Japan's Proven Solutions to Prevent Unseating of Bridges during a Seismic Event

Benjamin Z. Reeve, P.E., Structural Technologies
Katsunori Yasui, SHO-BOND&MIT

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Agenda

A. Brief Introduction of Structural Group and SHO-BOND

B. SHO-BOND's Seismic Devices

(1) Shearing Stopper

(2) Restraining Chain

C. Actual Example

D. Q&A

structural group

Making Structures Stronger & Last Longer

structural TECHNOLOGIES VSL

- Investigation
- Products
- Engineering Support
- Misc. Services

- Contracting Licensees

structural TECHNOLOGIES
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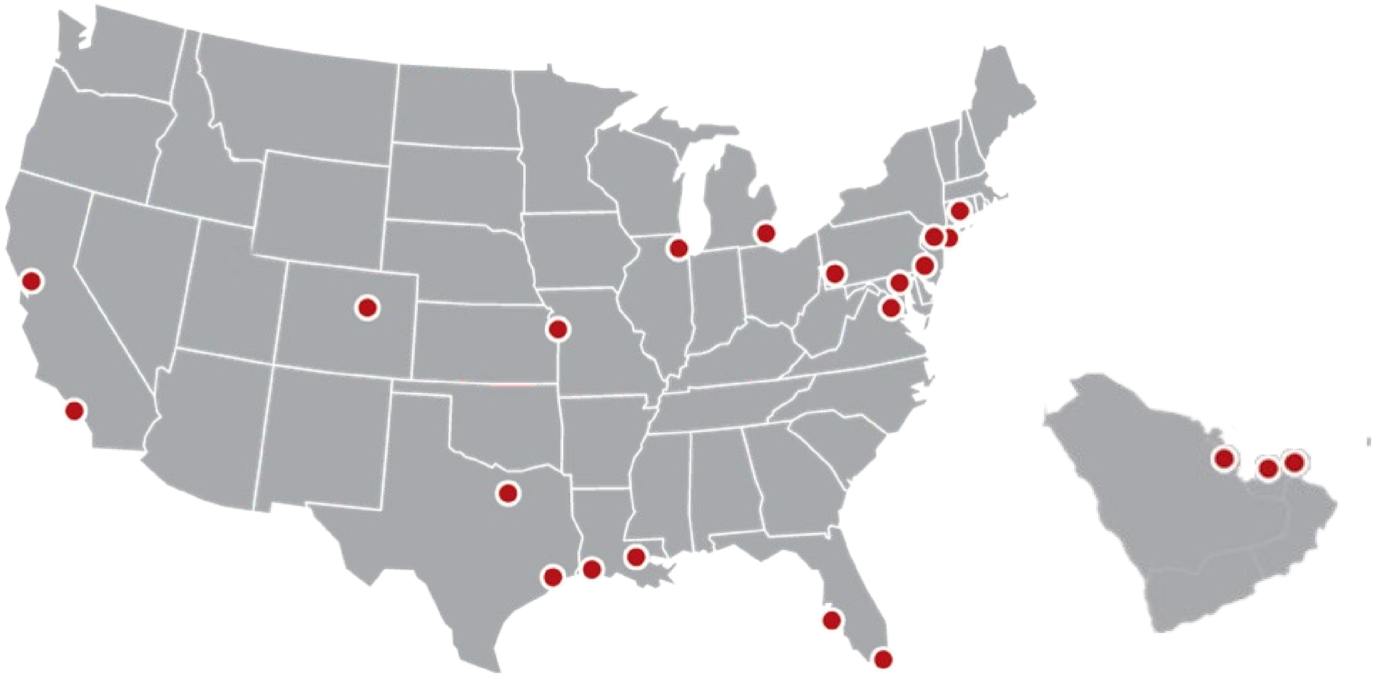
PULLMAN



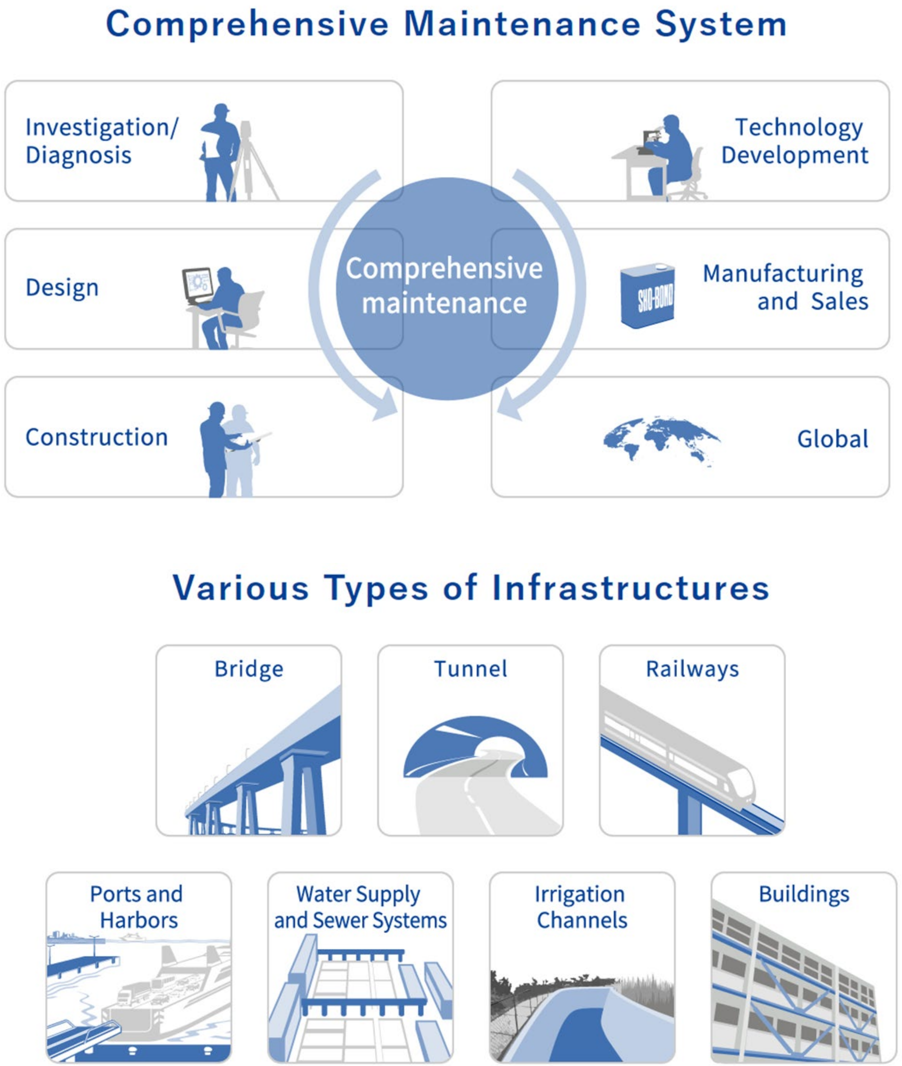
Annual Sales	$685 million
Employees	3,000 +
ENR Ranking	#3 Concrete Specialty & #39 Specialty Contractor
Projects	Over 2,000 annually
Typical Range	$2,500 to $60 Million
Offices	33 in North America 3 in Middle East

