Damage of Bridges due to kumamoto Earthquake

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1. Introduction of Kumamoto Earthquake

2. Okirihata Bridge

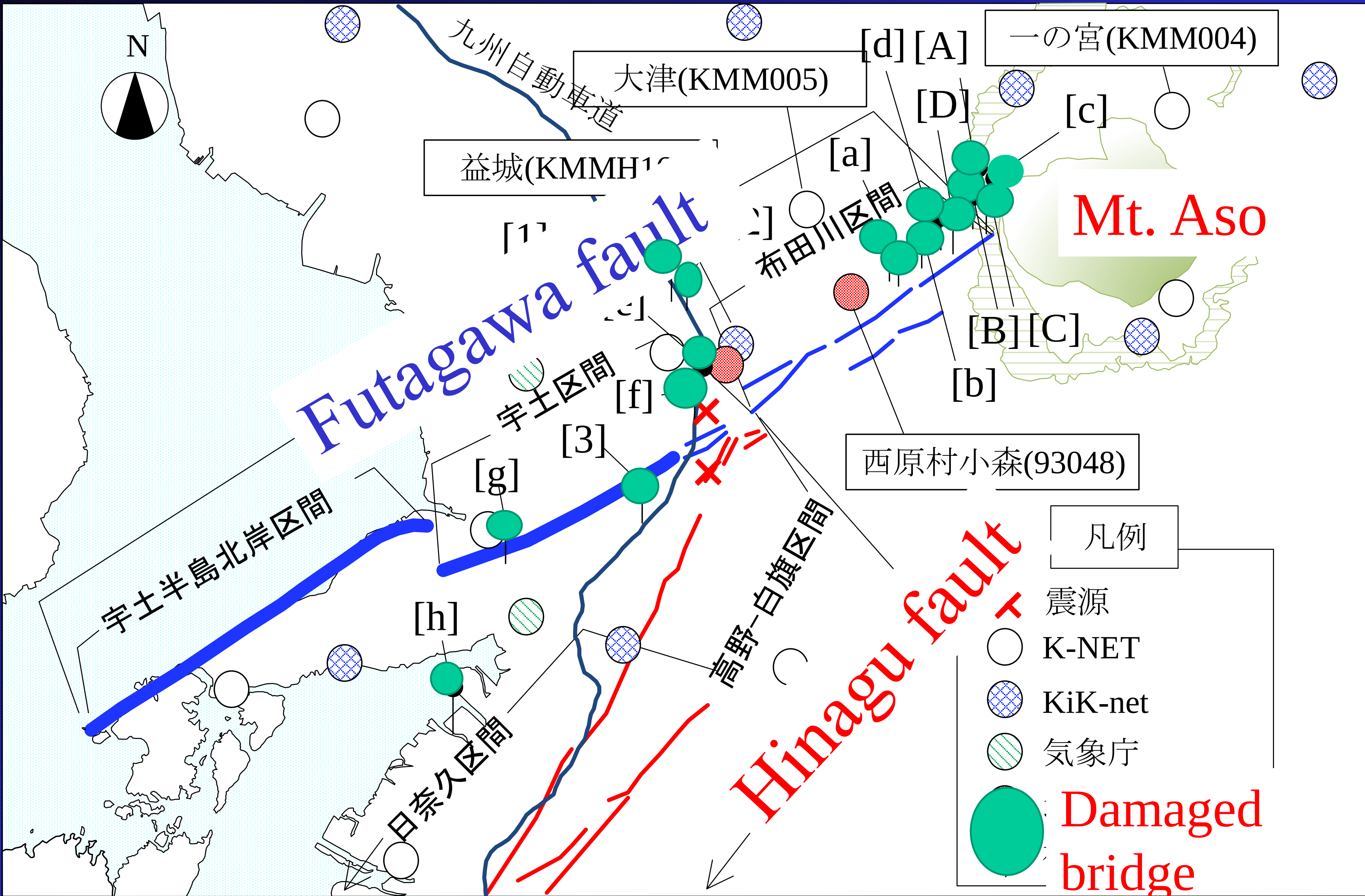
3. Aso Bridge

4. Minami-aso Arch Bridge

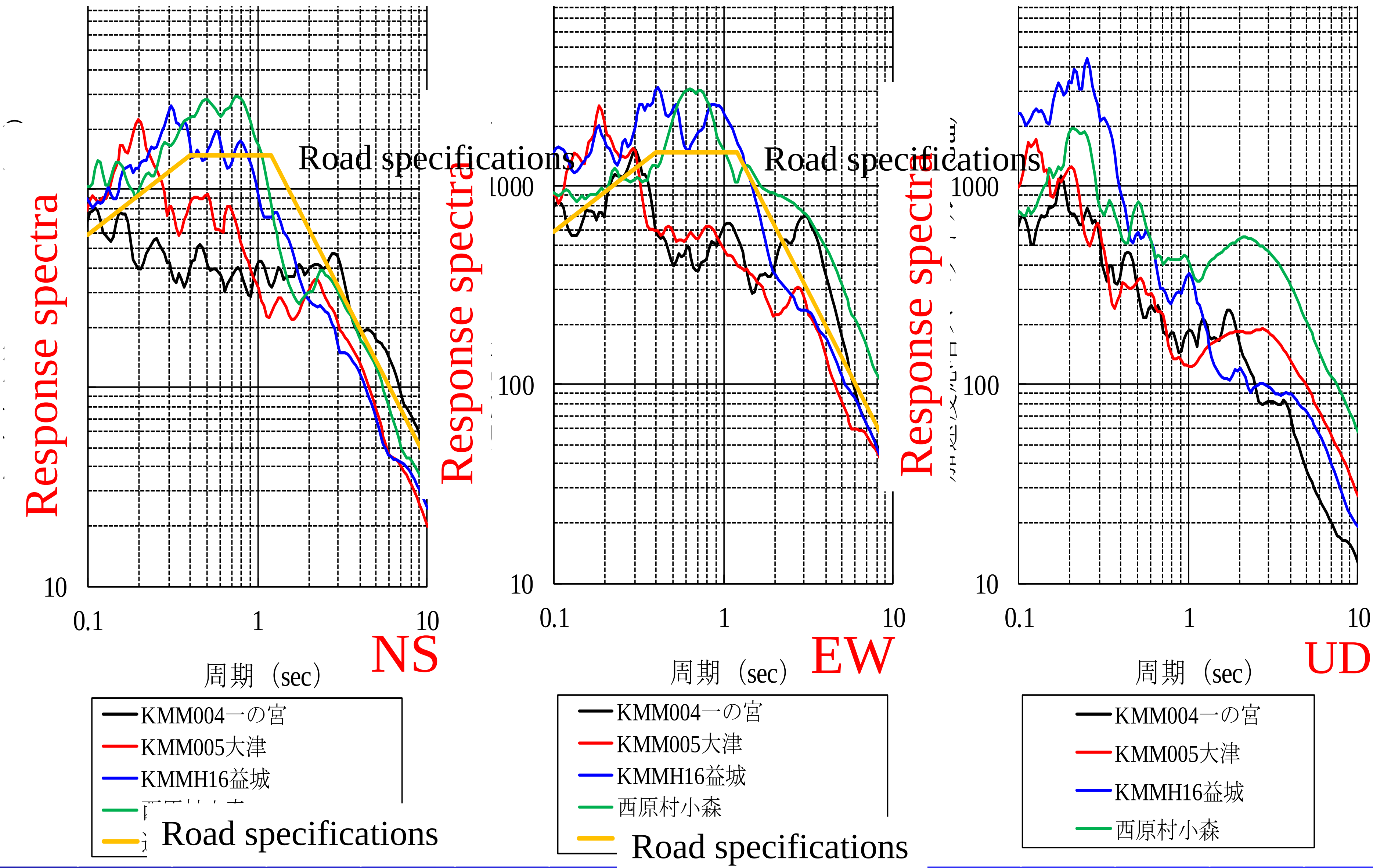
5. Damage to Rocking Piers

6. Damage to Footings

1.(1)Bridges were damaged along Hinagu and Futagawa faults. Damage was caused by ground motion and ground movement.

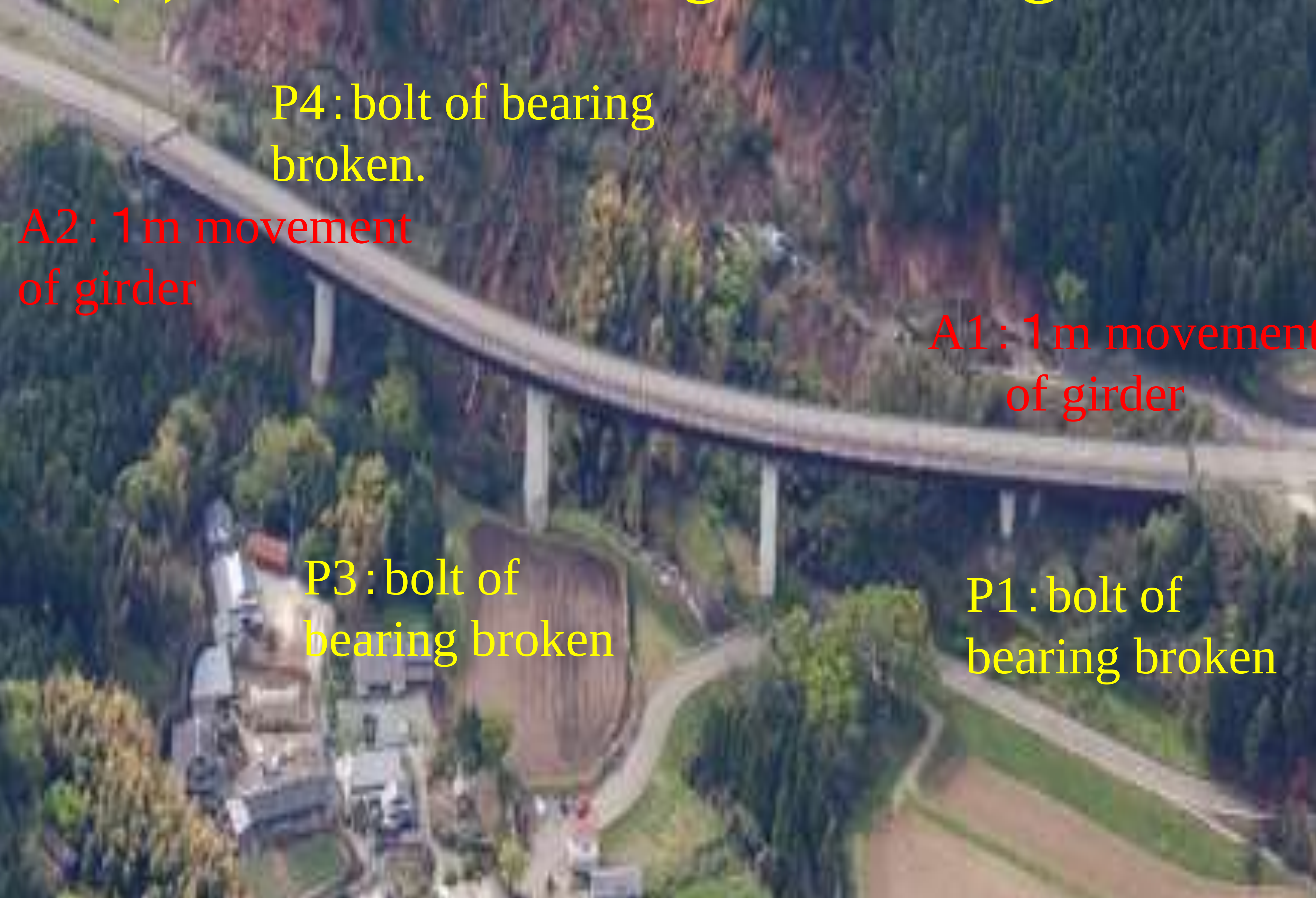


Acceleration response spectra of Kumamoto Earthquake

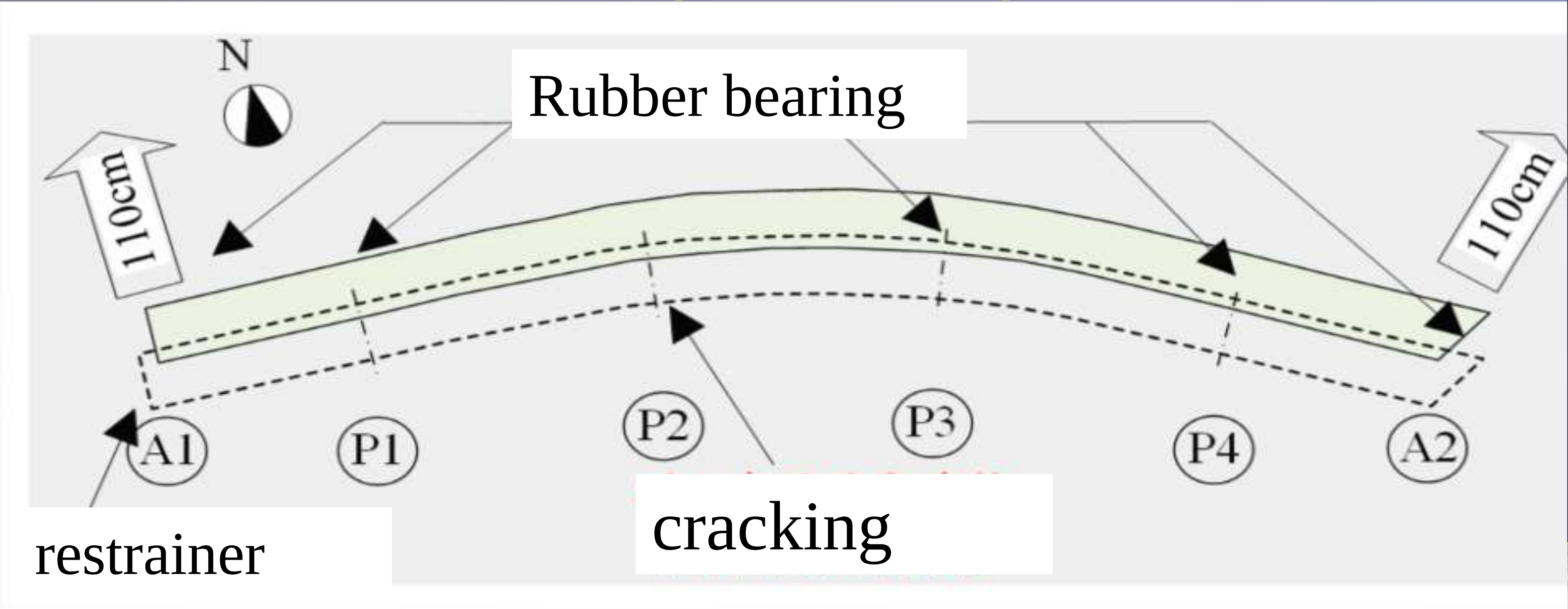


1.(2) Kumamoto spectra exceeds stad. spectra by Road Spec.

