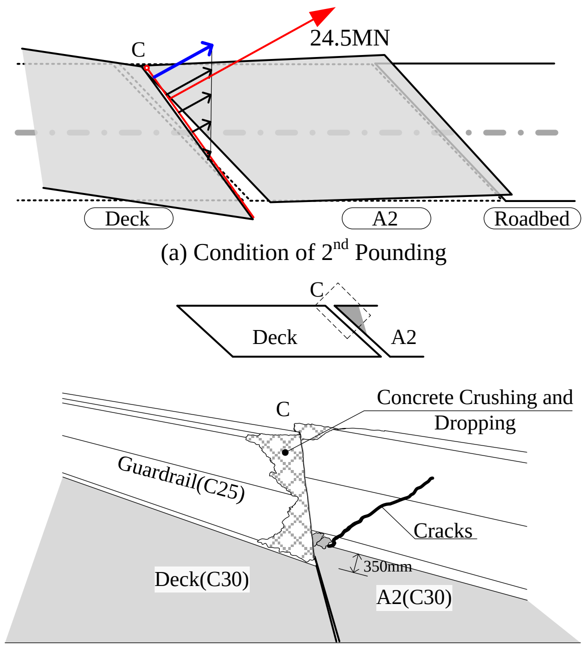
Fig.4 Pounding Force History



(a) Condition of 1st Pounding

(b) Damage Condition

Fig. 5 Condition of 1st Pounding and Damage



(a) Condition of 2nd Pounding

(b) Damage Cnodition

Fig. 6 Condition of 2nd Pounding and Damage