Transportation Market

SHO-BOND

Japan’s pioneer in structural repair and reinforcement

- Year established: 1958
- Annual revenue: $700M
- Employees: 900+



Kobe Ohashi, Hyogo, Japan,

Nanadaru Spiral Bridge, Shizuoka, Japan

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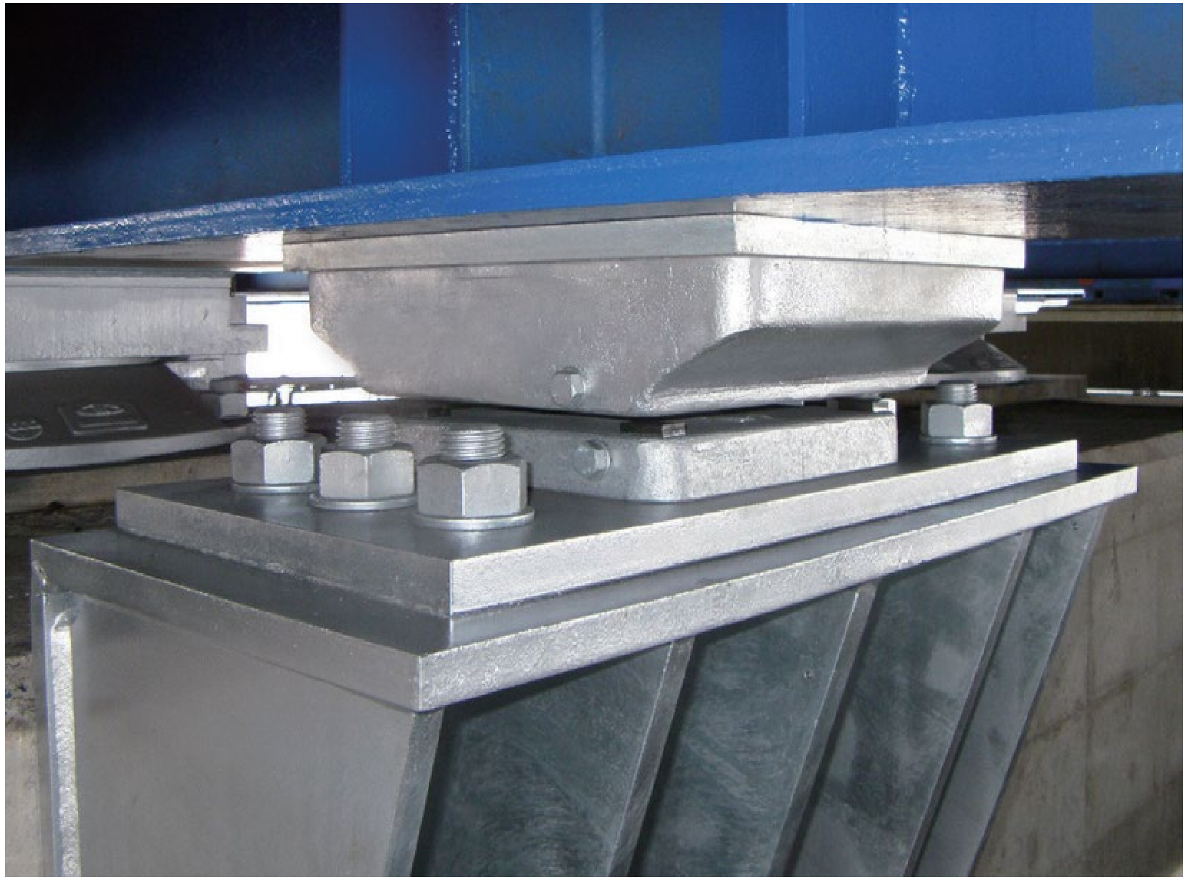
SHO-BOND's Seismic Devices



Shearing Stopper

Restraining Chain

Why unseating prevention?

- Top priority: prevent bridge collapse and protect human safety
- Strengthening substructure is a must.
- However, **even if substructure is solid**, **superstructure could still fall**.

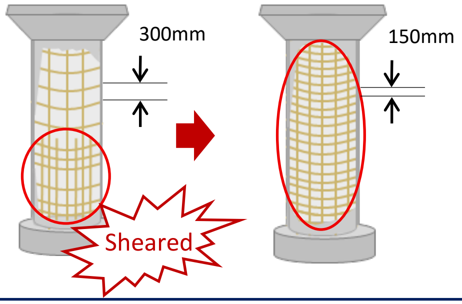
➡ **Unseating prevention is as important as strengthening substructure**

History of Seismic Requirement in Japan

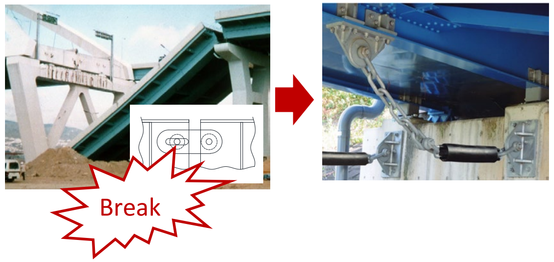
1923 Great Kantō Earthquake	1943 Tottori 1944 Tonankai 1945 Mikawa 1946 Nankai 1948 Fukui	1964 Nigata Earthquake	1978Miyagi Earthquake		**1995 Great Hanshin Earthquake**	2011 Great East Japan Earthquake
1926 First Seismic Code	Revised Several Times	1971 Revised	1980 Revised	1990 Revised	**1996 Stringent Code**	2012 Revised

Examples of 1996 changes

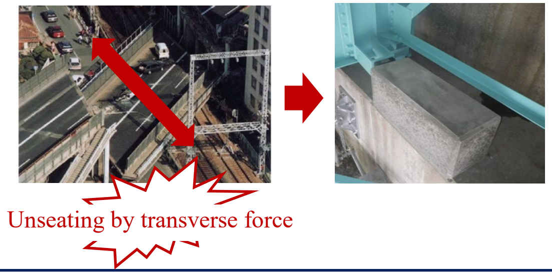
- Require full arrangement of reinforcing bars and shortened gap between bars



- Unseating prevention devices are required to **restrain more loads (1.5G)** and **alleviate impact force**

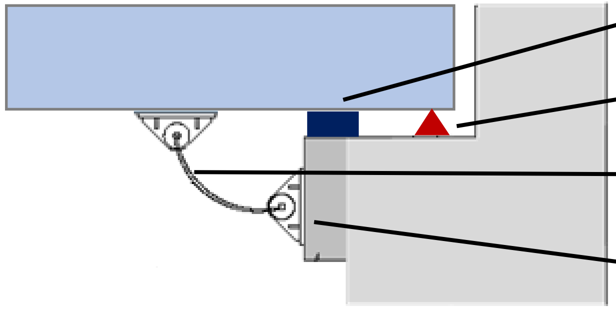


- Components restraining transverse displacement are newly required for some skew/curved bridges

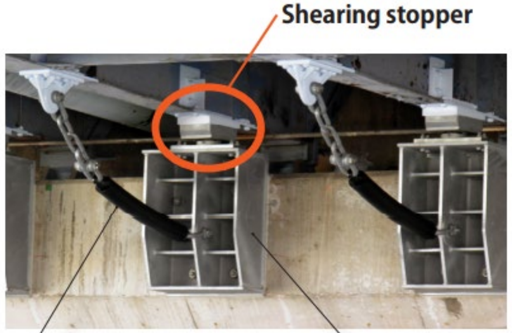


Japanese Unseating Prevention System

【Normal Time】
(Service load condition)