2. (1) Okirihata Bridge - Damage



2. (2) Okirihata Bridge - Damage



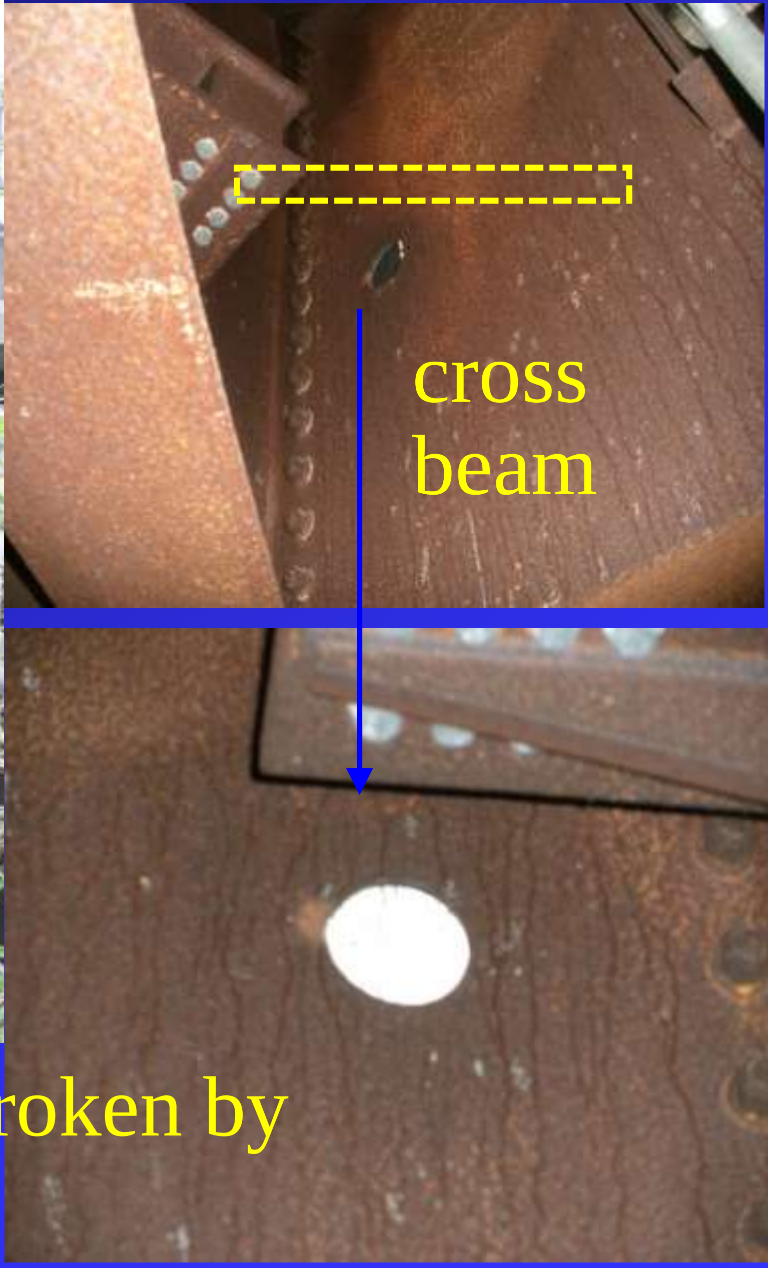
1. At A1, A2, P1, P3, P4, rubber bearings were broken.
2. At P2, cracking occurred at the column.
3. At A1, PC cable restrainers were broken.

2. (3) Okirihata - Rubber Bearing

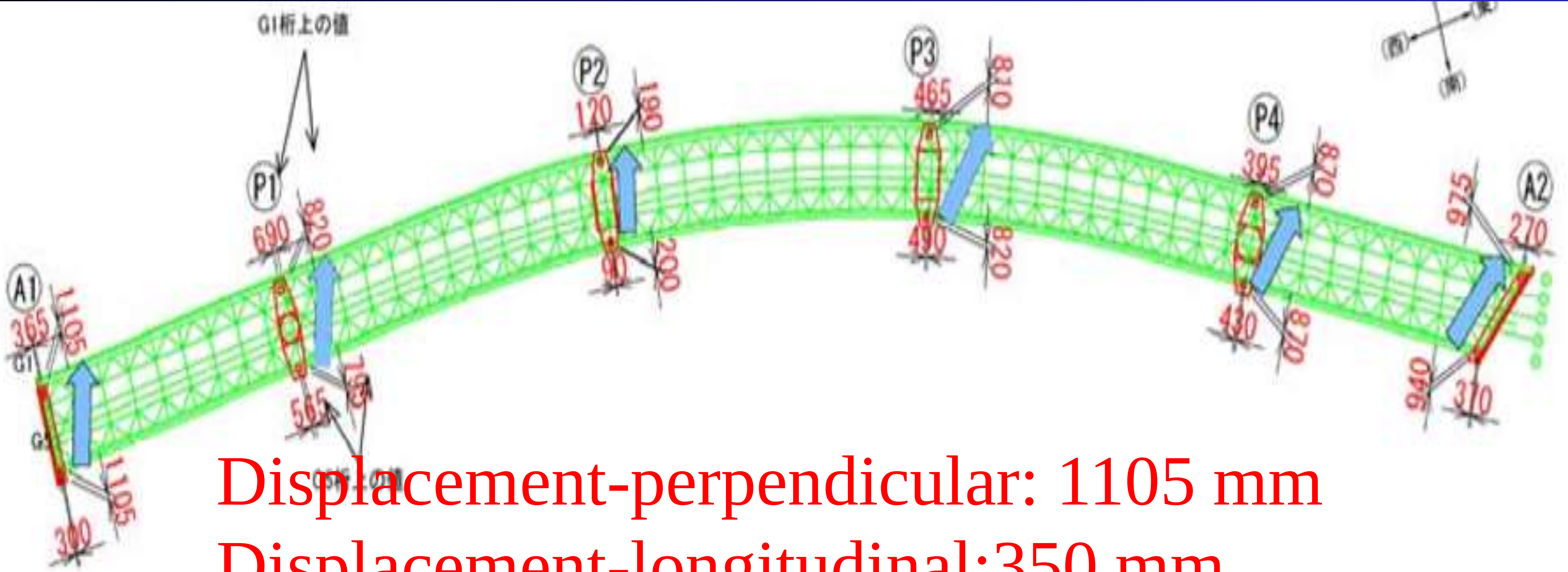
Rubber portion of rubber bearing was broken.

Main girder moved to the transverse direction about 30cm.

2. (4) Okirihata Bridge - cable restrainer



All (10) cable restrainers were broken by the movement of girder.



Displacement-perpendicular: 1105 mm
Displacement-longitudinal:350 mm

2. (5) Okirihata Bridge – Damage of Rubber Bearing

1. The Rubber portion was broken into two parts.
2. Displacement between upper rubber portion and lower rubber portion was measured.
3. About 1 m displacement was observed due to the movement at substructure.
4. Rubber bearing was weak for ground movement

2. (6) Okirihata Bridge – Damage of Rubber Bearing

h= 20cm

Allowable displacement=20·300% =60cm

Actual Displacement=100cm

Rubber bearing was weak for ground movement

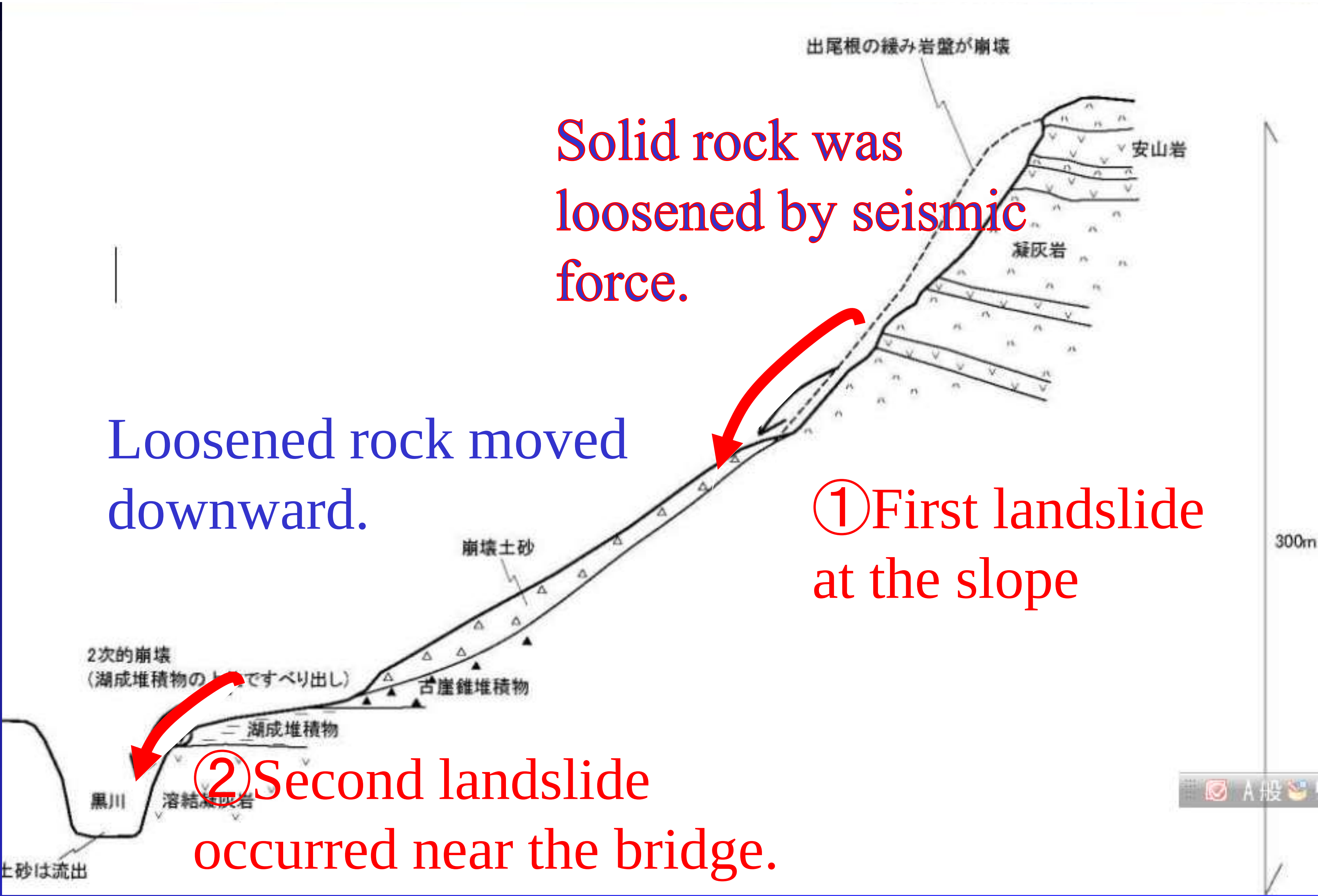
3.(1) Aso Bridge - Slope Failure

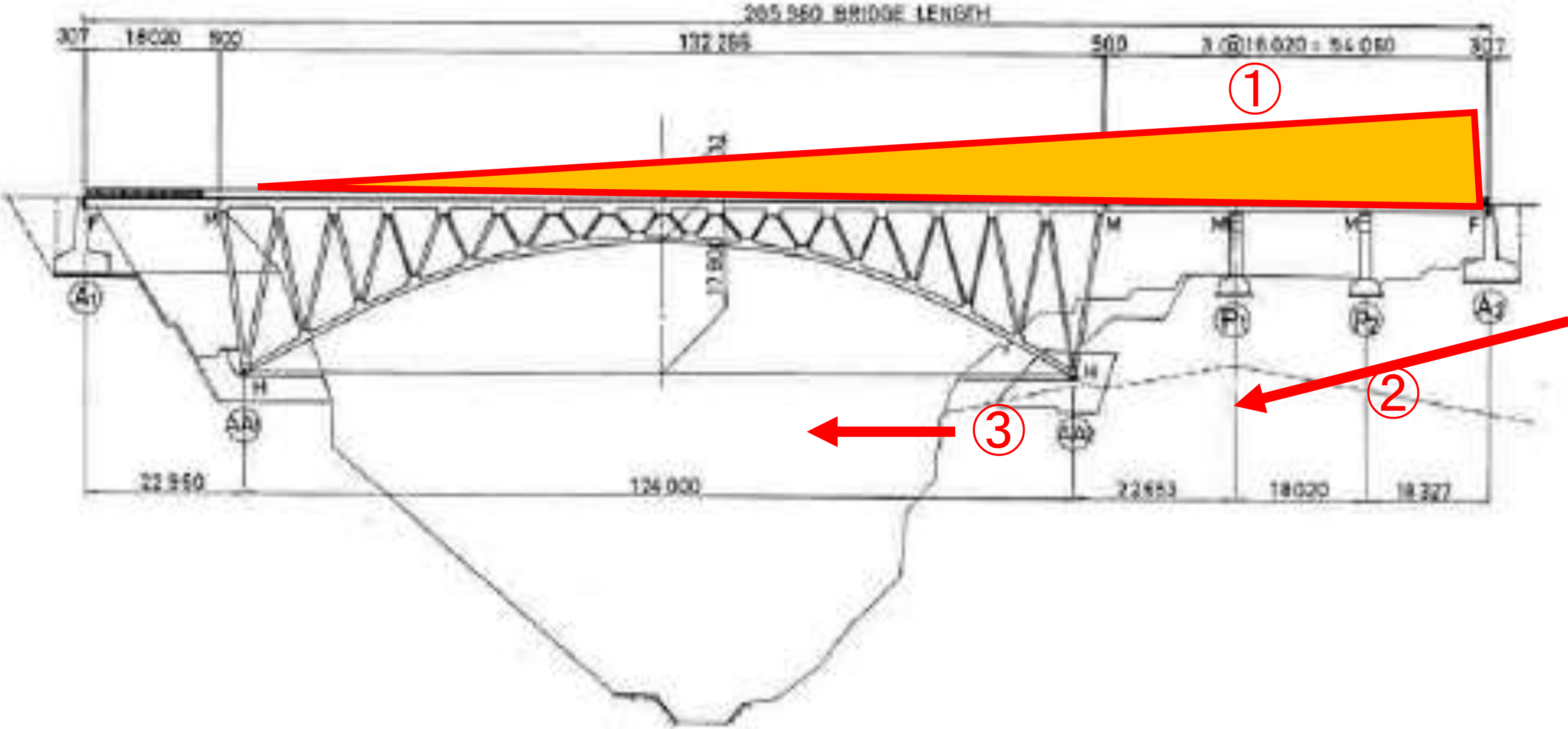
Many people considered the Aso Bridge collapsed due to landslide. Was it true?

