Damage Analysis of a RC Rigid-Frame Arch Bridge affected by Sichuan Earthquake, 2008

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1. Introduction

Xiaoyudong Bridge (in Fig.1), which is a 4-span, rigid-frame arch bridge, was damaged extensively by Sichuan Earthquake, May 12th, 2008, Ms8.0 by CEA. By field survey, damage condition was summarized. Pushover analyses are used to evaluate the bearing capacity, and to approach the failure mechanisms of Span 4.

2. Damage Condition

The overall damage condition is illustrated in Fig.1, from which we can see that Span 1 had the greatest shortening likely caused by the surface fault behind A1 in Fig.2. As Span 2 only changed slightly, the effect of the surface faults on Span 2, 3 and 4 is considered limited (the measure method is explained in Fig.3, Span 3 and 4 for example). However, the decks of Span 3 and 4 collapsed entirely, and Pier 3 titled about 7.5º. As shown in Fig.4, a 20cm permanent displacement of the support on the top of A2 into backsoil, and shear failures on the side wall were found, from which we inferred the girder lost the support from A2. Besides, at the joints of the girder and arch legs, different types of failure occurred. On the left (see from downstream, Point A), by negative bending moment, rebars on upside of the girder resisted tension and downside concrete resisted compression. On the right (Point B), by positive moment, the girder was pulled to separate from the joint, which caused the obvious crack at the joint.

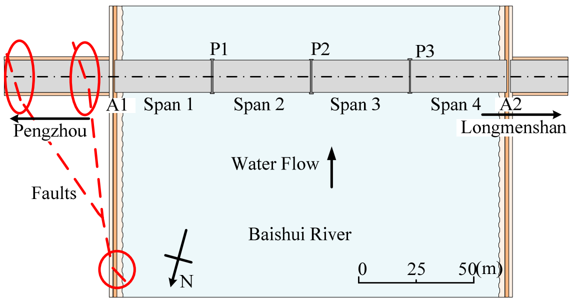

Fig.2 Surface Faults near Xiaoyudong Bridge

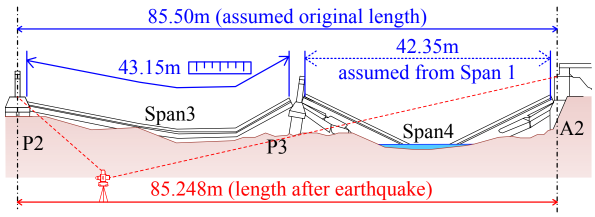

Fig.3 Measure Method (Span 3 &4 from upstream)

3. Pushover Analysis

Single-frame model is used to evaluate the bearing capacity of this bridge for Case 1. Horizontal and rotational springs are set for footings. Frictional and supporting springs are used between girders and piers. Further, rigid elements were set at footings, beams above piers and joints between legs and girder. Axial force under only dead load is used to calculate the tri-linear M-Φ relationship. For Case 2, to approach the mechanisms of Span 4 after lost support, the right support is removed without change for the other condition.

For Case 1, shown in Fig.5(a), as the horizontal load growing up to 0.40g, the tensile reinforcement at middle span will yield due to negative moment, and then reaches at the ultimate stage at 0.62g

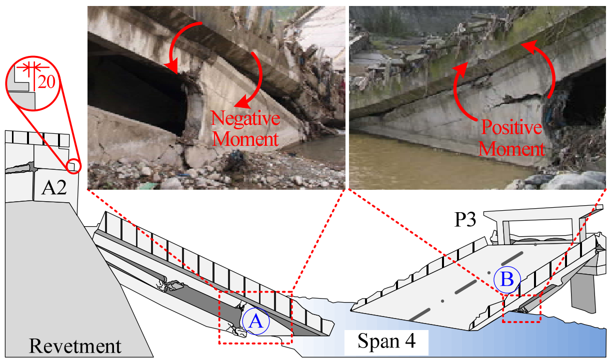

Fig.4 Failure Condition of Span 4 (upstream, unit: cm)

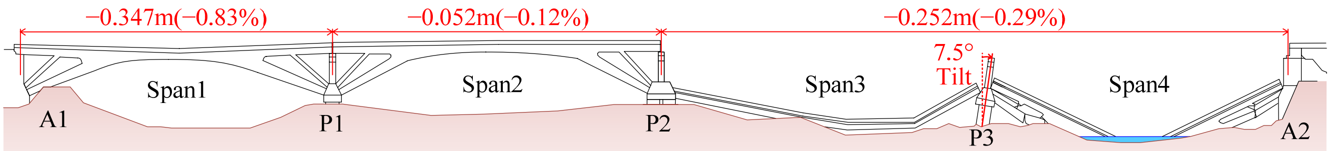

Fig.1 Overall Failure of Xiaoyudong Bridge (from upstream)

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horizontal load. For the inclined legs, the first yield of tensile reinforcement occurs to the left bottom at 0.47g horizontal load. The same point will reach at the ultimate stage soon. Then the yield of tensile reinforcement and the ultimate stage will happen to the right bottom of the inclined leg at 0.53g. After this, considering the entire capacity may lose after serious failures occur to these three points, 0.53g is thought to be the capacity of this bridge.

For Case 2, shown in Fig.5(b), due to the loss of support, the top of the right inclined leg (Point A) and the girder next to the right joint with the arch leg (Point C) will reach their ultimate stages, while rebars will yield at the bottom of the right inclined leg (Point B) under only dead load. Compared with Case 1, the yield of the tensile reinforcement at the middle span (Point D) occurs earlier at 0.17g. (the curvature of Section D is illustrated in Fig.6) Failures at Point A, B and C will lead to the drop of girder at the right side. This may cause further failures of the right arch leg due to collision. Thus, the damage at Point A, B, C and D will cause the entire rigid-frame arch to lose its stability. These two reasons above, are likely to cause the failures shown in Fig.4 that joints of girder and arch legs suffered moment in different directions.