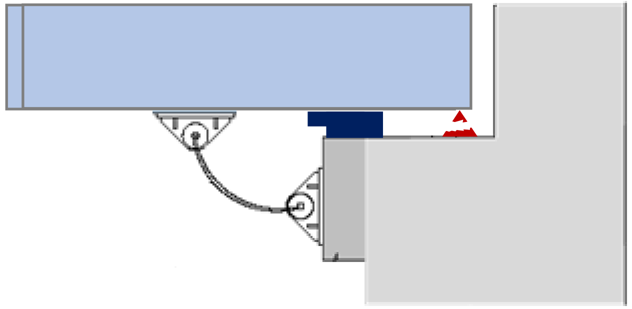
※This will work first



※This will work Next

【During Earthquake】

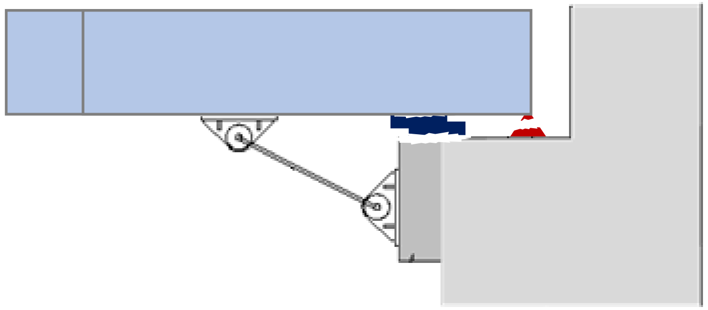
For Moderate ~Large Earthquakes



① When bearings fail

② **Bearing supplement devices prevent displacement of girder**

For Large Earthquakes



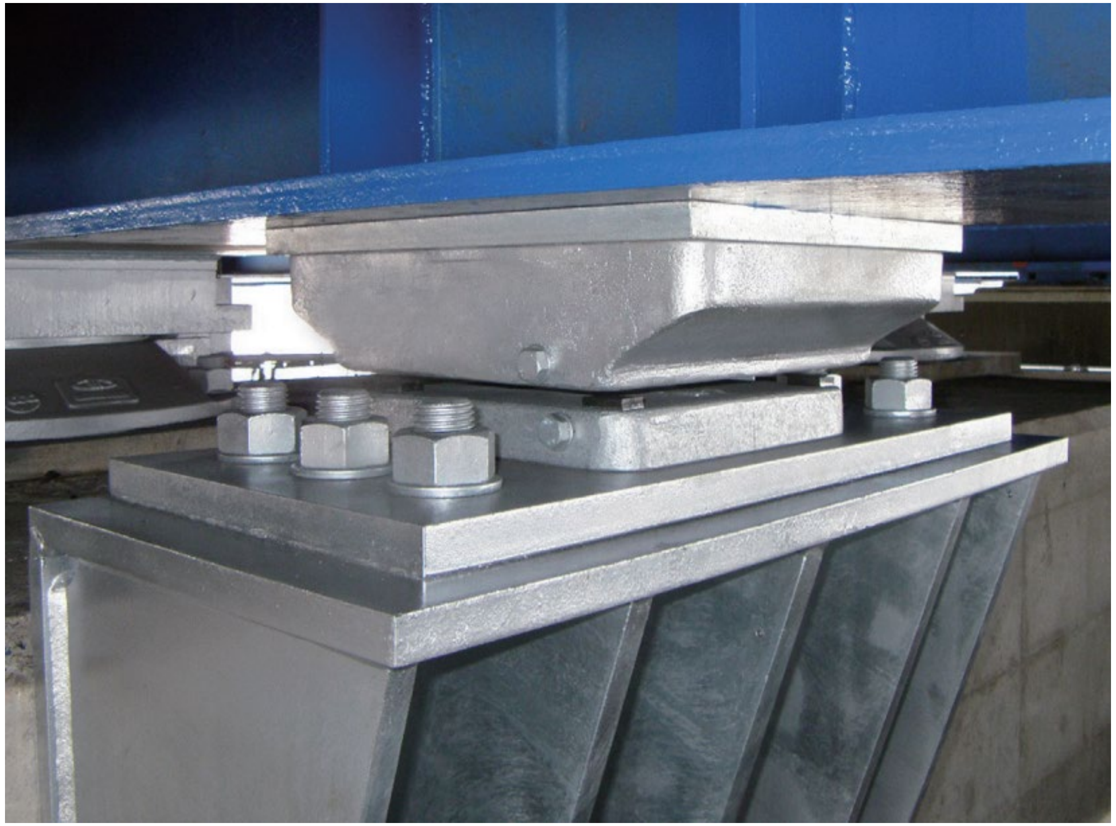
If force is larger than designed capacity

③ Bearing supplement devices fail

④ **Unseating prevention devices prevent unseating** as fail-safe device

Device 1: Shearing Stopper

- **Supplement to bearings**
- **Superior alternative to Shear Key & Bumper Block**
- More than 28,000 have been installed over past 15 years
- 19 types: 200kN-3000kN (45kip-675kip)

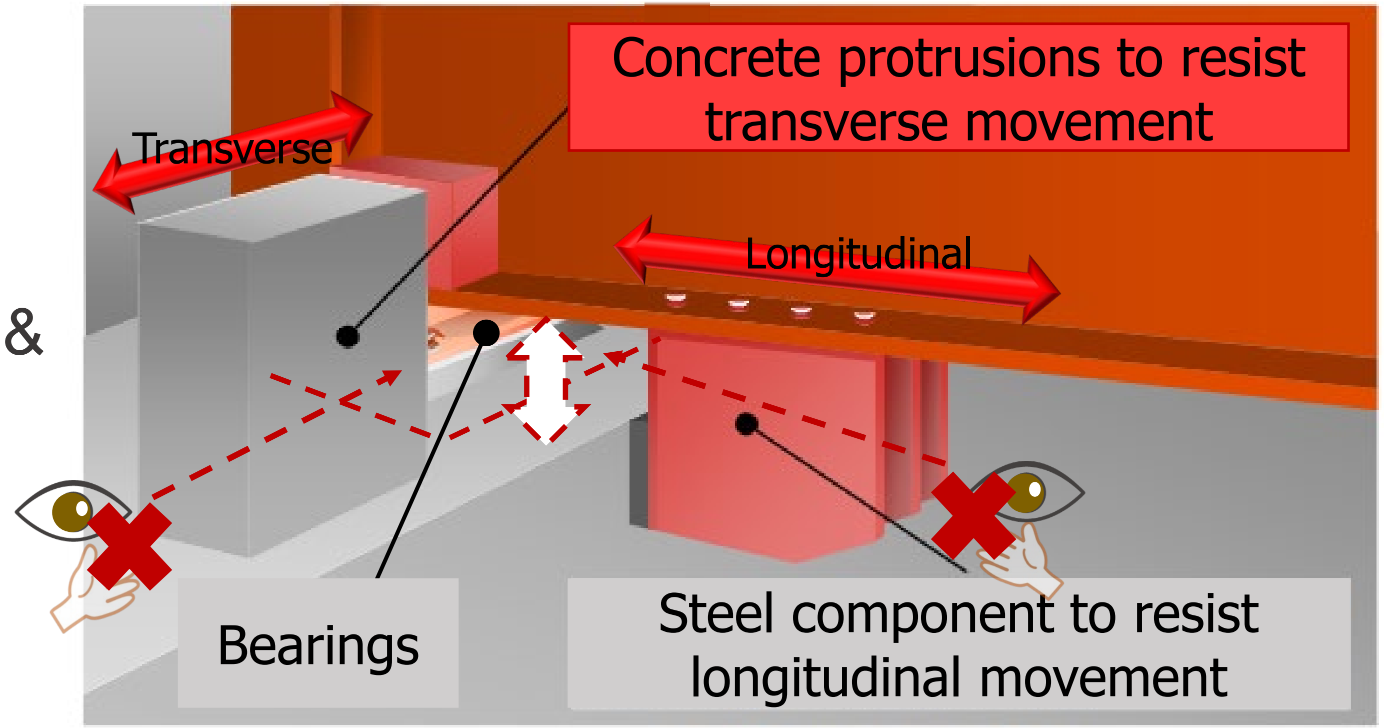


Why was it developed?