3.(2) Aso Bridge- Collapase of bridge

Collapse of bridge (main span & side span)

3.(3) Aso bridge - slope failure





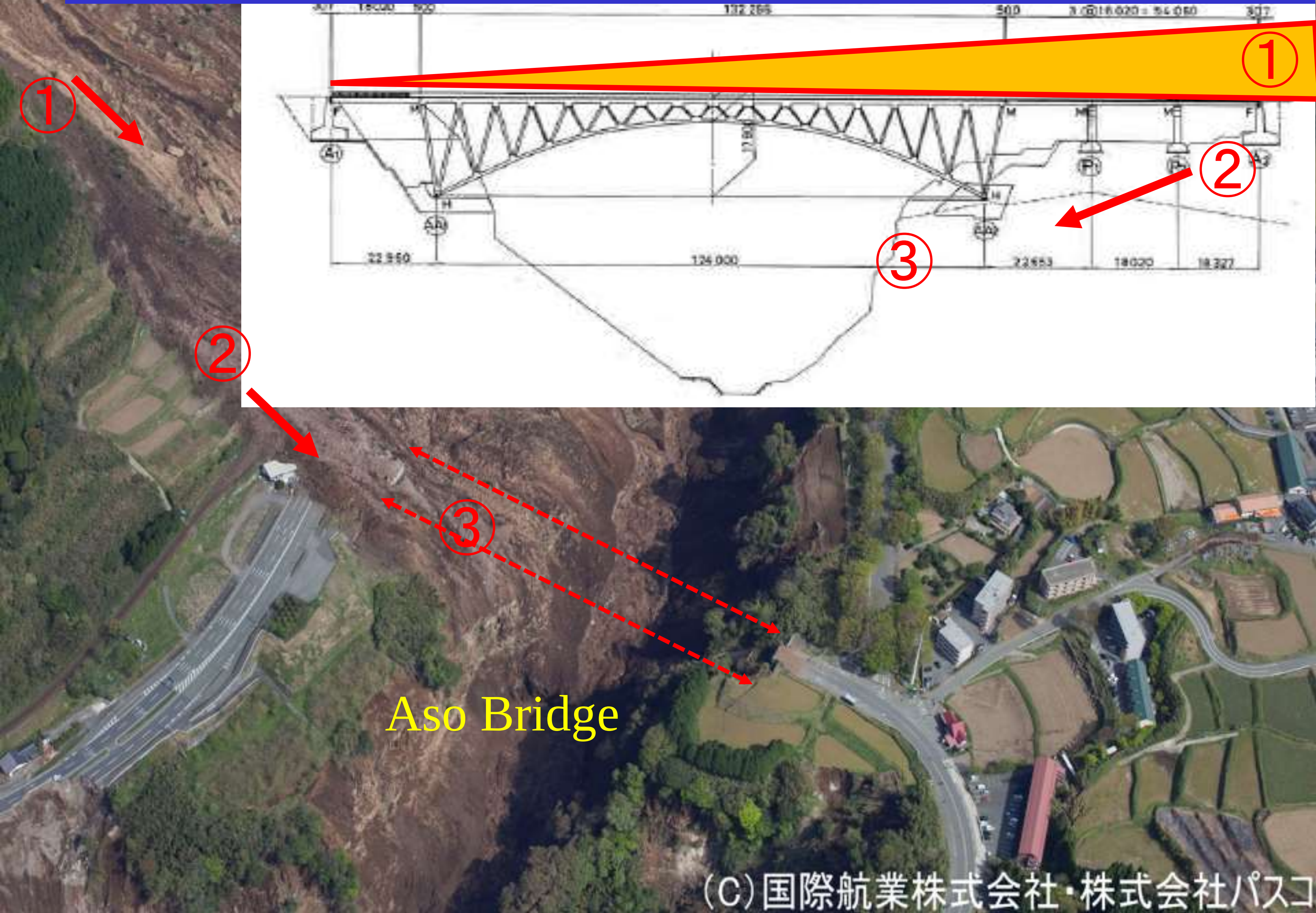
3. (4) Possible cause of bridge collapse

①Accumulated soil by the first landslide

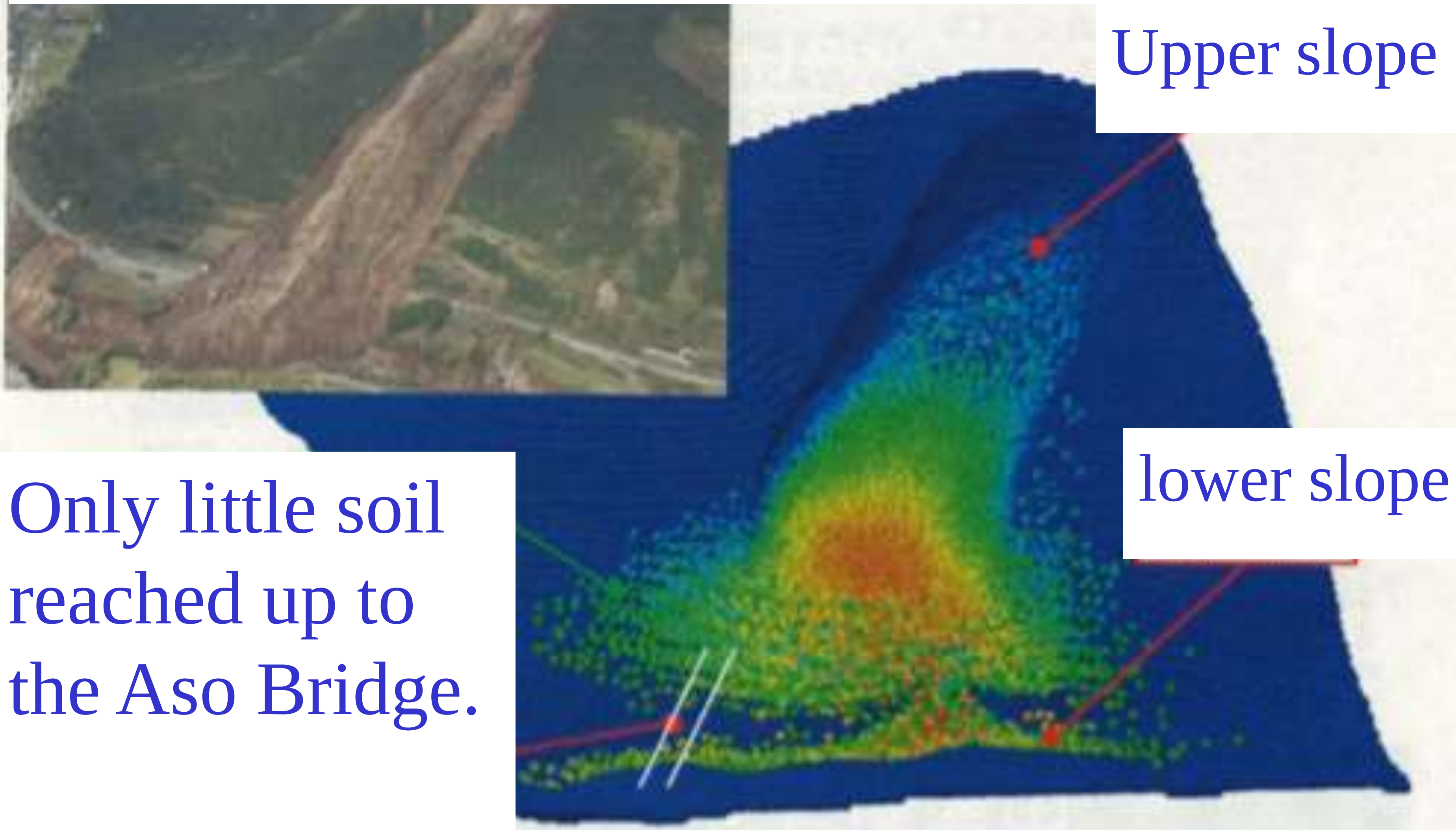
②Movement of soil by the second landslide, or

③Displacement of abutment (Fault effect?)

3. (5)Possible cause of bridge collapse:①, ②or③

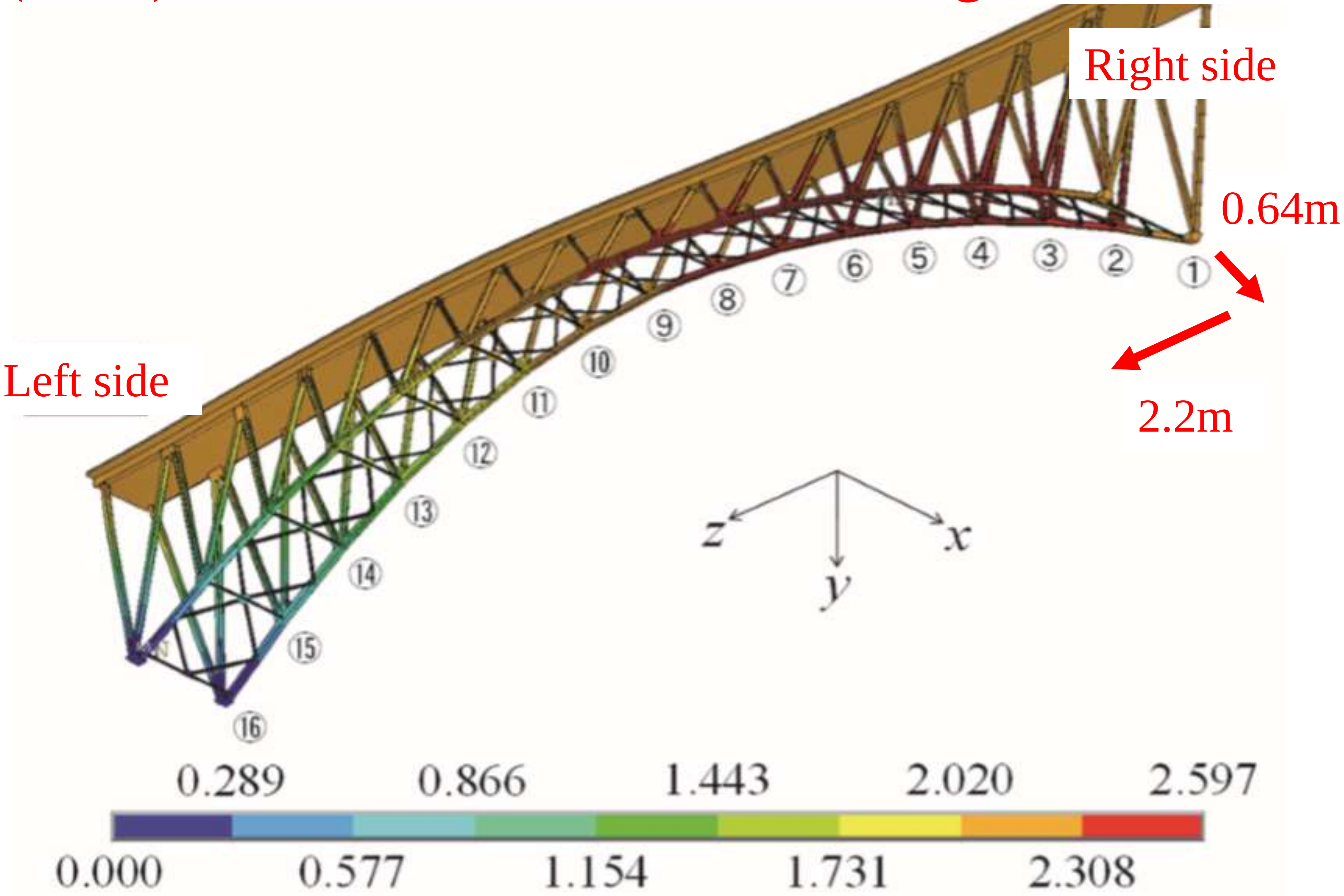


3. (6) To investigate Cause①, SPH(smoothed particle hydrodynamics) method was applied (Kiriyama)



Little possibility as to Cause① (first landslide)

3.(7) Cause2 or 3:Displacement of abutment (2.2m)lead arch rib to the ultimate stage.(che)



3. (8) We need more information.