4. Possible Mechanisms of Failure

As step 1 shown in Fig.7(a), the earthquake effect and the move of foundation caused the deck of Span 4 moved longitudinally, which led to the collision between the deck of Span 4 and A2. Most likely, the deck of Span 4 moved towards A2 at first and caused the parapet and the pavement on A2 slid into the backsoil (Fig.6(a)). Then, the girder moved on reversal direction also due to the earthquake (Fig.6(b)). Considering the original seat length on A2 was about 35cm (by field survey), this 20cm backward move likely caused the seat length remain only less than 15cm, and made the girder considerably easily lose support by any vibration. Thus, based on result of Case 2, inclined legs and the girder at right side received greater applied load, and caused the damage here. Then, failure would happen to middle span soon (Fig.7(b)). As the pier and inclined leg still supported the girder at left but failures already occurred to the right half span, the girder was pulled to separate from the left joint with the arch leg by positive moment (Fig.7(c)). Thus, the left half also failed and the entire span collapsed into the water. Consequently, Pier 3 was pushed to tilt by the force from Span 3, which caused the enormous chain failure of Span 3.

5. Conclusions

1. By field survey, both Span 3 and 4 fell entirely, Pier 3 tilted about 7.5°, and surface faults mainly influenced on Span 1.

2. By Case 1, the bearing capacity of this bridge is considered to be 0.53g horizontal load, till when the reinforcement will yield at the cross sections of middle span, and bottoms of both inclined legs.

3. If the girder loss the support, damage is likely to occur as early as 0.17g horizontal load, which is probably the main reason of the entire failure of Span 4, and the chain failures of Pier 3 and Span 3.

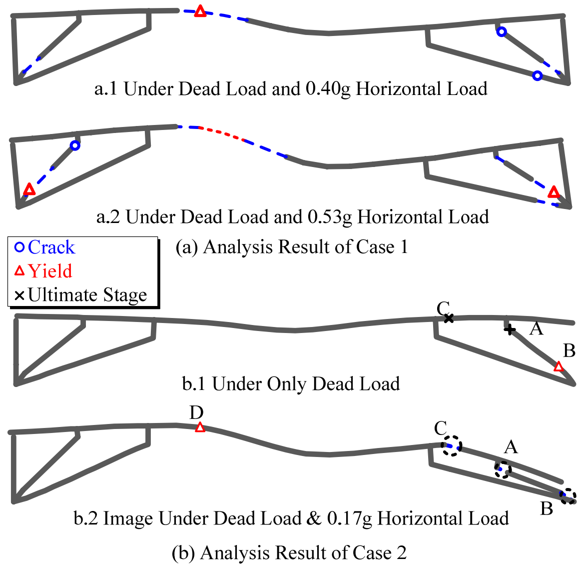

Fig.5 Analysis Result

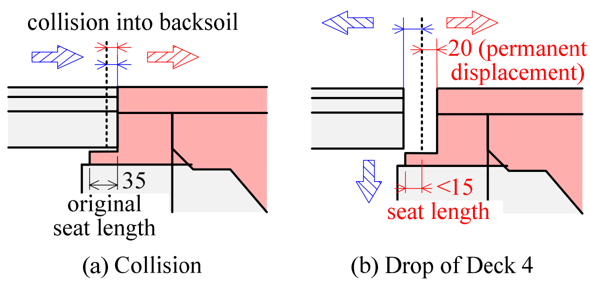

Fig.6 Support Lost of Deck 4 (unit: cm)

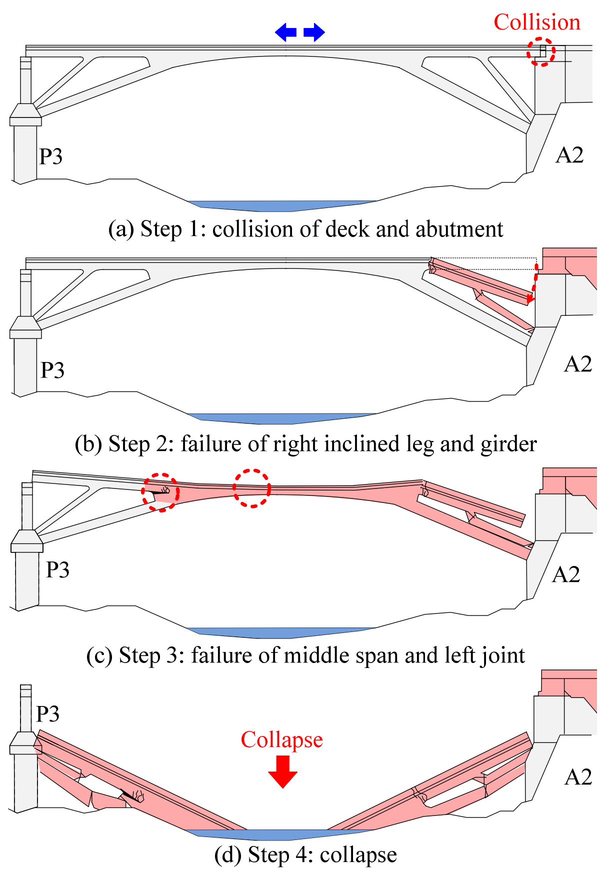

Fig.7 Failure Mechanisms of Span 4(upstream)