1. **Difficulty of replacing existing bearing**

2. **Conventional method limits access to bearings**
   → hinders (1) regular inspection & maintenance and (2) post-earthquake inspection & repair

3. **Only one direction by one method**
   (transverse or longitudinal)

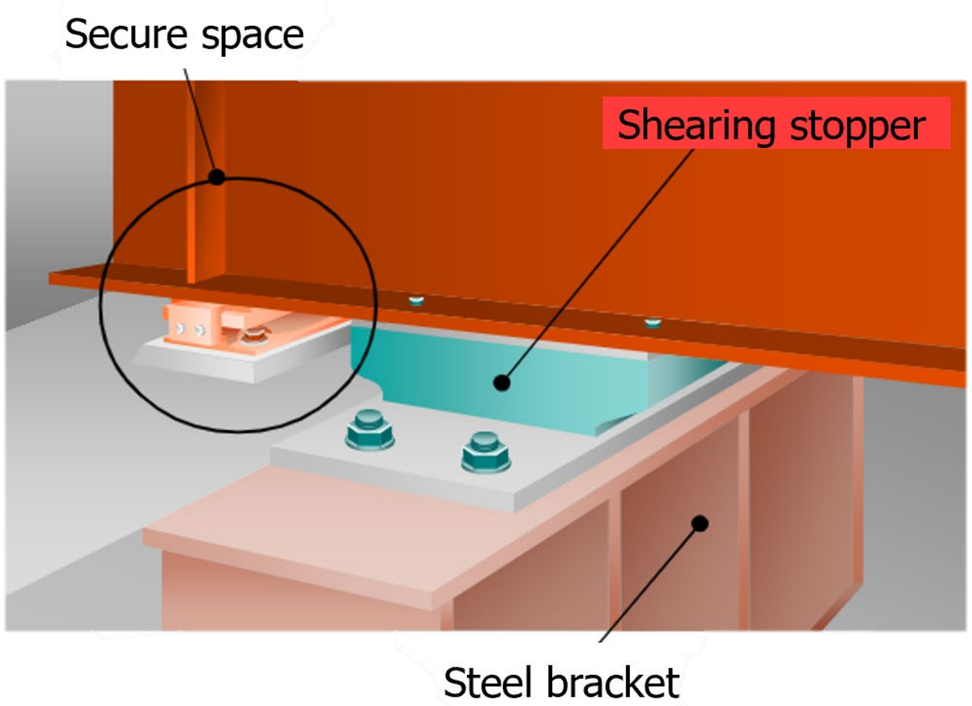


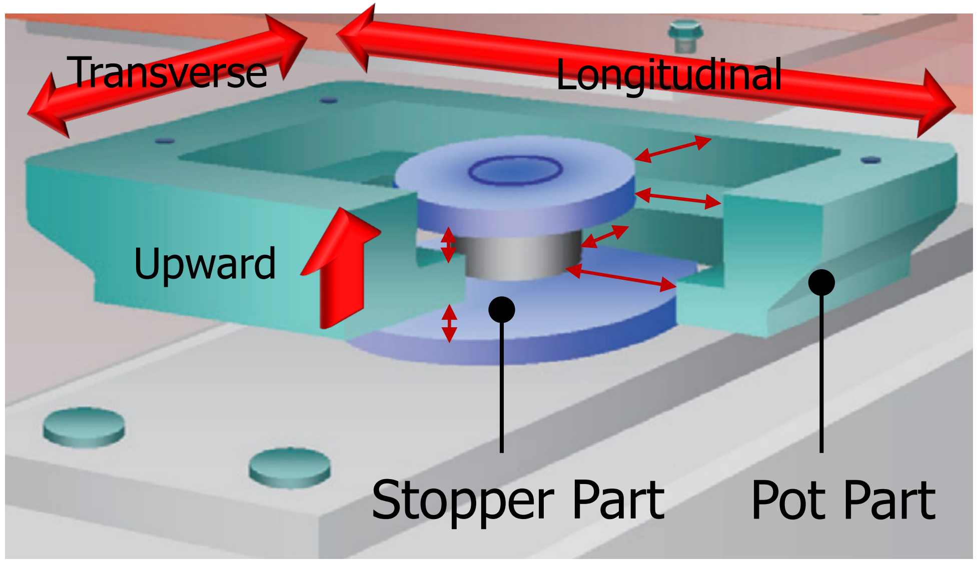
How does it work?

1. **Save space** around bearings
→ **Enable inspection & repair without difficulties** in normal time and after an earthquake

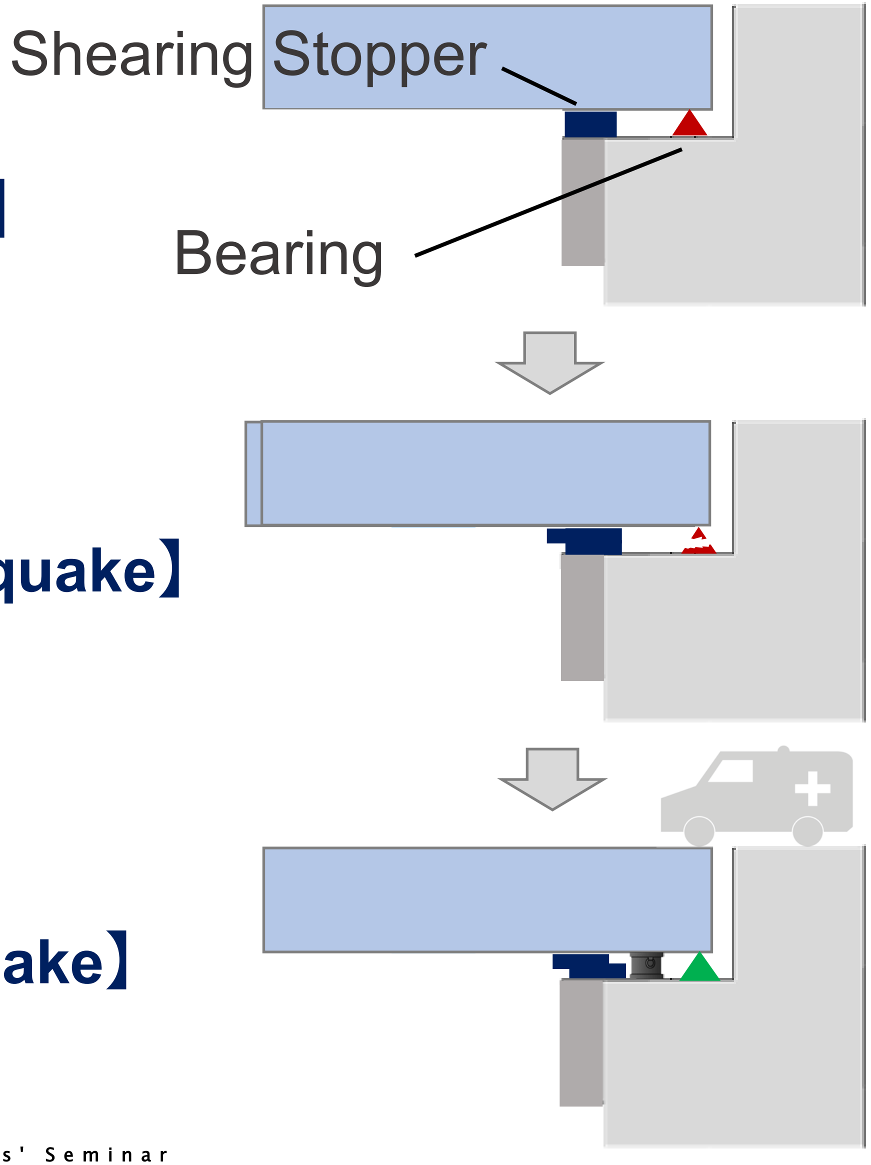
2. **Gap** between pot part and the substructure
→ **Follow normal movement of girder**

3. **Restrain transverse & longitudinal** + **upward force** when bearings fail
→ **Prevent girder displacement**





How does it work?