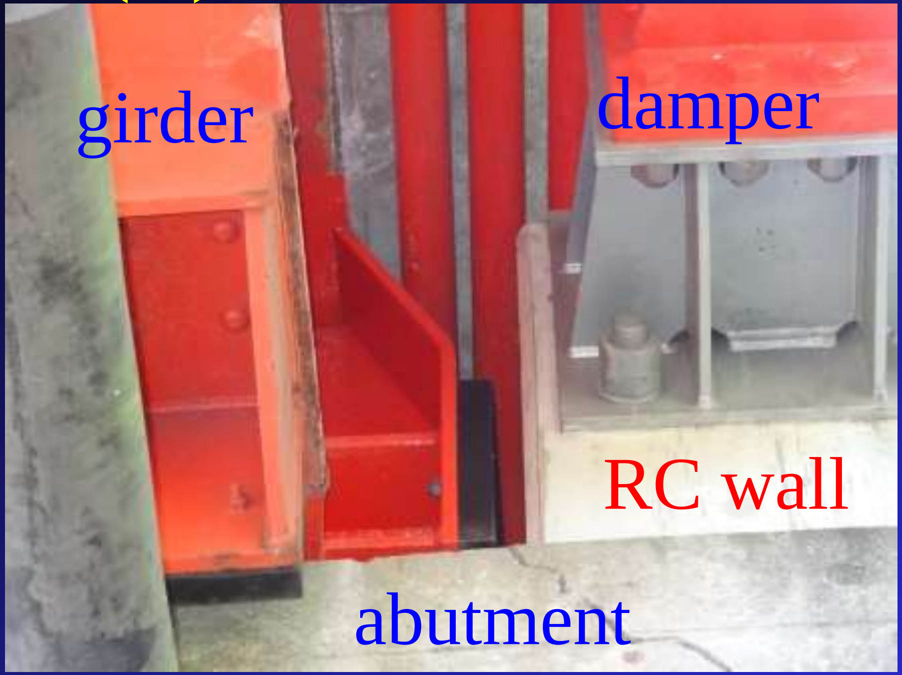
1. How far was the arch abutment displaced?

2. How much landslide soil was accumulated around the bridge?

4. (1) Minami-aso Arch Bridge

Damper had been installed as retrofitting. Punching shear failure occurred between damper and abutment.

4. (2) Direction of movement



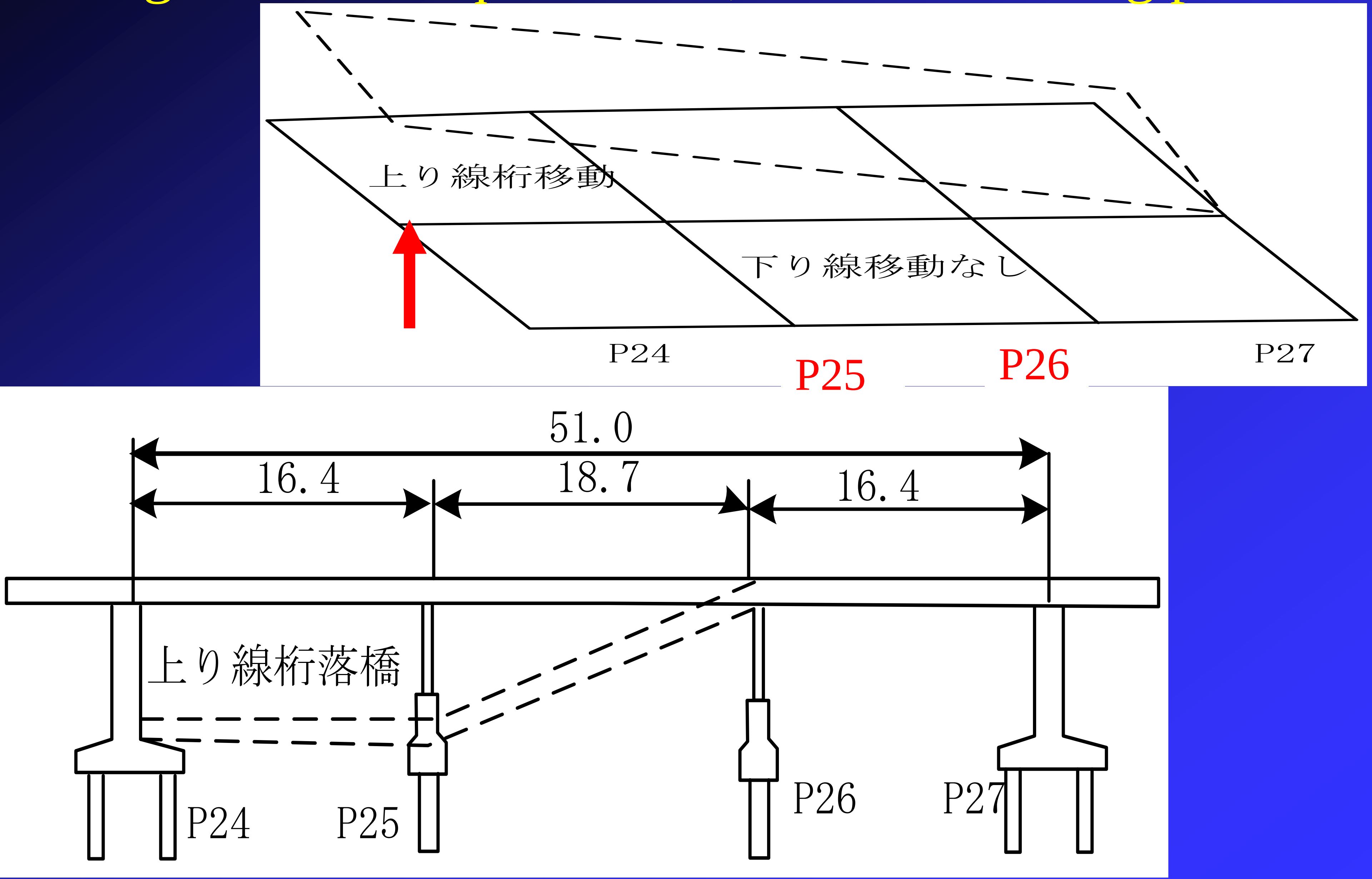
1. Side block was not damaged.
2. The girder beside the RC wall was not damaged, so the movement was not in the transverse direction.
3. Movement occurred in the longitudinal direction

4. (3)Scratch due to movement was observed.
Punching shear failure had not checked during design.

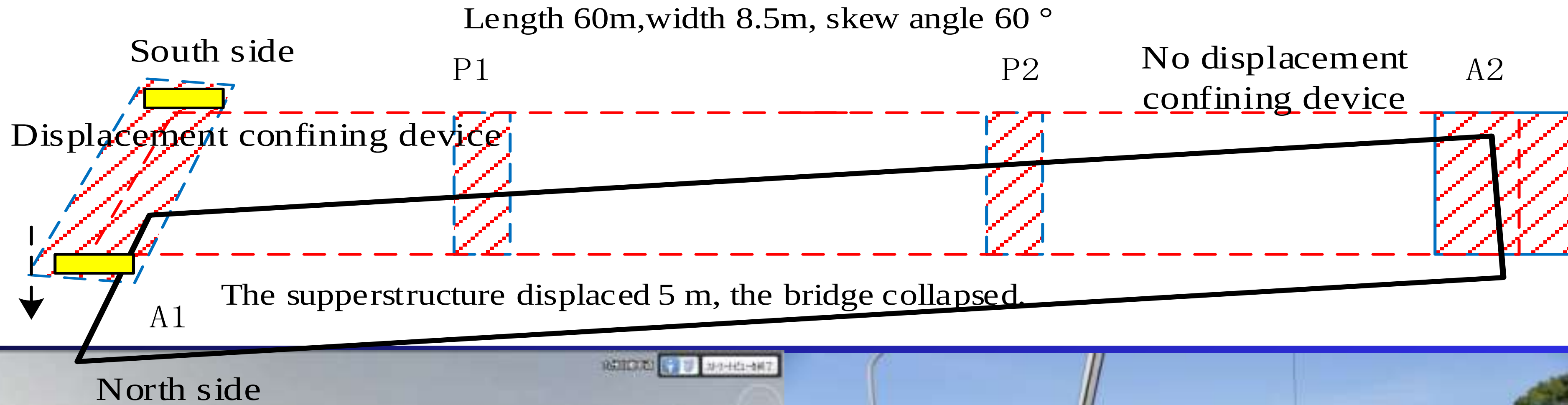
5. (1) Damage to Rocking Piers

1. Rocking piers (Kawaragi) damaged in the 1995 Kobe Earthquake.
2. Rocking piers at three bridges (Furyo, Higashihara, Takagi) were damaged in the Kumamoto Earthquake
3. We investigated the cause of failure of rocking piers.

5. (2) One rocking pier (Kawaragi) was collapsed during Kobe earthquake. P25, 26 were rocking piers.



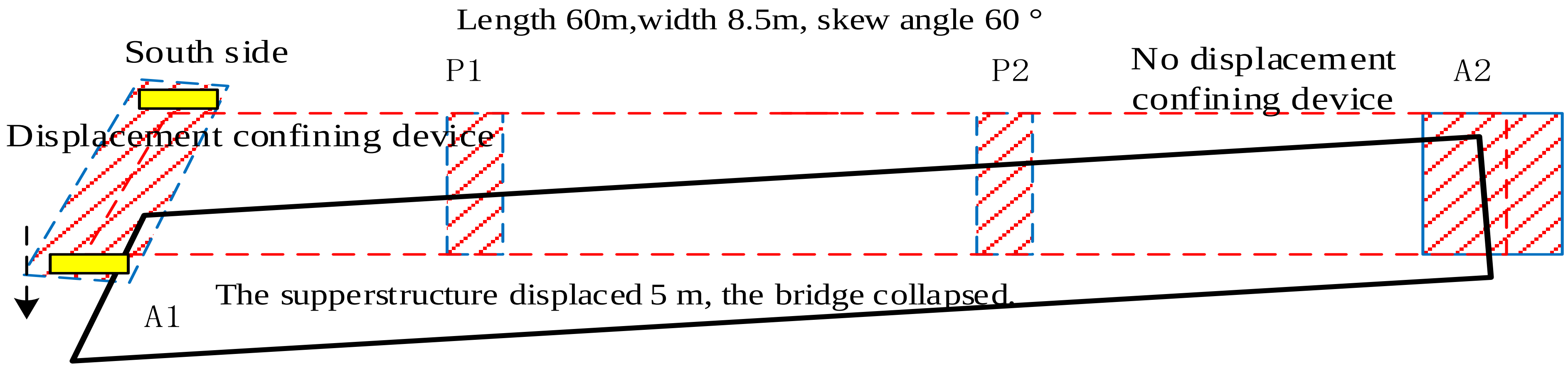
5. (3) Skew girder rotated and fell down in the 1995 Kobe Earthquake.



5.(4)Furyo Daiichi Bridge in Kumamoto Earthquake

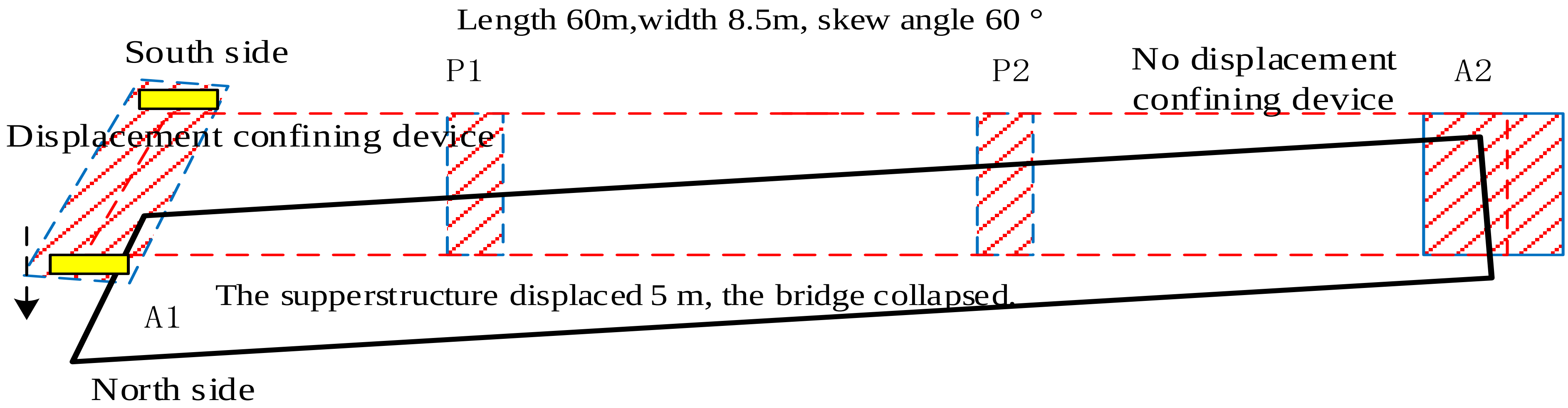
Span length was 60m. P1 & P2 were rocking columns.

Skew girder rotated and fell down.



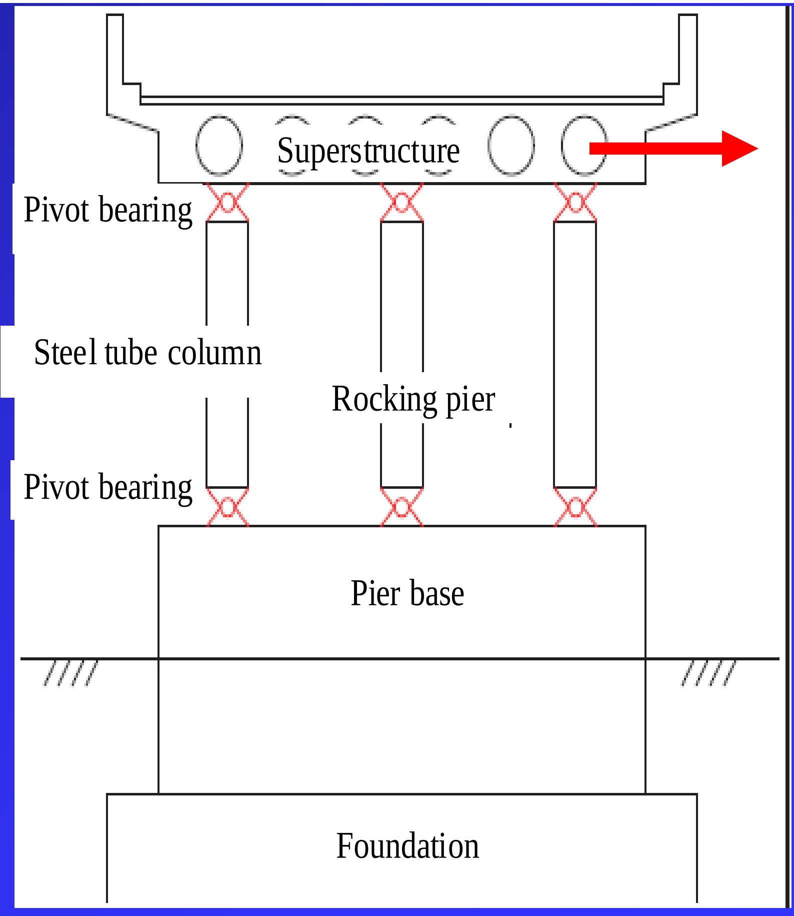
5. (5)Damage at Furyo Daichi Bridge

1. The girder collided with the restrainers due to rotation.
2. Punching shear failure occurred at the connection of restrainer and abutment.



