Damage Approach of a RC Rigid-Frame Arch Bridge affected by Wenchuan Earthquake

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1. Introduction

The Wenchuan Earthquake, May 12th, 2008, had a magnitude of 8.0 by CEA. Xiaoyudong Bridge, which is a 4-span, rigid-frame arch bridge, was damaged extensively in this earthquake. 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 failure condition is shown in Fig.1. Noticing that extensive damage occurred to Span 3 and Span 4, they will be detailed illustrated as following. Shown in Fig.2, Pier 3 (at Point A) tilted averagely 7.5° toward Span 4 (about 8.08° at upstream side and 6.85° at downstream side, measured by the electronic total station). The piles under Pier 3 (at Point B) suffered great damage because of the tilt. Span 3 and Span 4 collapsed entirely, and the legs on them failed as well. Shown in Fig.3, for A2, a 20cm permanent displacement of the support on the top of A2 into the backsoil and shear failures on the side wall have been found, from which we inferred the girder lost the support from A2. Besides, at the joints of the girder with the arch legs, different types of failure occurred to the left and the right. On the left (see from downstream, Point A and the photo shown in Fig.3), 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 between the girder and the joint.

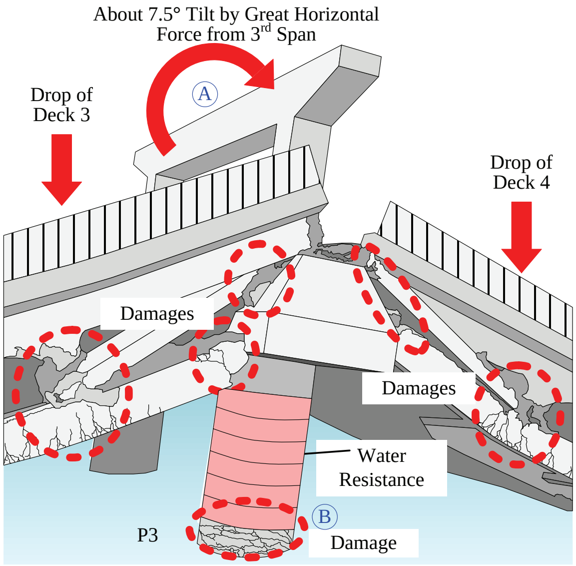

Fig.2 Failure Condition of Pier 3 (upstream)

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.4(a), as the horizontal load growing up to 0.40g, the tensile reinforcement at middle span will yield due

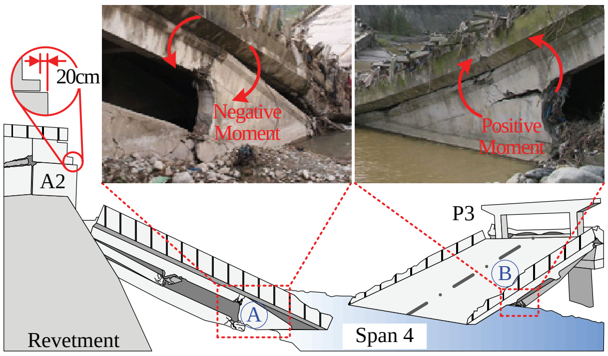

Fig.3 Failure Condition of Span 4 (upstream)

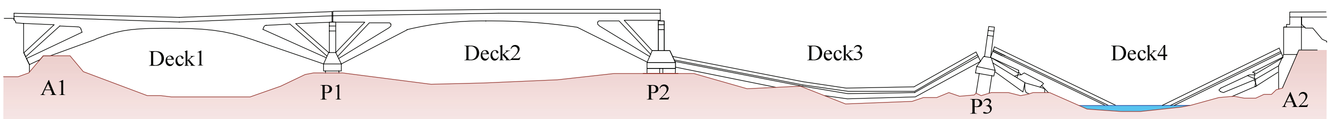

Fig.1 Overall Failure of Xiaoyudong Bridge (upstream)

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to negative moment, and then reaches at the ultimate stage at 0.62g 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.4(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. (curvature of Section D is illustrated in Fig.5) 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.3 that joints of girder and arch legs suffered moment in different directions.

