Special Session 24.4 Great East Japan Earthquake
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A Great Success and Future Challenges for Mitigating Damage of Bridges

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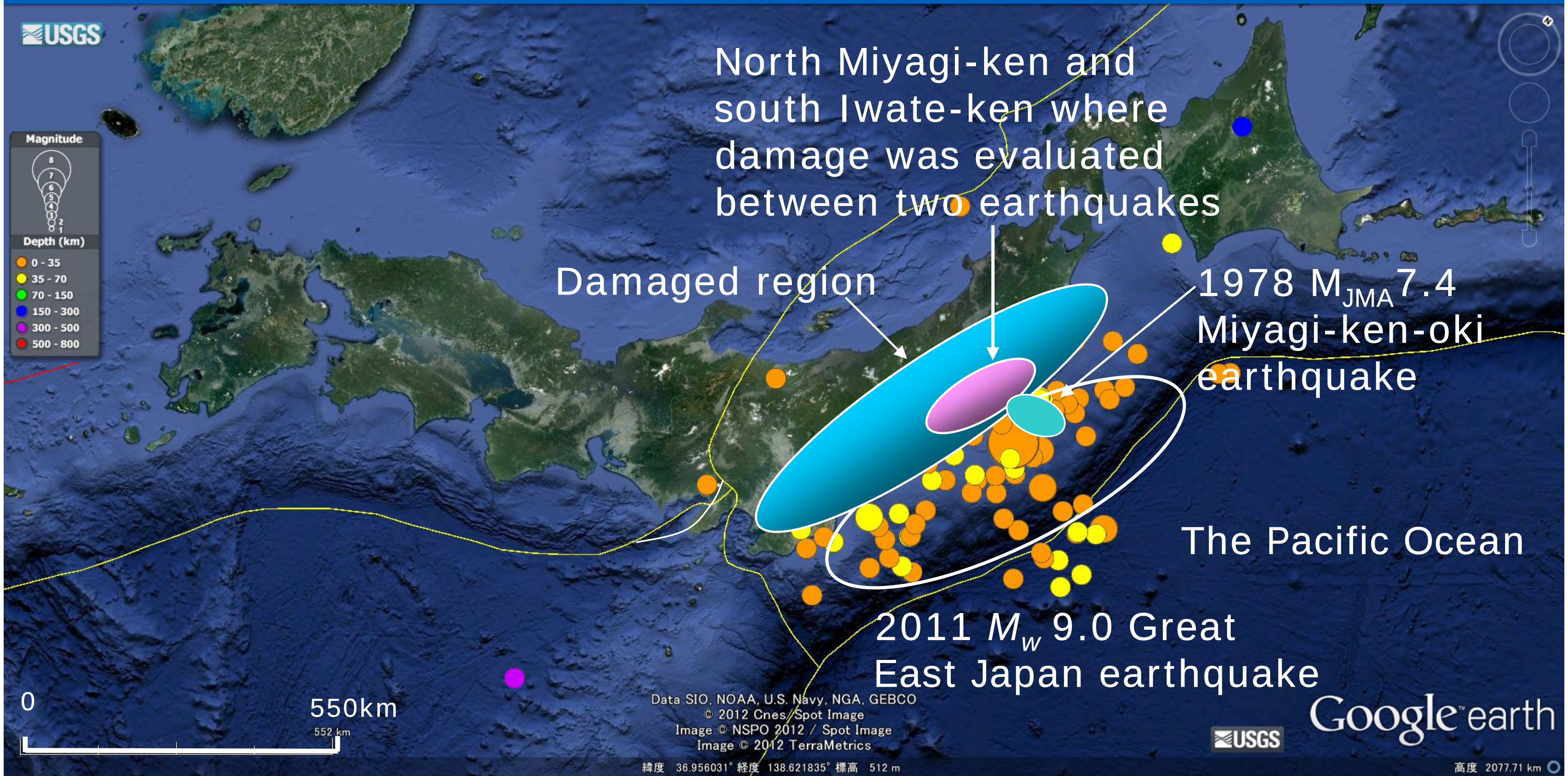