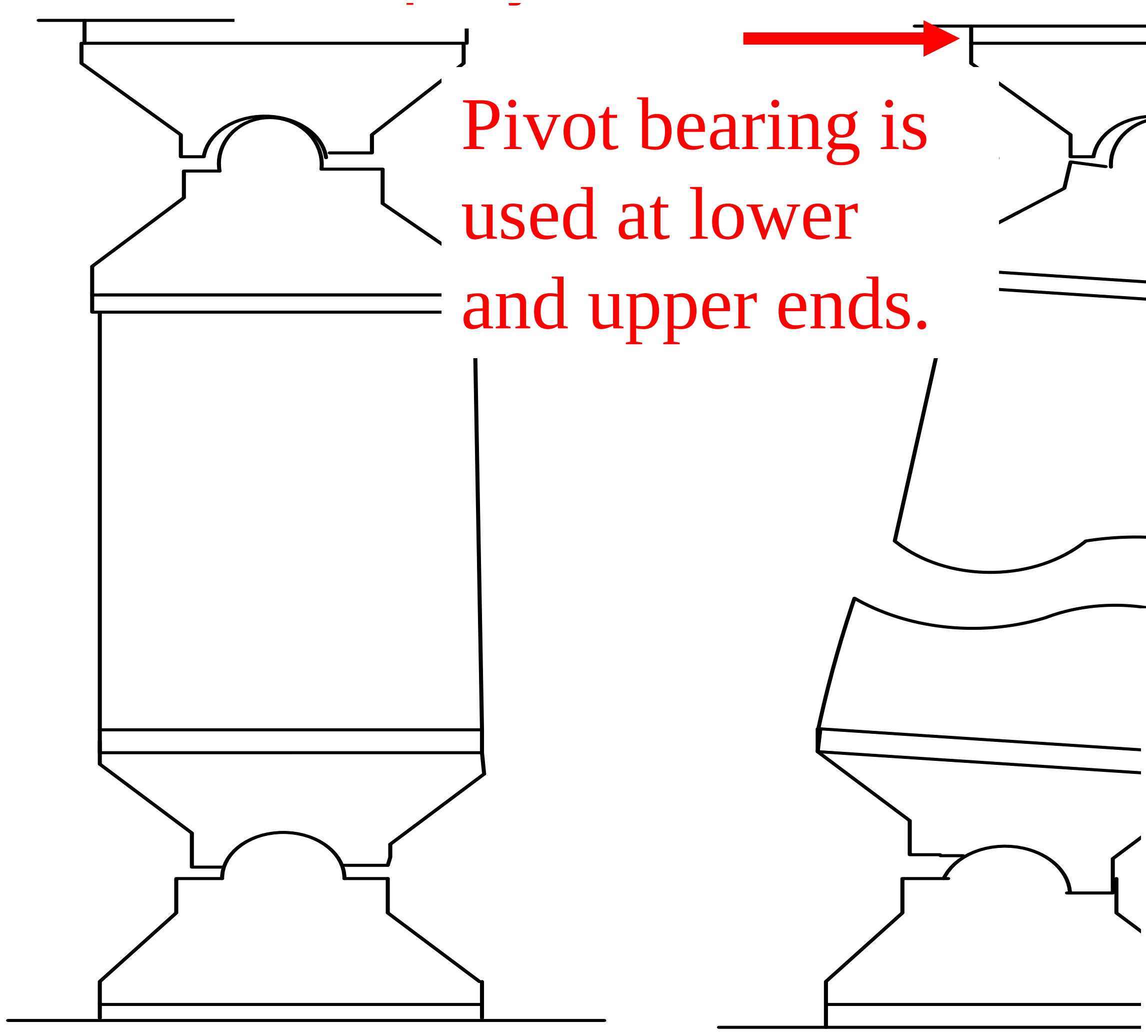
5. (6) Damage to rocking piers

1. Girder moved to the transverse direction.
2. Pivot type bearing was used.
3. When the rotating angle was over 0.06 rad, pivot bearing collided with plate, and leads to the collapse of the bearing.

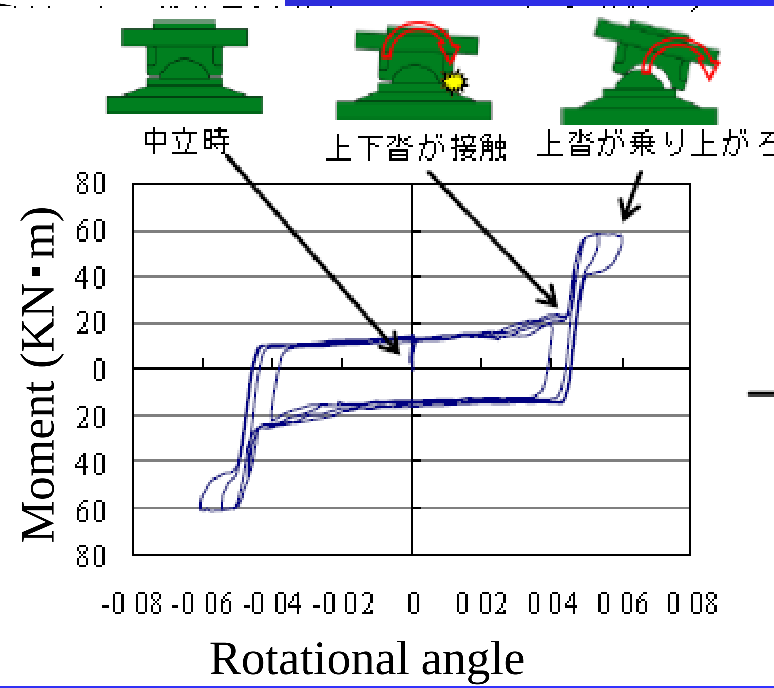


Under dead load

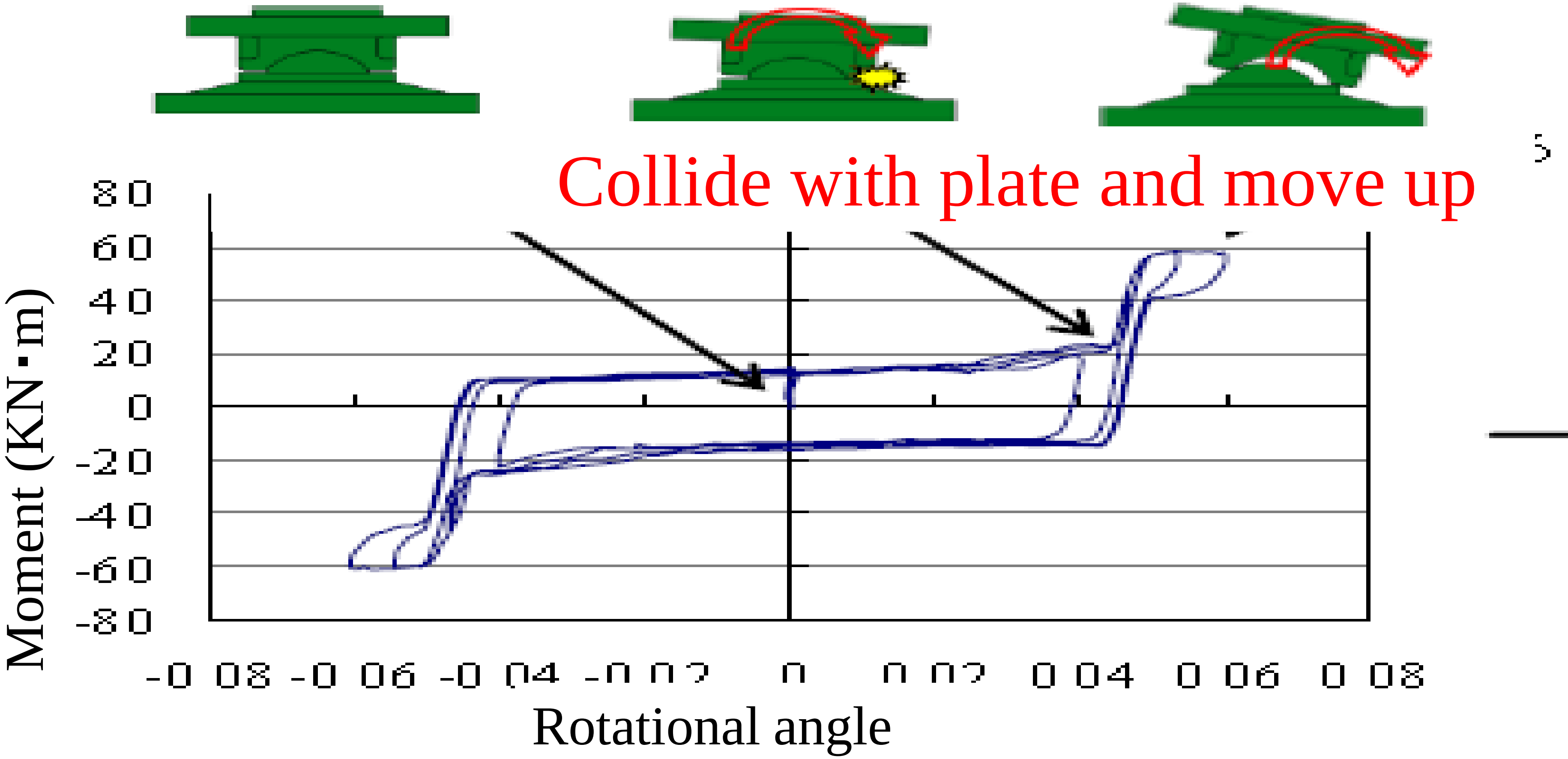
Under seismic force



Pivot bearing is used at lower and upper ends.



5.(7)Bearings were damaged due to large rotation.

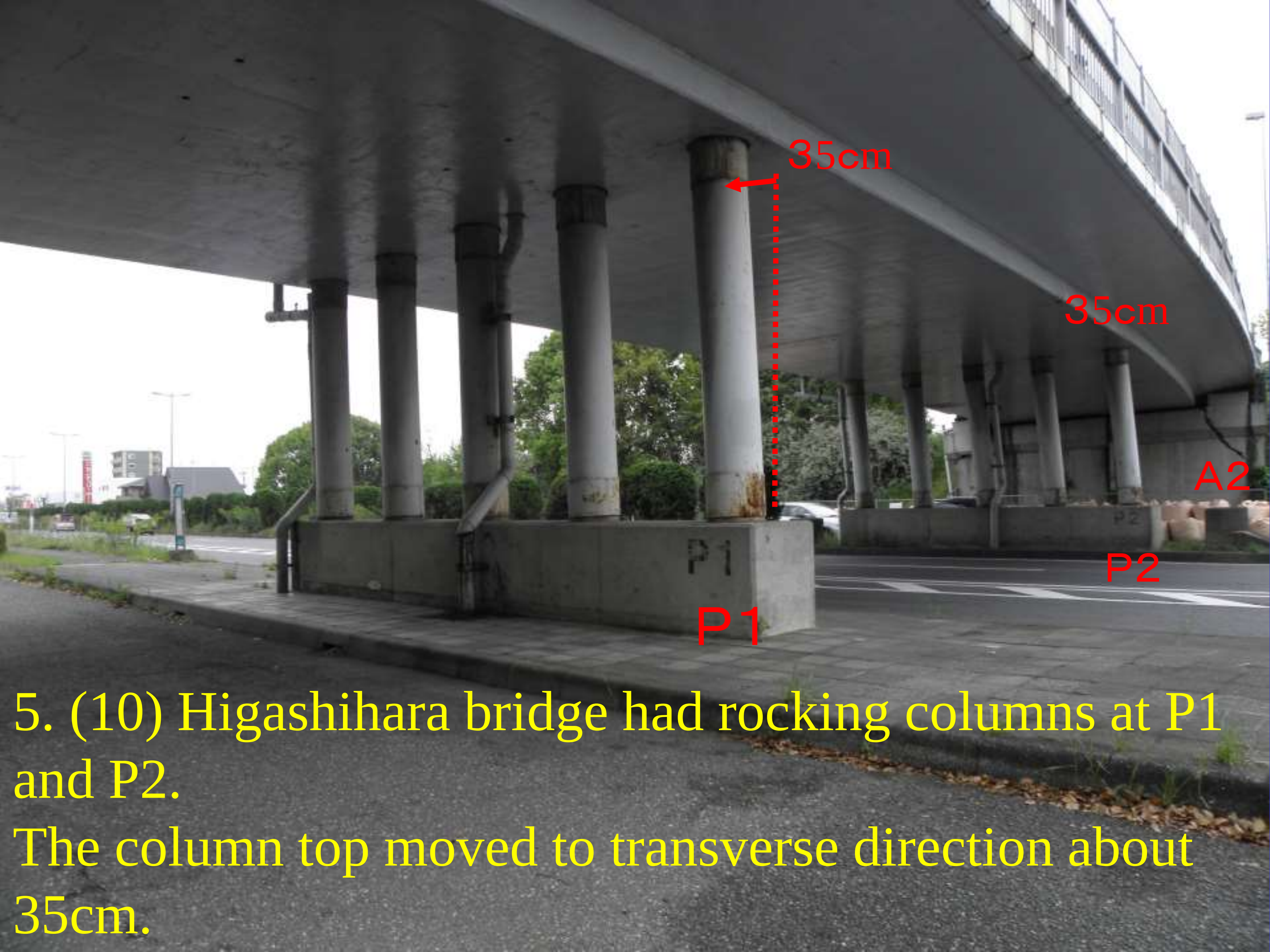


5.(8)1. When rotational angle of column was 0.06rad, this value is the limit angle of pivot bearing.