4. Possible Mechanisms of Failure

As step 1 shown in Fig.6(a), the decks of Span 4 moved longitudinally due to the earthquake effect, 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 about 20cm into the backsoil. Then, the girder moved on reversal direction also due to the earthquake. Once the displacement towards left became greater than 20cm, Span 4 lost the support from A2. Thus, based on result of Case 2, the inclined legs and the girder on the right side received greater applied load, which caused the damage occurred to them. Then, failure would happen to middle span soon (Fig.6(b)). Then, as the pier and inclined leg still supported the girder on the 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.6(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. From field survey, both Span 3 and Span 4 collapsed entirely and Pier 3 tilted about 7.5°.

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 the bottoms of both the right and the left 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.

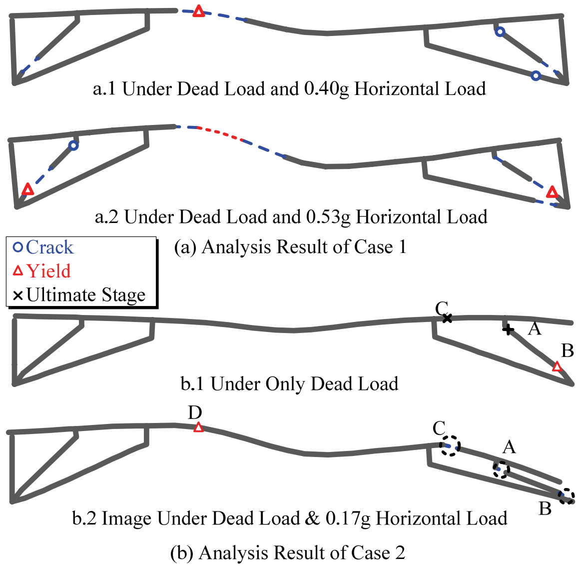

Fig.4 Analysis Result

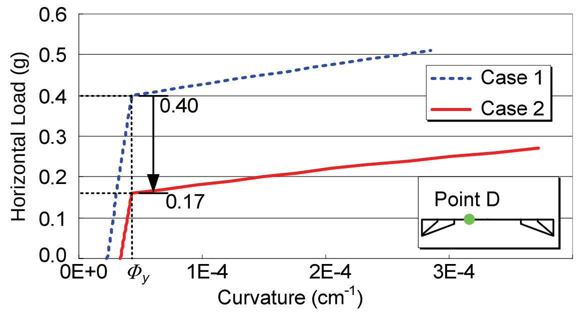

Fig.5 Curvature History of Middle Span

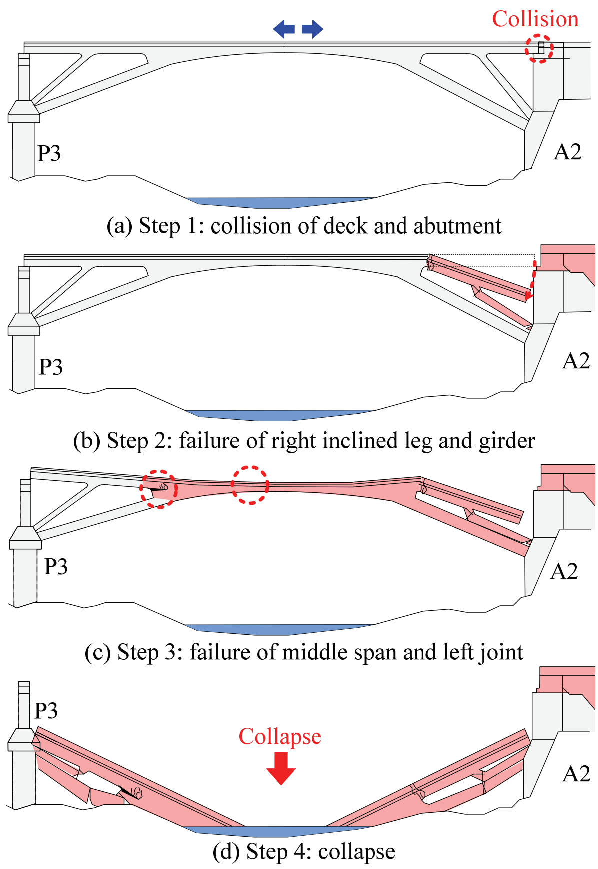

Fig.6 Failure Mechanisms of Span 4(upstream)