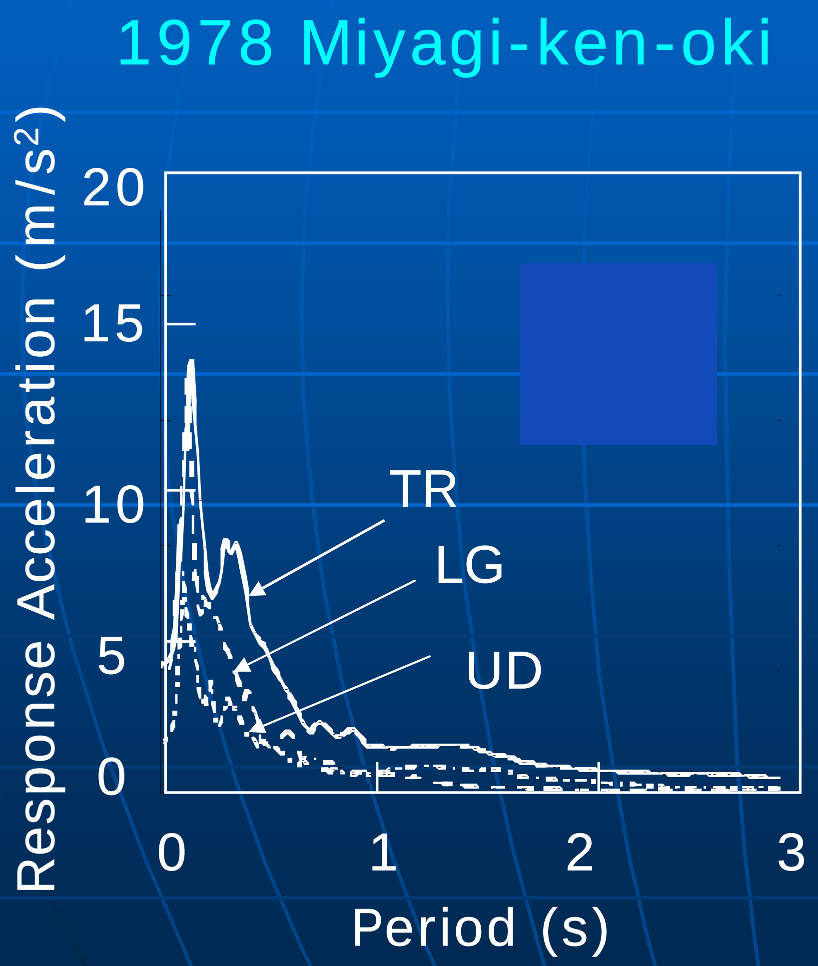
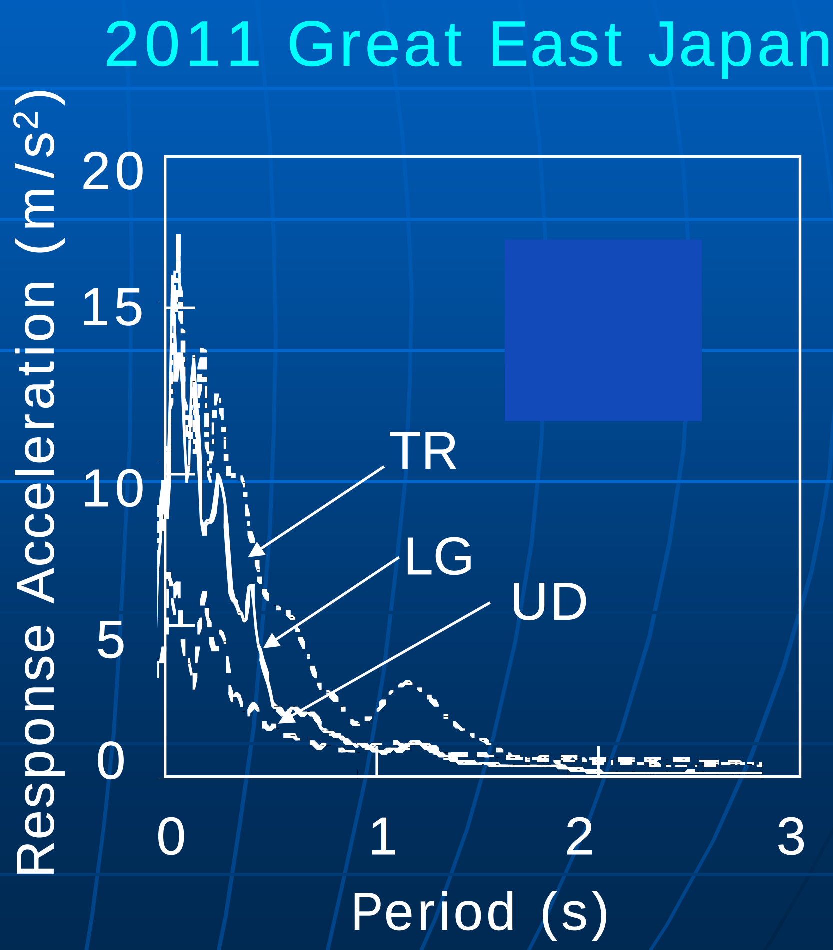
2011 Great East Japan earthquake was a good opportunity to learn whether damage of bridges was mitigated as a consequence of code upgrading since 1990