【Normal Time】

⓪ Shearing Stoppers
allow easy access to bearings and
follow normal movement of girder

【During Earthquake】

① When bearings fail

② Shearing Stoppers work to
prevent displacement of girder

【After Earthquake】

③ Shearing Stoppers
allow inspection & repair without difficulties and
realize prompt recovery of bridge

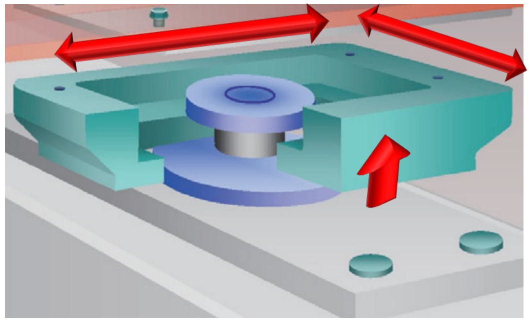
Maintenance and Durability

- Maintenance-free device
- More than 28,000 have been installed over past 15 years and there has been no reported issue related to durability
- Even in the harsh environment of the coastline, the durability of galvanized parts is generally 25 years

Comparison to Conventional Methods

Japan's code recommends avoiding techniques such as Shear Key due to difficulty in maintenance of bridges

	Shearing Stopper	Shear Key & Bumper Block
Restrain horizontal force	✔(two directions)	△(one direction)
Restrain lift force	✔	✕
Save space around bearings	✔	✕
Removable	✔	✕
Prompt recovery of bridge	✔	✕
Easy installation	✔	✕



Examples of installation

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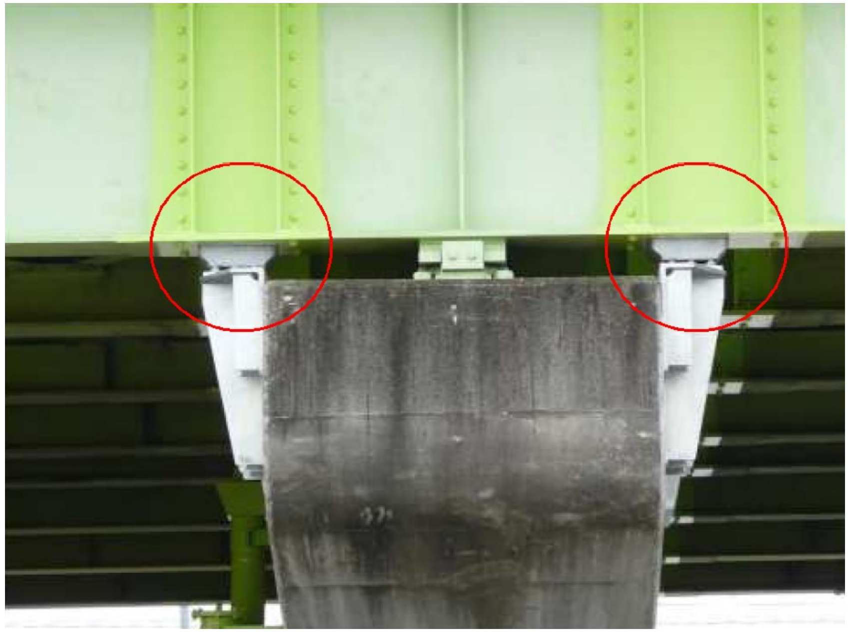

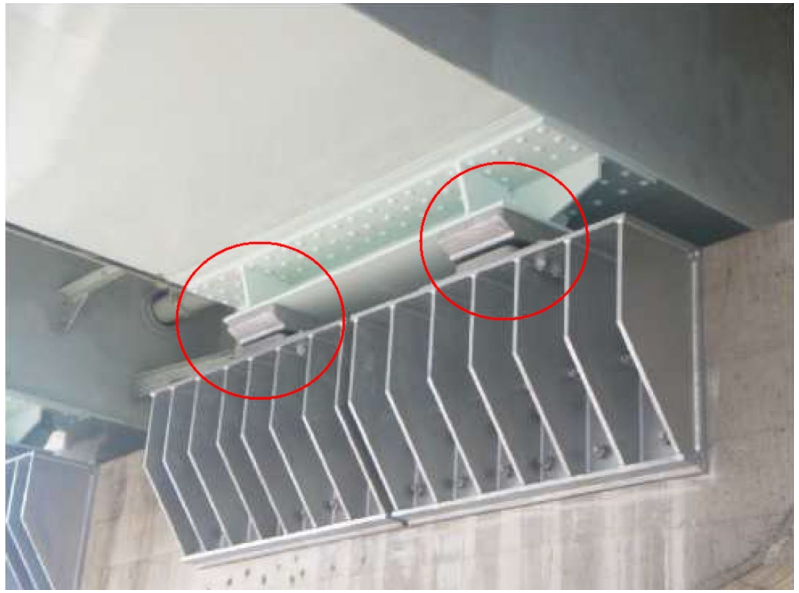

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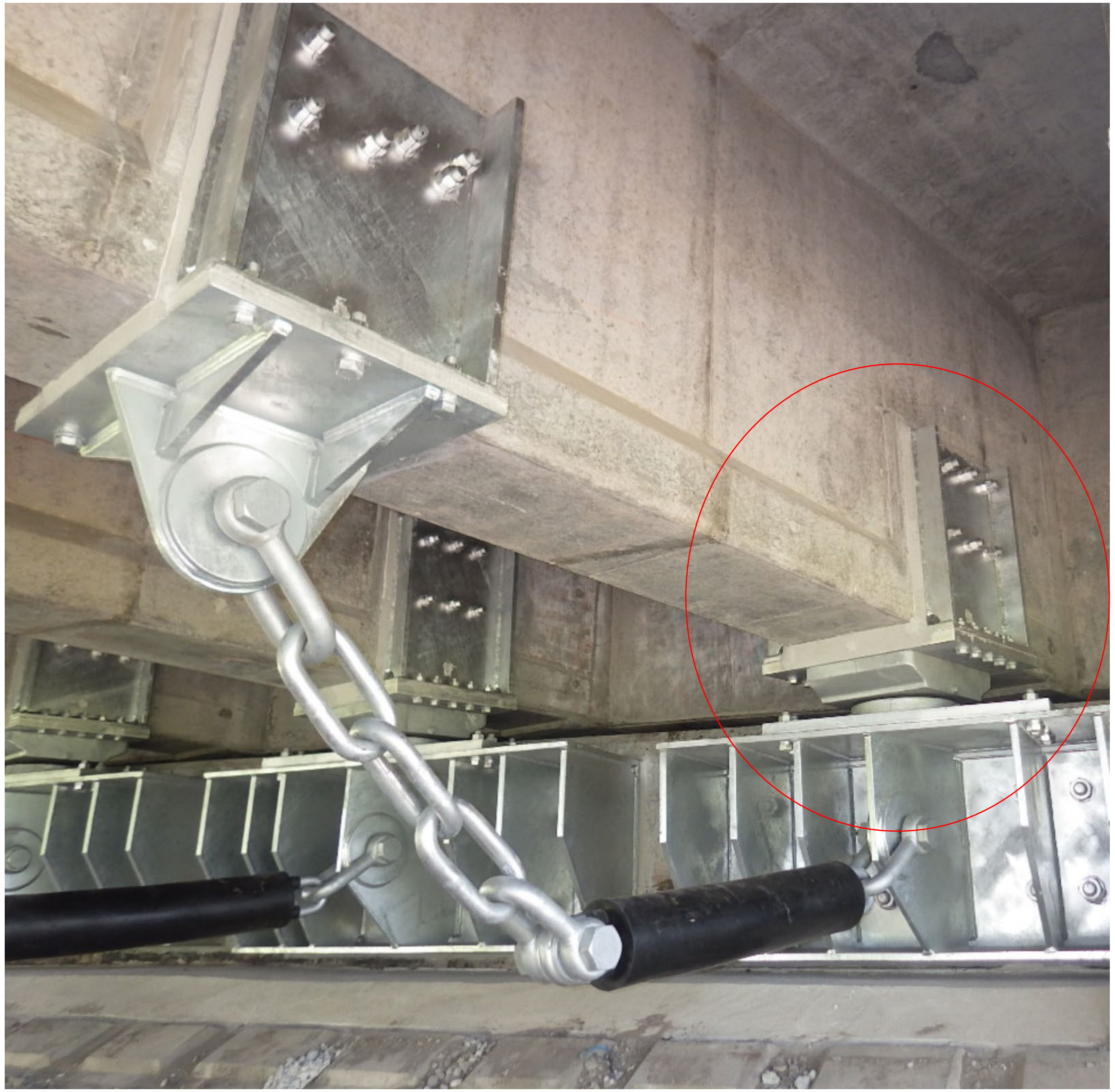
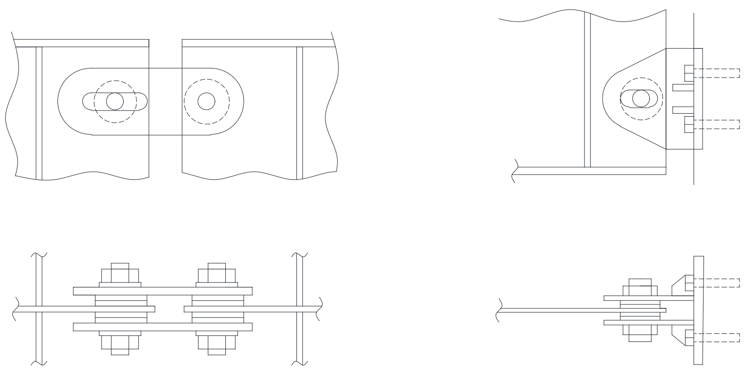