2. As the restrainers were completely collapsed, the pivot bearings rotated over 0.06rad, and the bridge collapsed.

5. (9)Design problems of Furyo Daiichi Bridge

1. P1, P2 were rocking columns. There was not installed for longitudinal restrainers.
   There was installed for transverse restrainers to protect rotation of girder.
2. F (Acting force for transverse direction)
   3kh (seismic coefficient:0.75G), Rd (Dead load)
   Ｆ＝3kh・Rd=1554kN
3. Actual applied acceleration would be larger than 3kh (about 0.75G).
4. Punching shear resistance=1076kN
5. Resistance is smaller than the acted force.

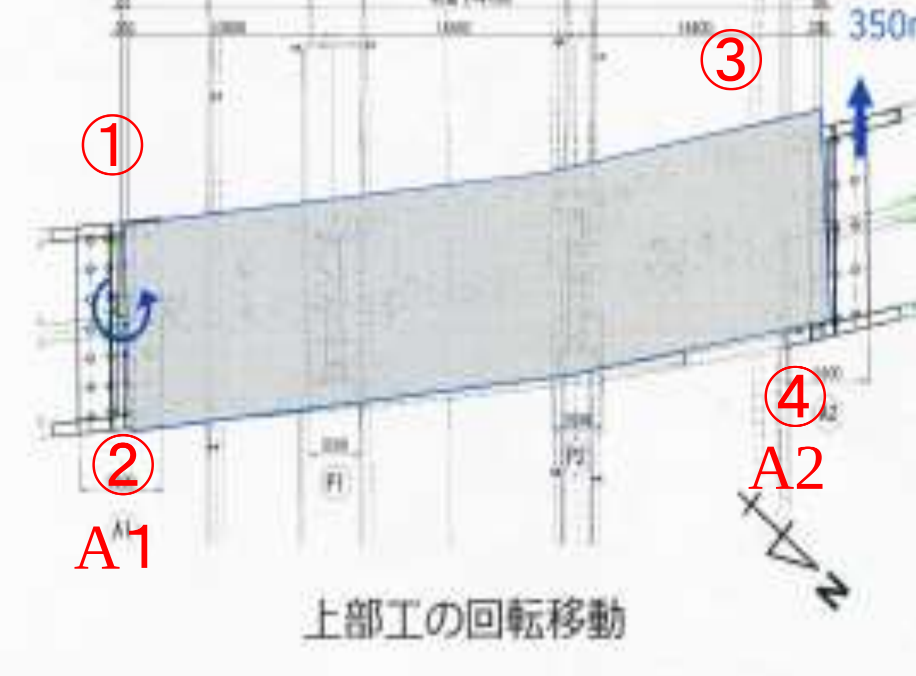


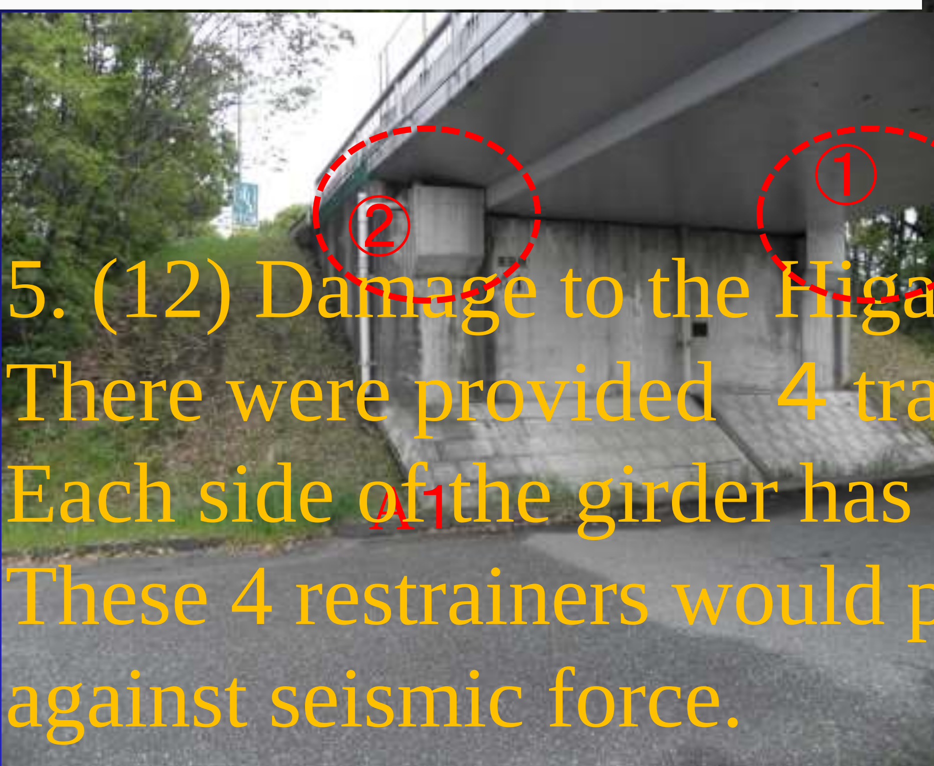
5. (10) Higashihara bridge had rocking columns at P1 and P2.
The column top moved to transverse direction about 35cm.

5. (11) Damage to the Higashihara Bridge

Transverse restrainers (concrete block) were completly damaged.

The bridge almost fell down to the national road.





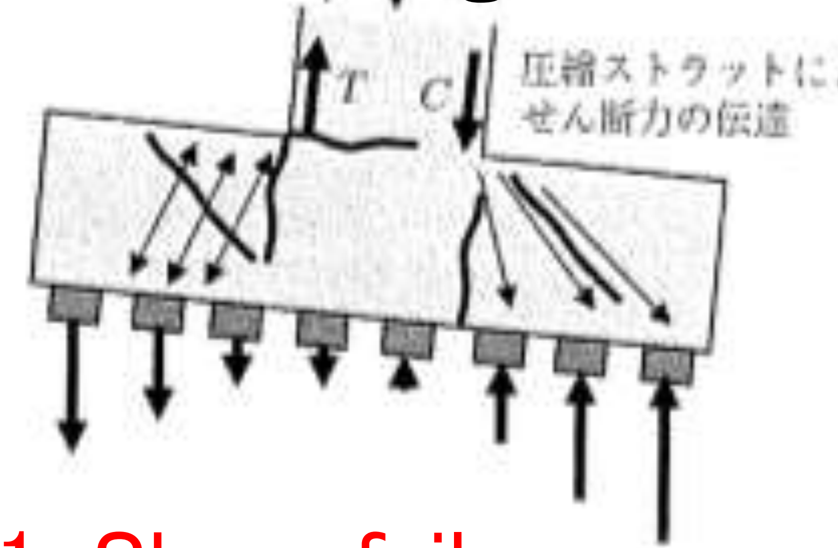
5. (12) Damage to the Higashihara Bridge

There were provided 4 transverse restrainers.

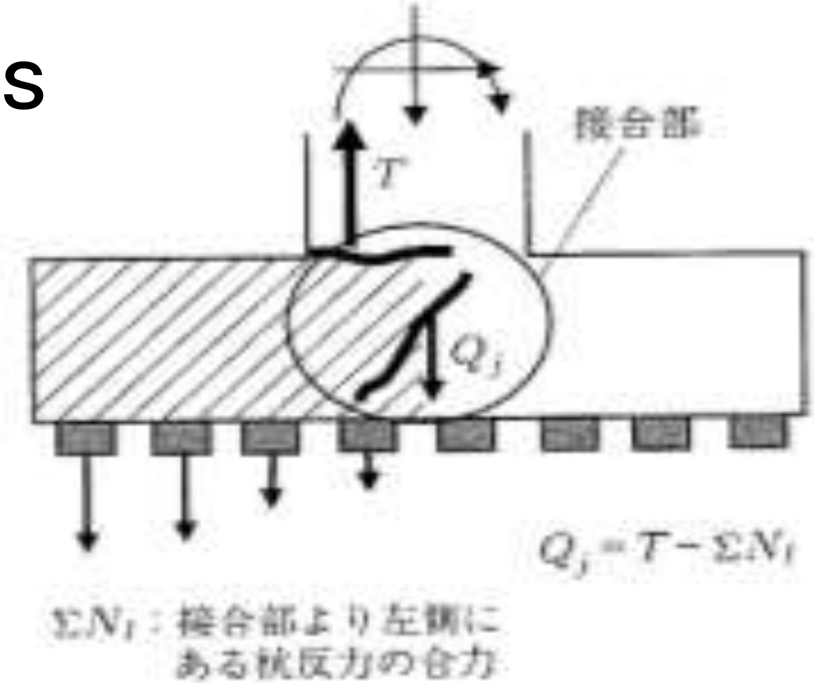
Each side of the girder has each restrainer.

These 4 restrainers would provide large resistance against seismic force.

6. (1)Damage to footings



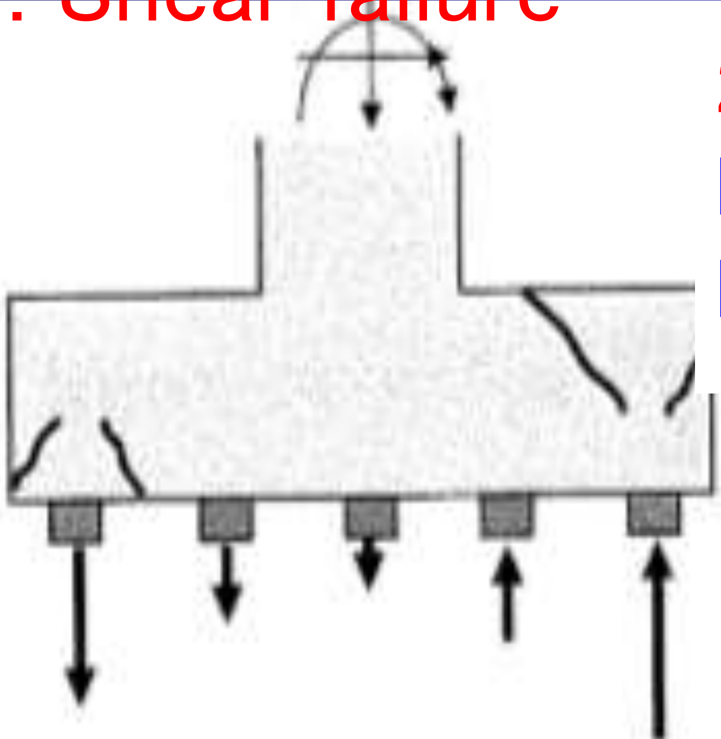
1. Shear failure



2. Shear failure at joint

Kobe EQ (Hanshin expwy)

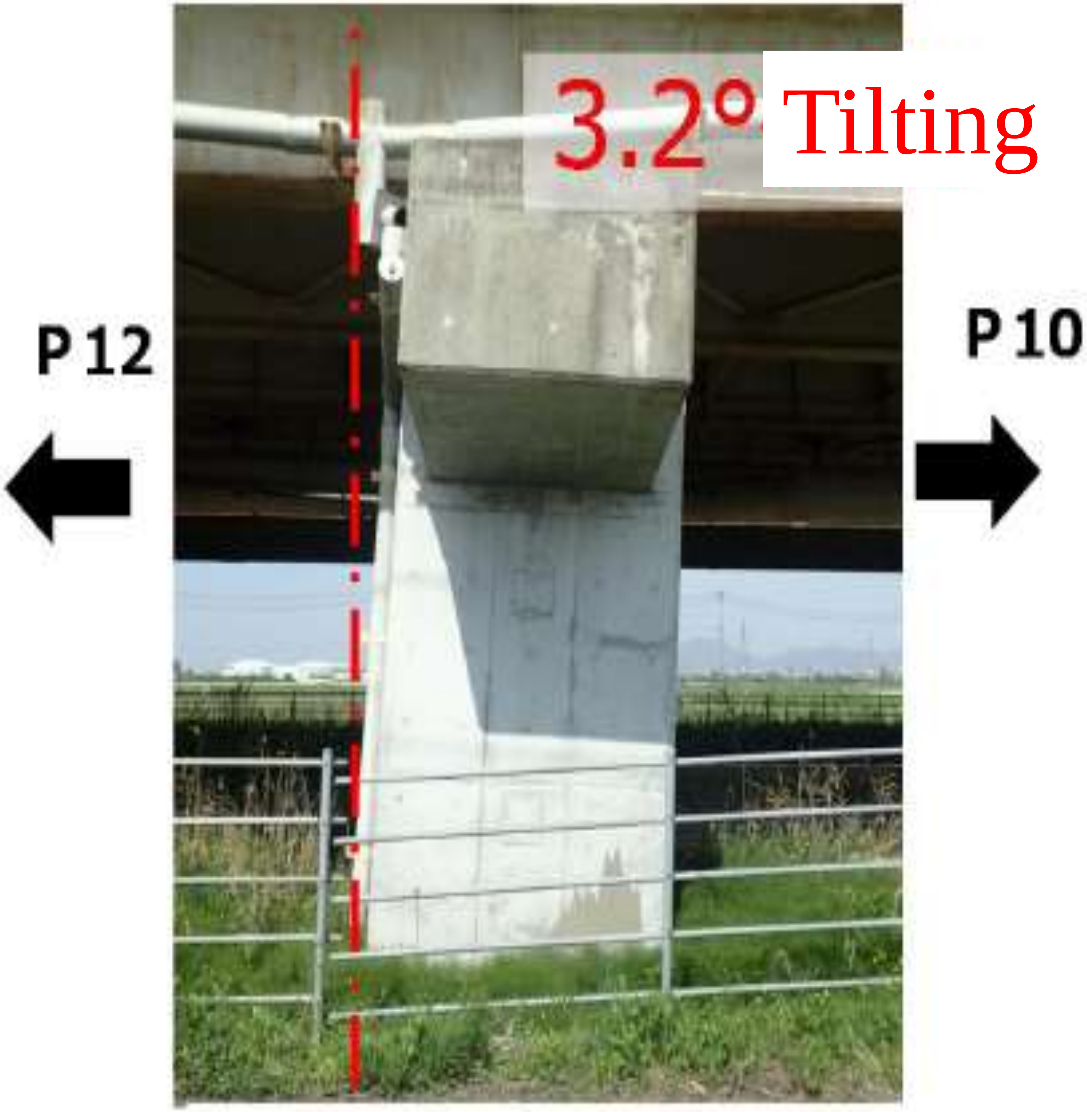
Kumamoto EQ (NEXCO expwy)