Ground acceleration was slightly stronger during the 2011 event the 1978 event





1978 Miyagi-ken-oki Earthquake (M_{JMA}7.4)

Damage concentrated to RC columns at lap splice of longitudinal bars

Sendai Bridge
National Road 6

Extensive Damage of Steel Bearings

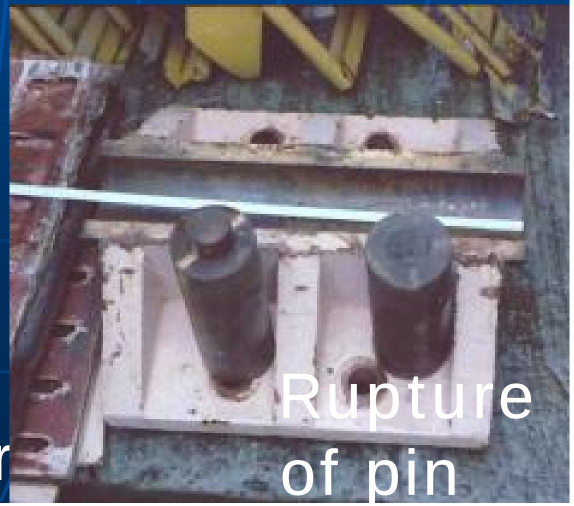
- Almost all side stoppers suffered damage
- Pin and roller bearings were vulnerable to damage

Damaged side stoppers

Failure of pier at bearing

Pull-out of anchor bolts

Pull-out of roller

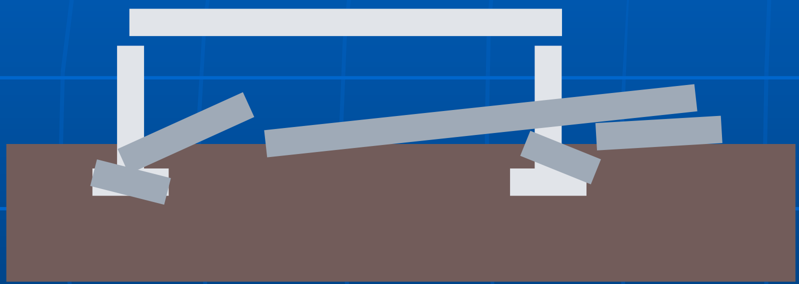


Rupture of pin

1978 Miyagi-ken-oki earthquake
-An Important Turning Point of Design

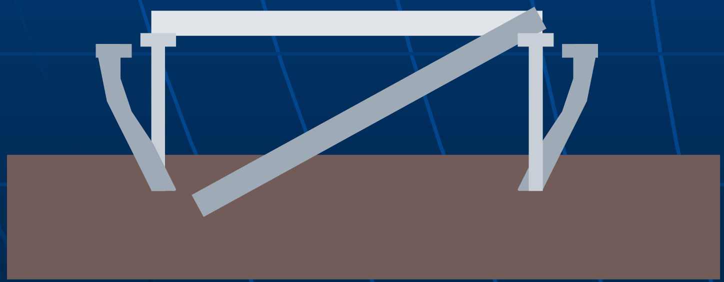
If we look back the past design,……

Stage 1: Days when seismic design was not conducted or it was insufficient(1868-1945)