Device 2: Restraining Chain

- **Fail-safe chain with shock absorber**
- **Superior alternative to existing restrainer cables/chains/rods**
- About 33,000 have been installed over past 10 years
- 9 types: 225kN-1545kN (50-350kip)

Why was it developed?

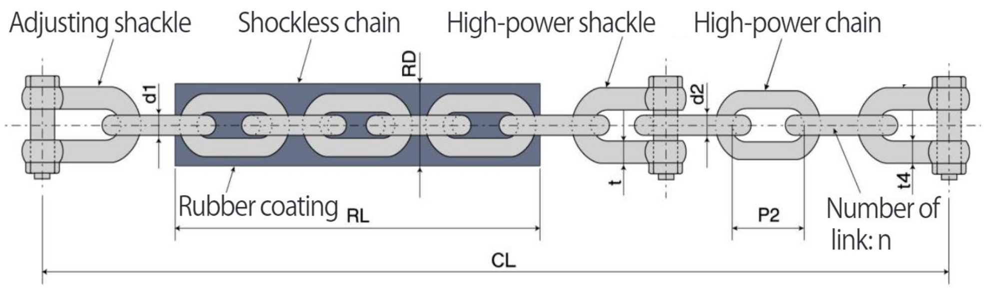
- **With extended seat length**, **superstructure fell** in the Great Hanshin Earthquake 1995.
- **Even with unseating prevention device**, superstructure still fell.
- This is because **(1) load was higher** than designed capability of the device in those days and **the device itself failed due to (2) impact force** and **(3) transverse movement**



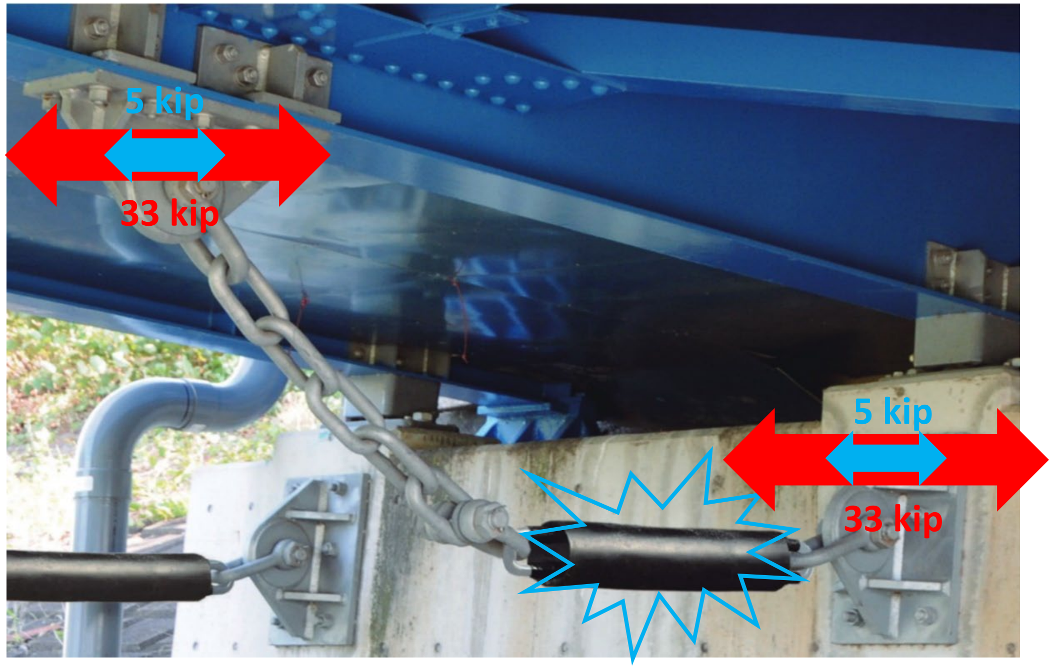
How does it work?