3. Punching shear

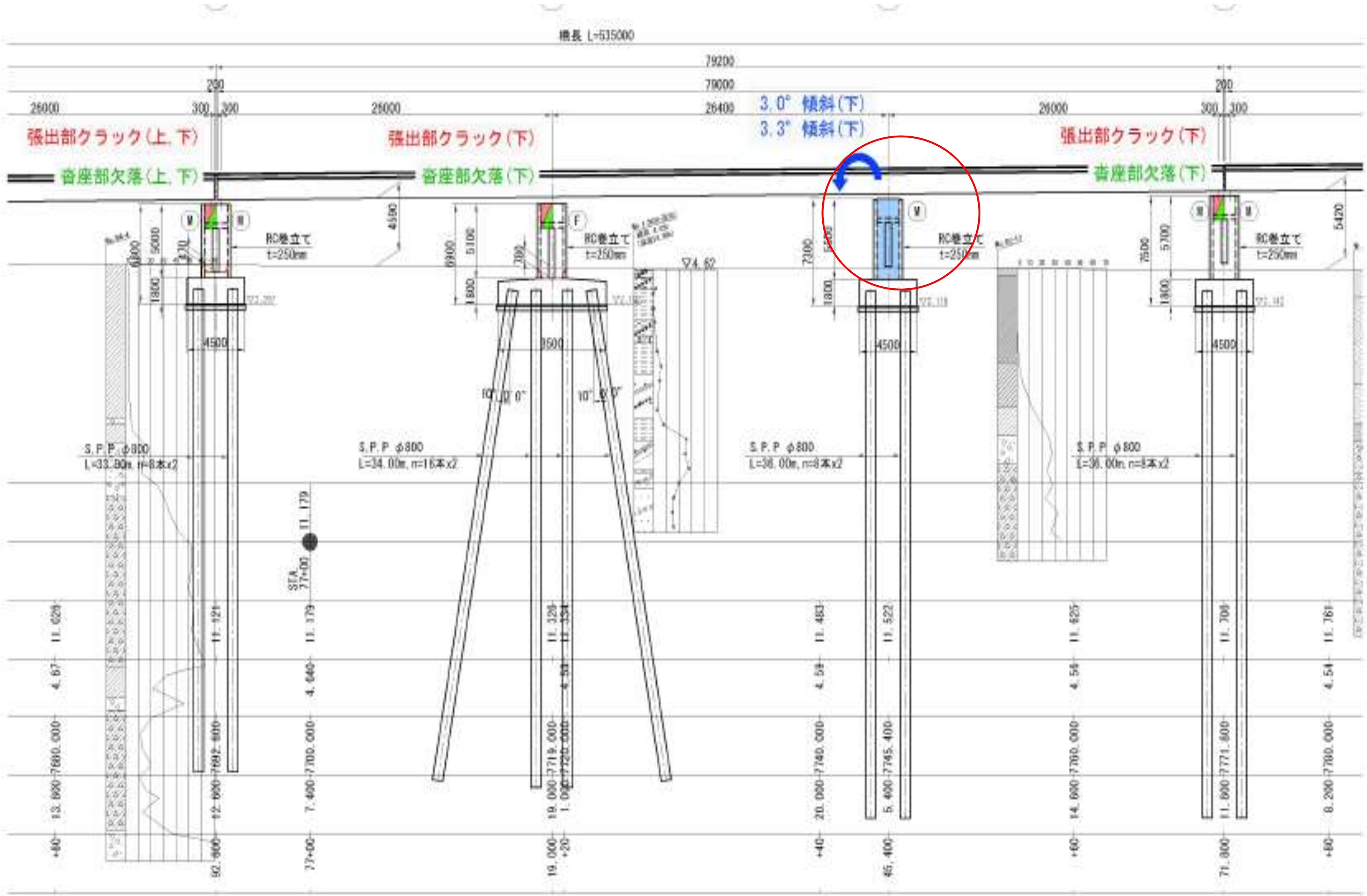
Kobe EQ (Hamate bypass)

6. (2) Damage to footings in Kumamoto Earthquake



Tilting of the column (3.2°) was observed.

6. (3) The RC column is retrofitted by concrete jacketing, and depth of pile is 40 m.



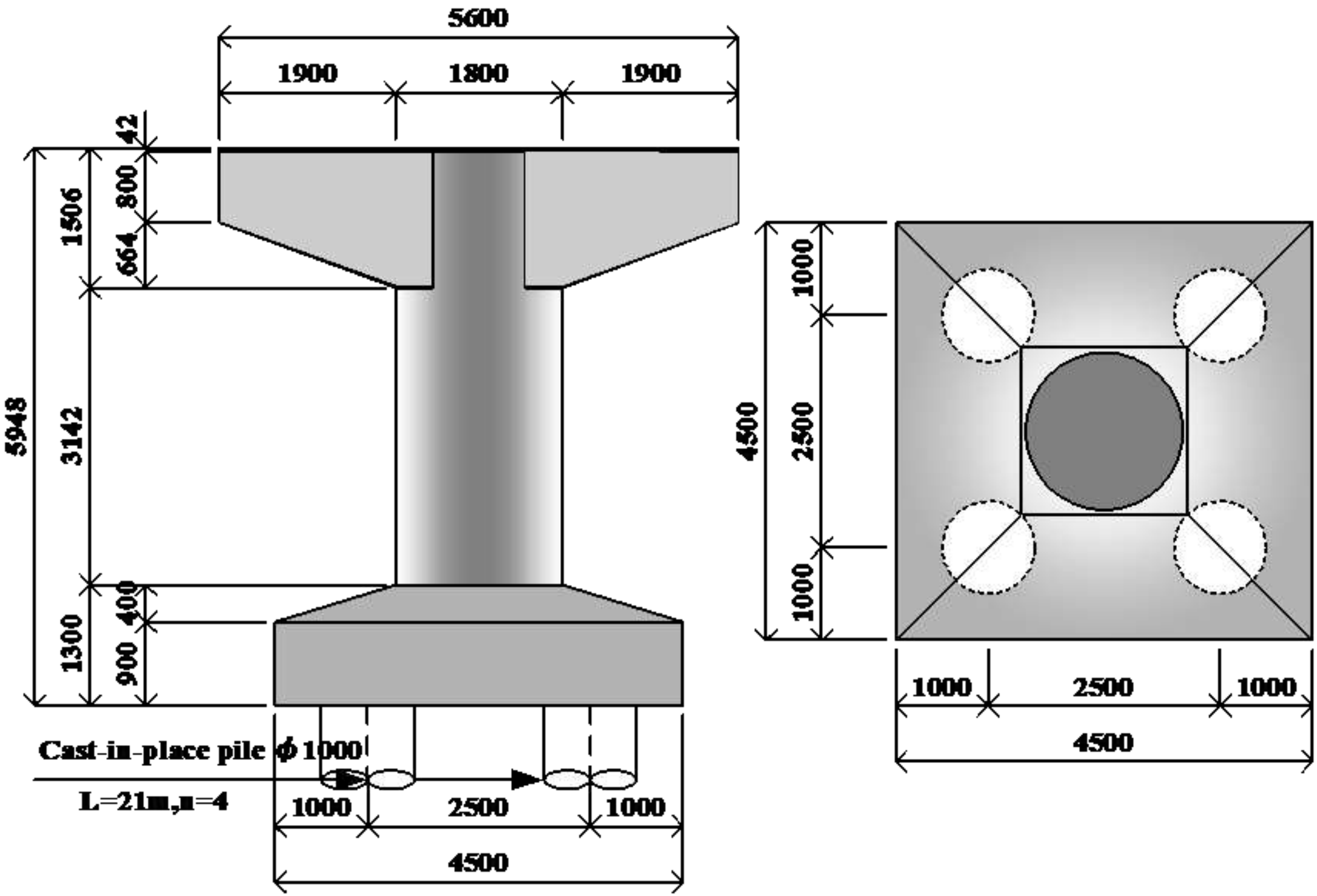
6. (4) Characteristics of damaged footing
Low main reinforcement & small sized footing

6. (5) Damage to footings in Kobe Earthquake

3 damaged footings were found.

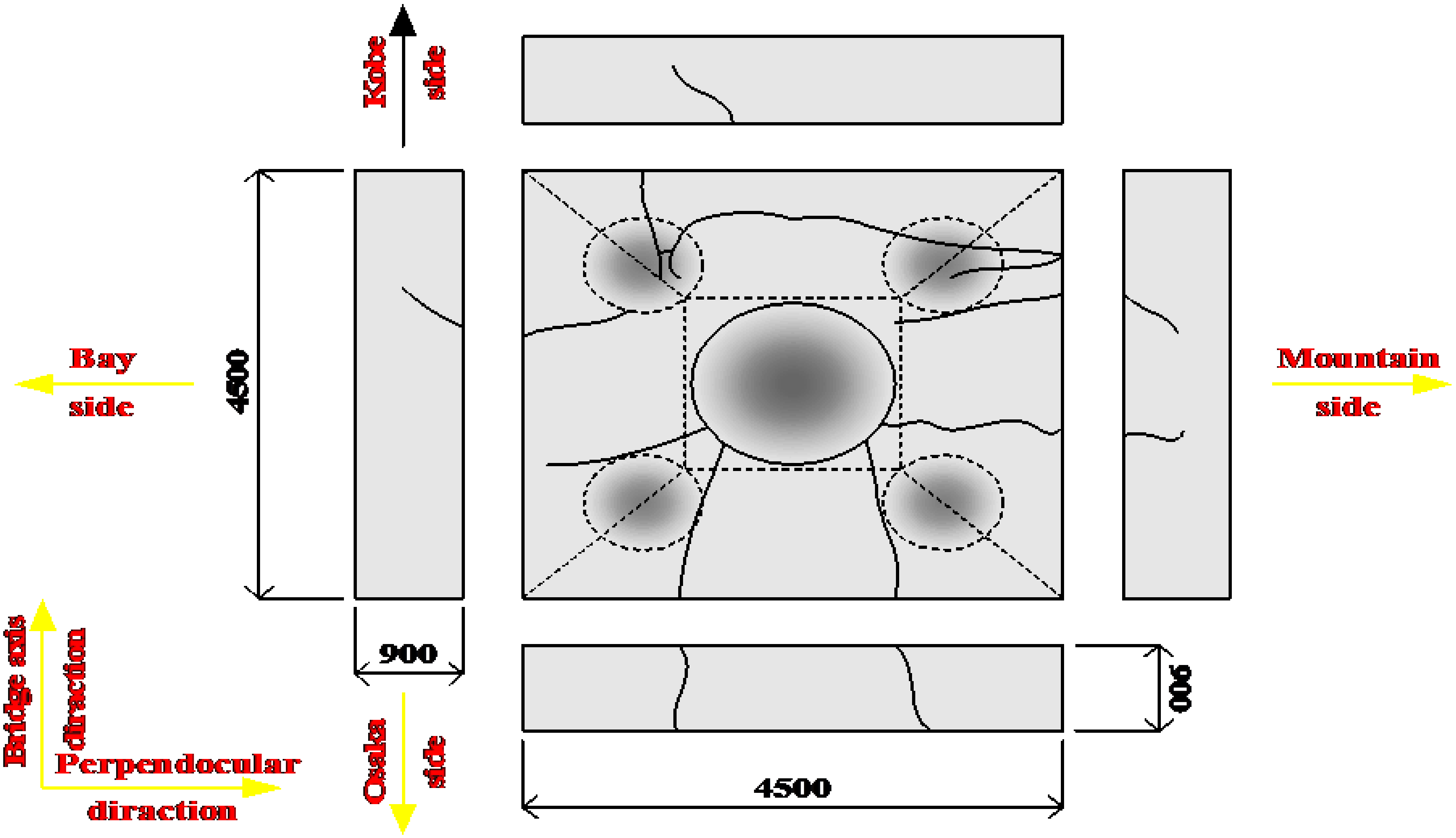
Cracks propagated to the radial direction.

6. (6) Cracks also propagated to the radial direction from the column.

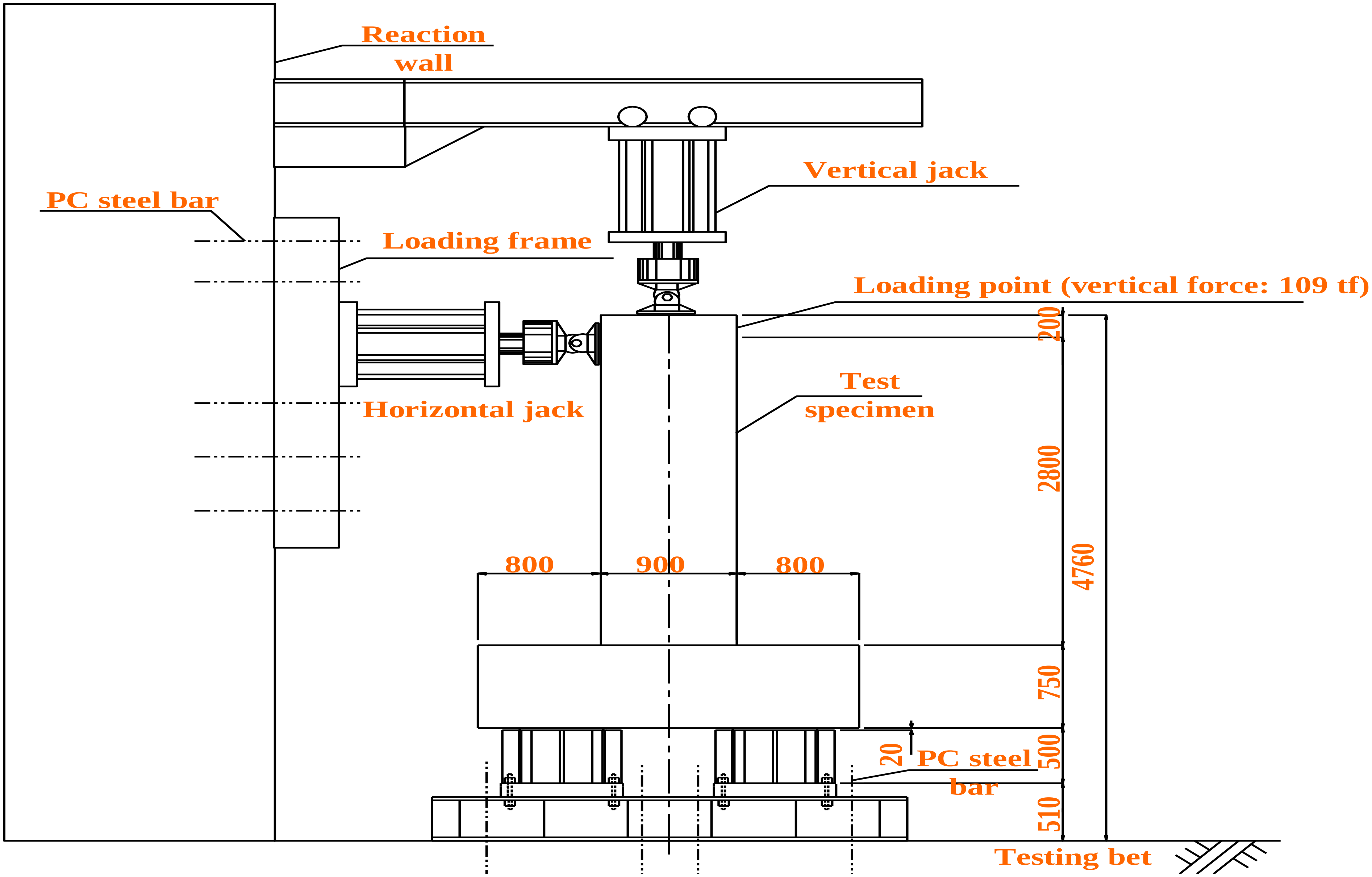


6. (7) Fig. General structure of the damaged footing

Maximum crack width 20 mm, average crack width 7mm. Proto-type (50 % scale) test was conducted.