Overturning, sliding or settlement of foundations
---→ Collapse

Stage 2: Days when we were not aware of liquefaction and unseating prevention devices were not yet developed (1964 Niigata EQ)



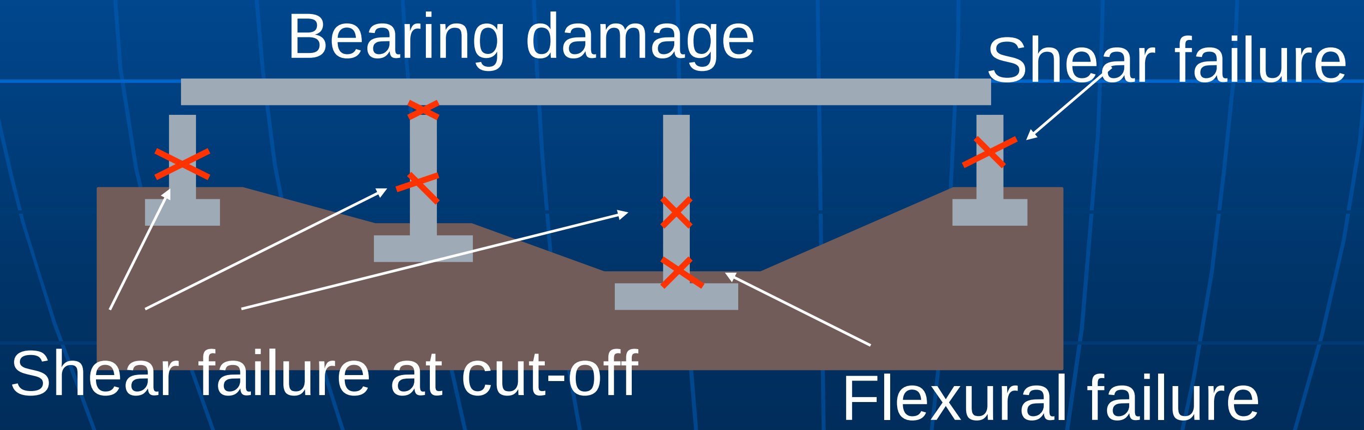
Excessive response of foundations & piers
----→ Collapse

1978 Miyagi-ken-oki earthquake
-An Important Turning Point in Design (2)

Stage 3: Days when we were not aware of the importance of ductility capacity of piers

Enhancing the past weak links led to damage in the next weak link. This became apparent during 1978 Miyagi-ken-oki EQ and 1982 Urakawa-oki EQ;