1. Resist high loads (1.5G) & prevent unseating

2. Prevent chains from failing by **alleviating impact force** and **following transverse movement**

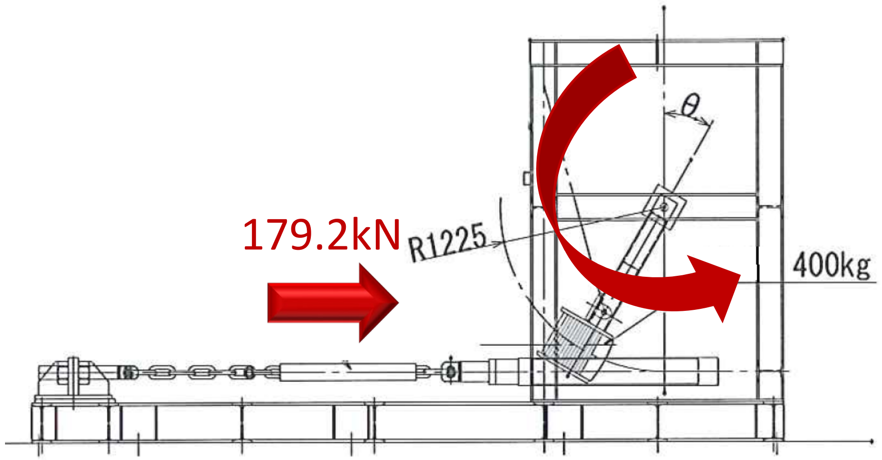


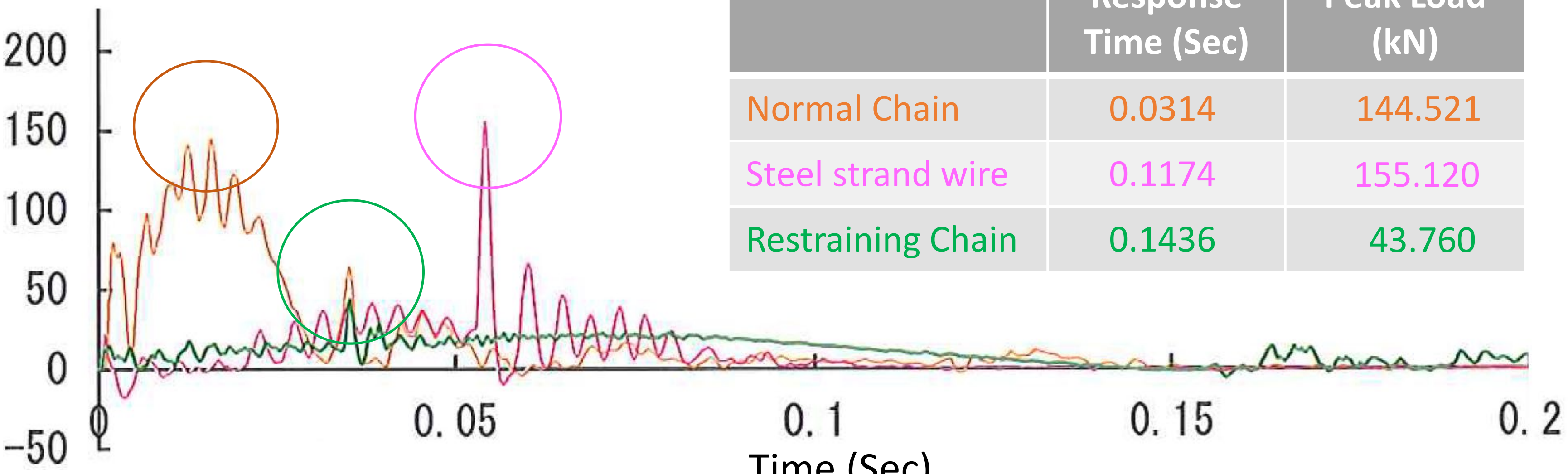
- Chain covered with special rubber
  - Alleviate impact force on the device
  - 75-85% shock alleviating rate
- Perform well under repeated loading



Alleviate impact force

- Load of 179.2 kN (40 kip) was applied
- Reduction rates of the peak
  - Normal chain: 19%
  - Steel strand wire: 13%
  - Restraining Chain: **75%**

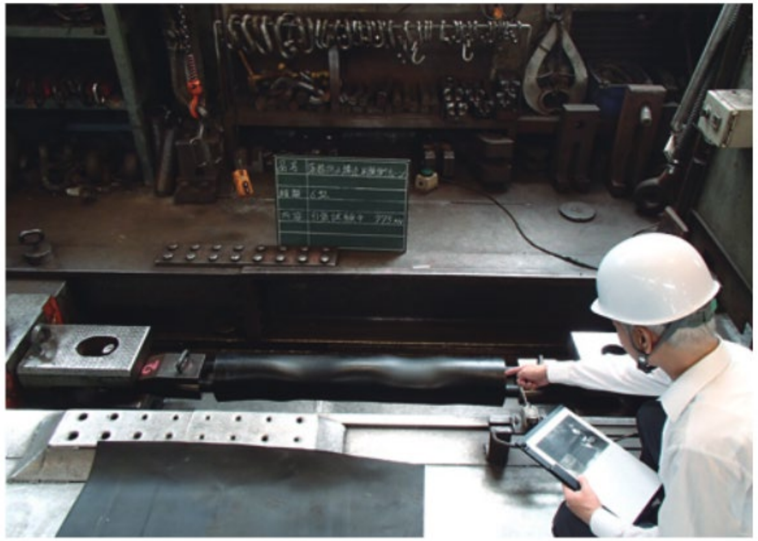




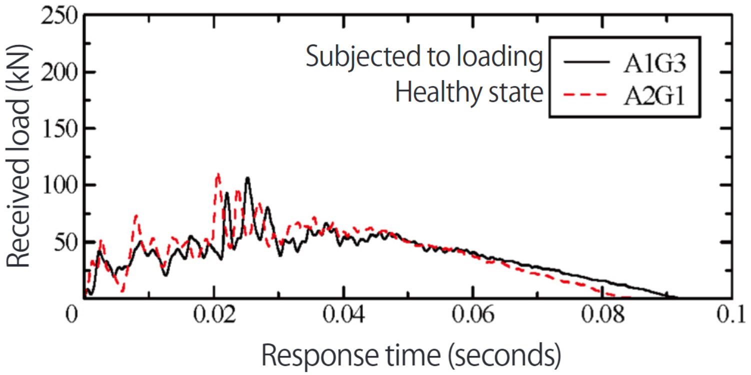
	Response Time (Sec)	Peak Load (kN)
Normal Chain	0.0314	144.521
Steel strand wire	0.1174	155.120
Restraining Chain	0.1436	43.760

Perform well under repeated loading

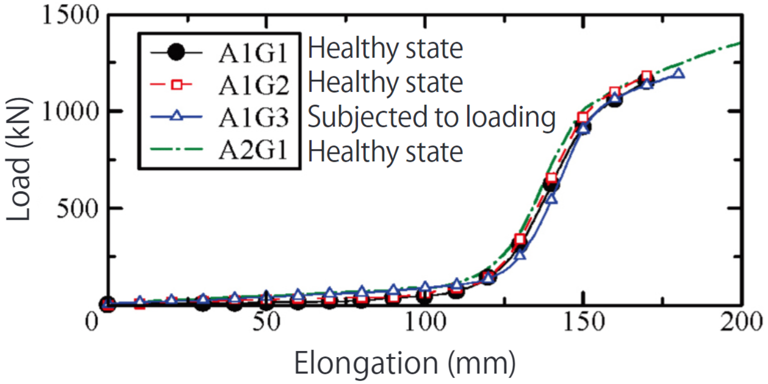
- Performance test under **repeated loading** confirmed that there was **no major change in shock alleviating function** and **load-elongation curve**



Result of impact testing



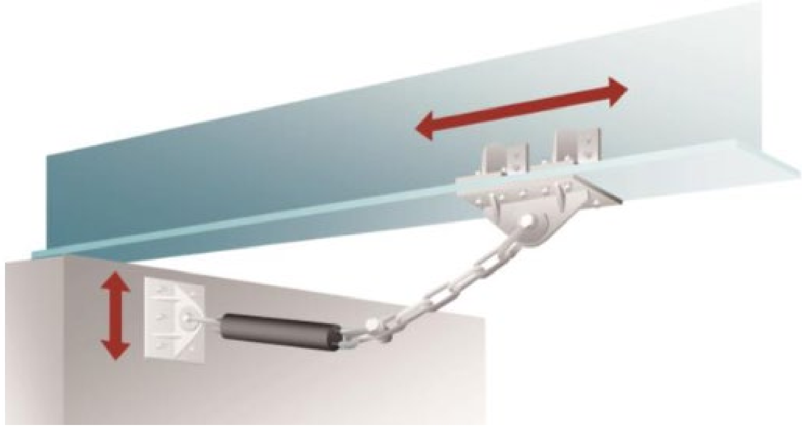
Result of static tensile test



High Workability

- Installation position can be changed depending on conditions of objects
- The chain can be installed by changing the number of links, installation angles, etc.