6. (8) Fig. Cracks observed on the footing

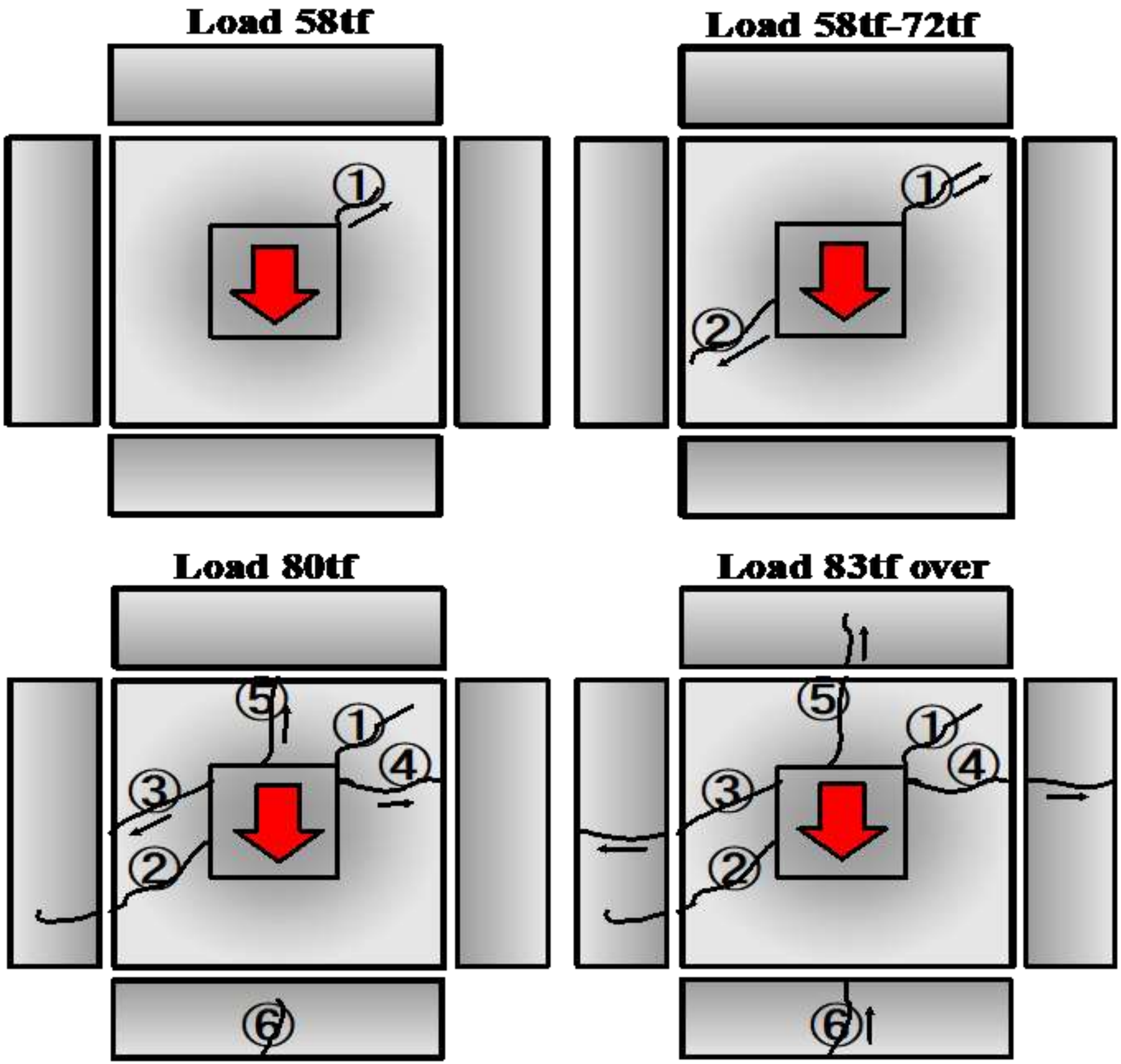


One-direction monotonic loading was applied.

6. (9) Fig. Test Setup

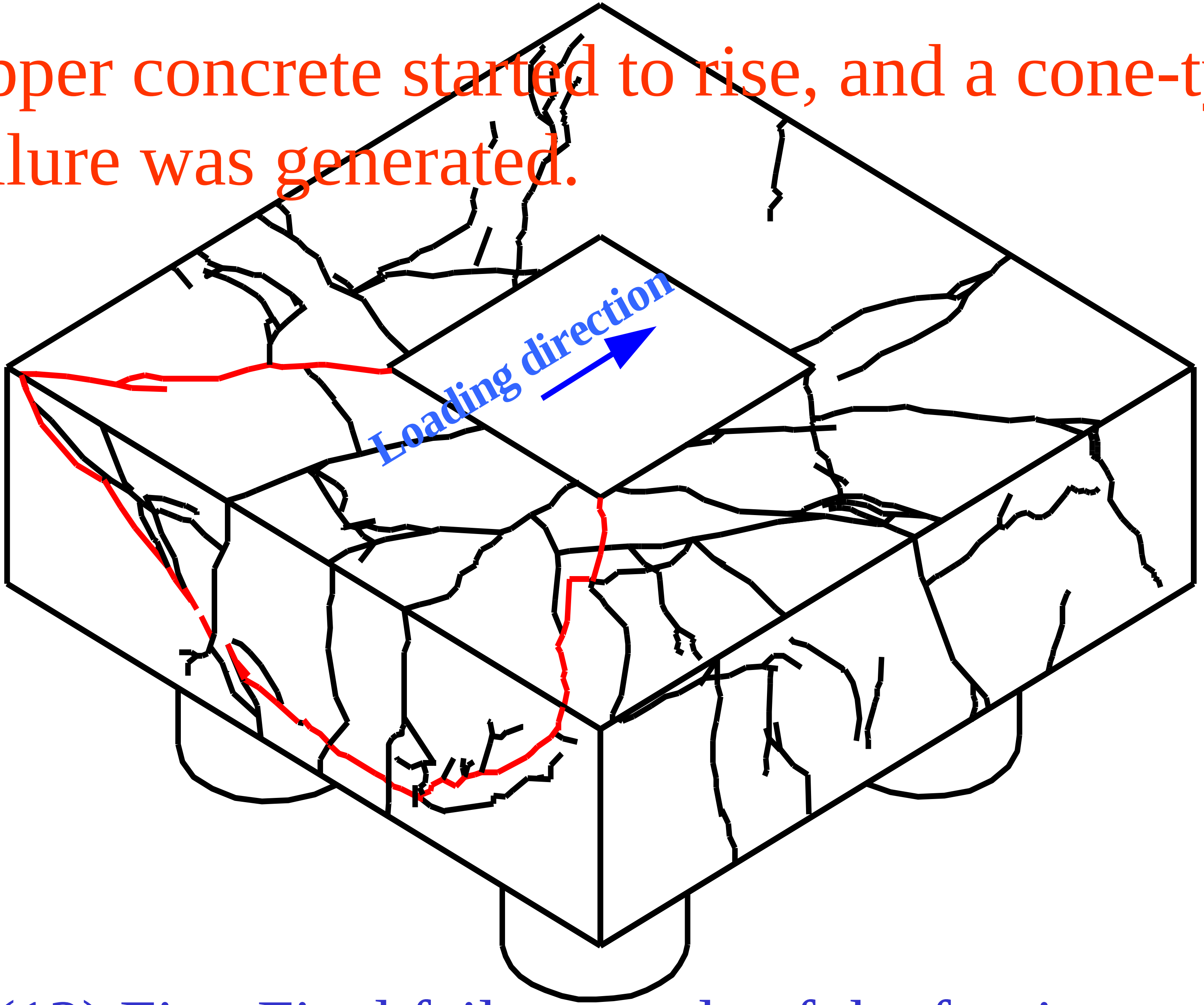
Horizontal load was increased. A vertical load was kept at 109 tf as dead load.

6. (10) Photo Test setup

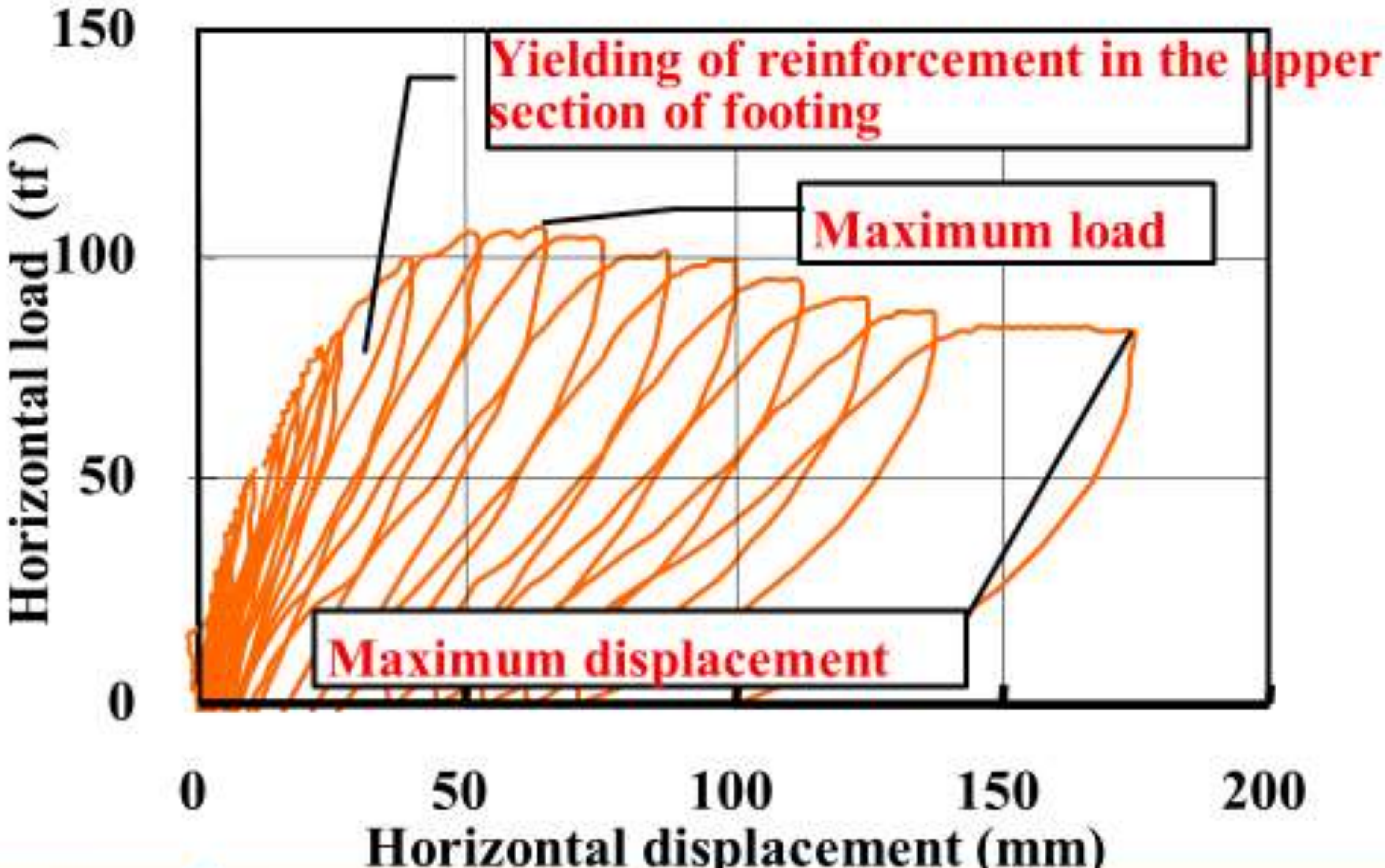


6. (11) Fig. Propagation of cracks under loading

Upper concrete started to rise, and a cone-type failure was generated.



6. (12) Fig. Final failure mode of the footing



6. (13) Fig. Load-displacement relationship taken at the column top

6. (14) Results of the experiment

1. Cracks appeared at the column-footing connection.
2. Damage that determines the maximum load is the yielding of the upper reinforcement.
3. Reinforcement in the upper area of the footing is effective to increase the bearing capacity.

7. Conclusions

1. In Kumamoto Earthquake, many bridges were damaged due to the ground motion and ground movement
2. Rocking columns were weak against large seismic force.
3. Restrainer should be provided to restrain movements of the girder in the longitudinal and transverse directions.
4. Footing damage was observed. It had an effect on the tilting of columns.