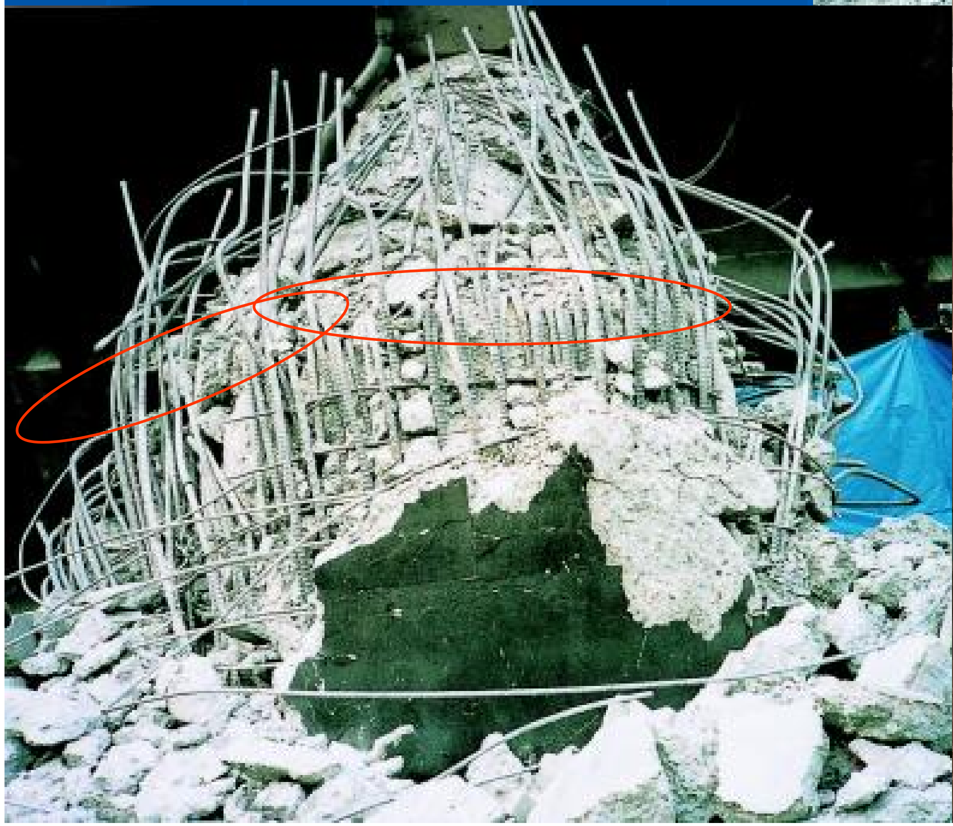
- Piers & columns
- Bearings



This type of damage extensively occurred during 1995 Kobe earthquake

Extensive Shear Failure at Cut-off of Longitudinal Rebars

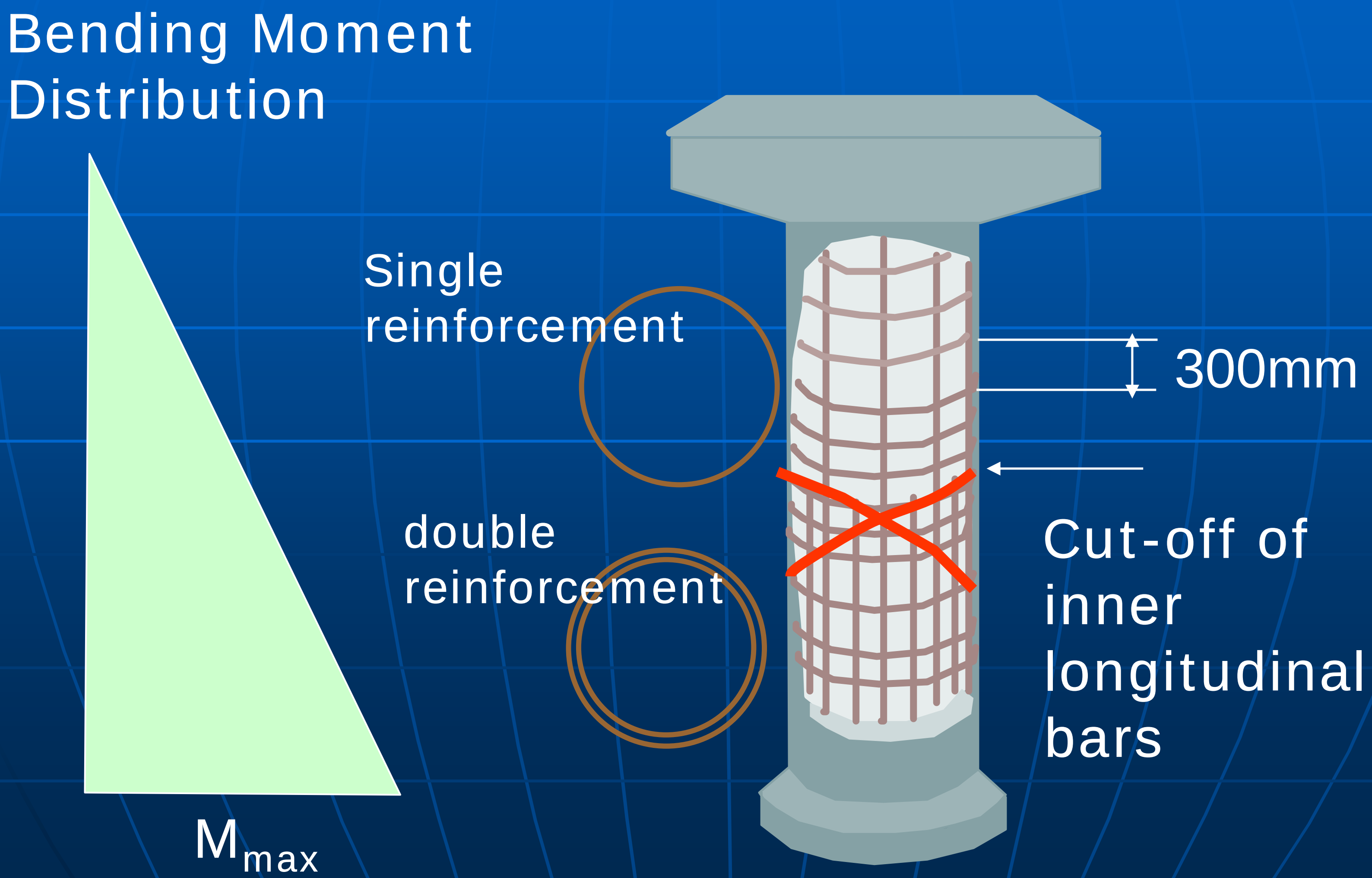
1995 Kobe earthquake



Courtesy of Prof. H. Kameda

Shear Failure at Cut-off of Longitudinal Rebars