Shock Absorber ≠ Damper

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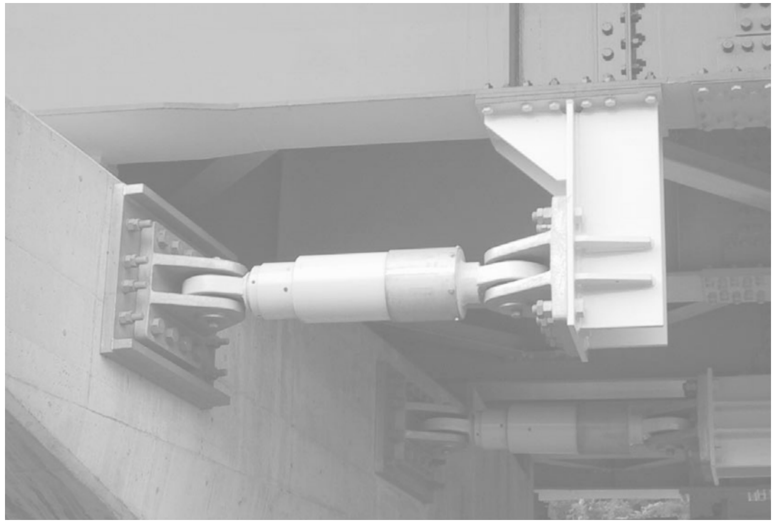
VSL

- **Shock absorber of chains alleviate impact only for the chains themselves**

- By alleviating impact force on the chains, **the chains themselves can endure strong impact force caused by an earthquake**.
  (Shock absorbers are about the matter of survivability of the chains.)

- This makes the device **different from existing restrainer cables/chains/rods** in the US.



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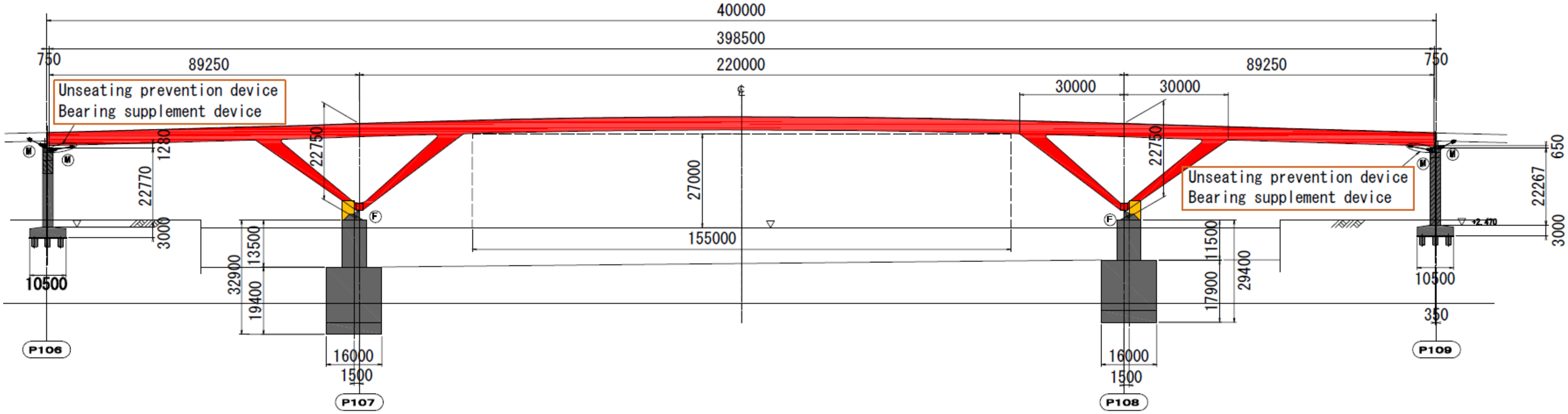
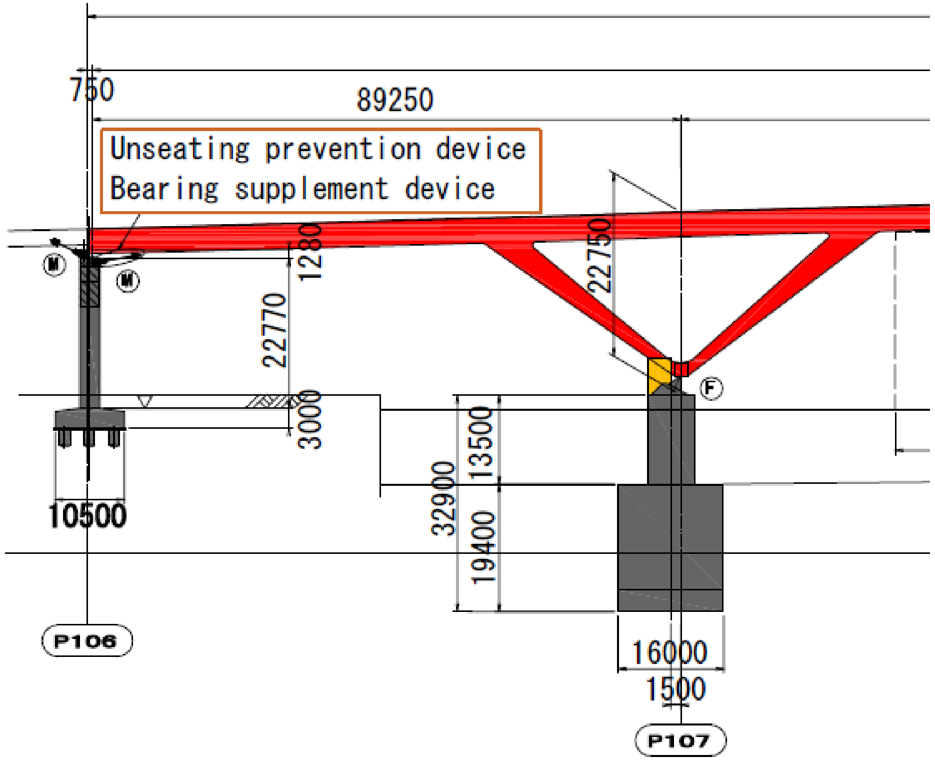
Example with Shearing Stopper & Restraining Chain

- Design: V-shaped rigid frame bridge
- Material: Steel
- Year built: 1992
- Length: 400 m (1310 ft)



Challenges and Solutions

- **Existing bearings were insufficiently resistant** to large earthquakes
- **Lift force** would be generated at end supports
- **Difficult to replace existing bearings with new bearings** resistant to large earthquake due to the physical height and area limitation
- **Old-generation unseating prevention device failed** in 1995



- Shearing Stoppers were chosen because:
  - ✓ **Resist horizontal and lift forces** after the bearings fail
  - ✓ **Not require replacement of the existing bearings**
- As fail safe, Restraining Chains were also installed to prevent unseating

Shearing Stopper

- Seismic forces at the end supports
  - ■ Horizontal force: 5600 kN (**1260 kip**)
  - ■ Lift force: 3600 kN (**809 kip**)

x1/4 x1/4

- 4 devices -> each device's design forces
  - ■ Horizontal force: 1400 kN (**315 kip**)
  - ■ Lift force: 900 kN (**202 kip**)
- Movement

  Existing bearings ± 210 mm (**8.2 inches**)

  + margin of 20 mm (**0.8 inches**)

  = ± 230 mm (**9 inches**)

* 200 mm (7.8 inches) in the upward direction were secured to prevent the main girder from reaching yield when lift forces take place

Restraining Chain

- Dead load at end supports (Rd)
3607 kN (**810 kip**)

x1.5

- Design seismic force
1.5*3607 (Rd) = 5411 kN (**1216 kip**)

- 4 chains → each chain's design forces
5411/4 = 1353 kN (**304kip**) x1/4

- The off-the shelf chain with a design load of 1545 kN (347 kip) was selected

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