A mandate Practice for saving cost prior to 1980



Full Scale Experiment for a Shear Failure Dominant Column: C1-2

E-Defense, NIED

Seismic Design was Extensively Enhanced since 1970

Pre-1990 Design Codes

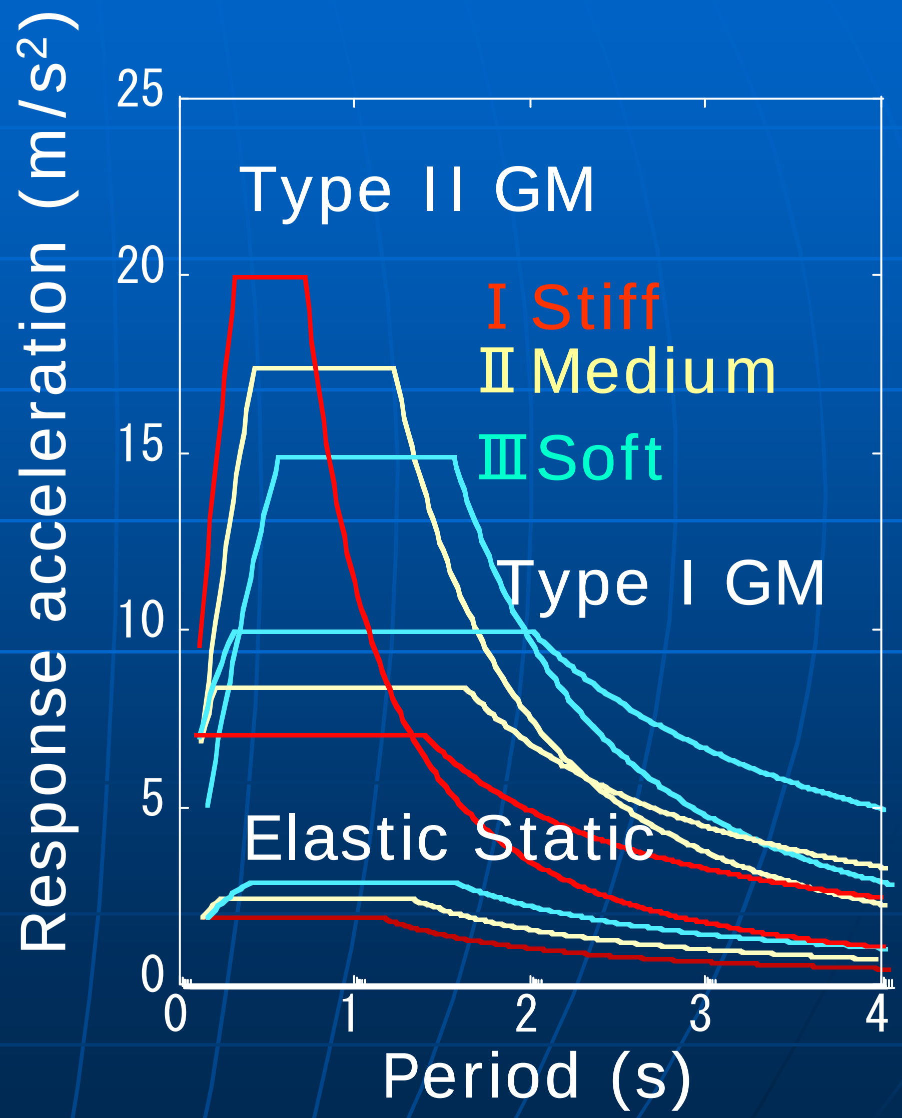
- Static elastic analysis
- 0.2-0.3g design response acceleration (L1)
- Allowable stress design
- Linear dynamic analysis
- Steel bearings

Post-1990 Design Codes

- Static inelastic analysis
- 0.7-2.0 g design response acceleration (L2)
- Linear & nonlinear dynamic analysis
- Elastomeric bearings including LRB and HDR

Departure from Elastic Static Analysis to Inelastic Static Analysis (Post-1990 Codes)

- ●Type I GM (1990-)
  - ✓M8 Subduction events at middle-field
  - ✓Long duration
  - ✓Typical GMs in Tokyo during the 1923 Kanto EQ
- ●Type II GMs (1995-)
  - ✓Near-field GM by M7 Events
  - ✓Short duration with High Intensity
  - ✓Typical GMs in Kobe during the 1995 Kobe EQ

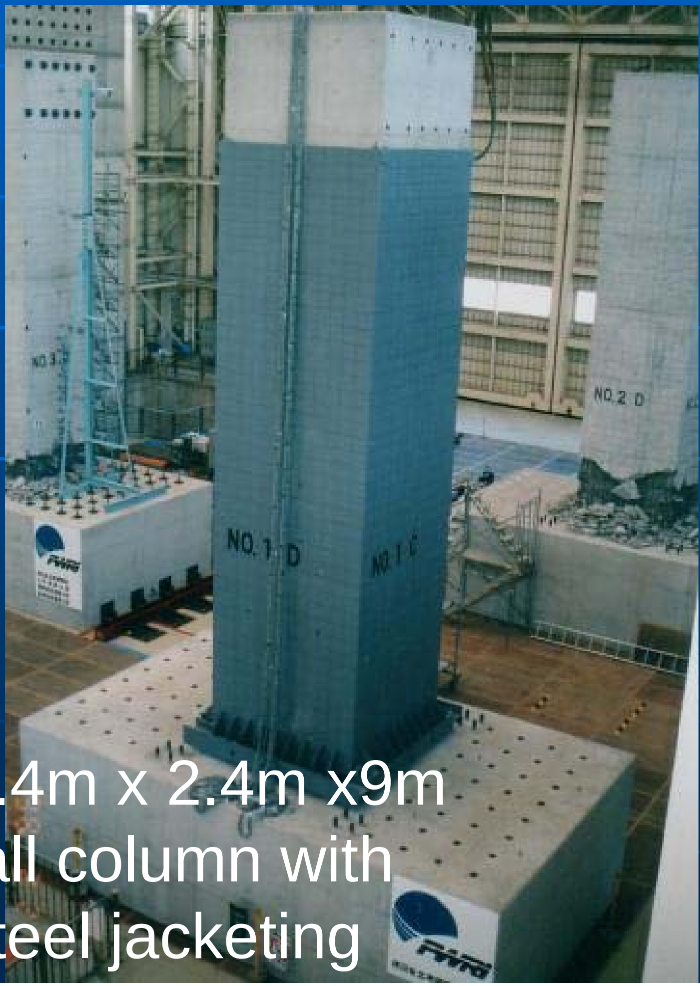


Seismic Retrofit

- RC jacket (standard for columns in water)
- Steel jacket (standard for column on land)
- Carbon fiber wrapping
- Prestressed jacket
- Aramid fiber jacket
- ....
- Implement of seismic isolation/ structural control

Some 30,000 piers & columns were retrofitted since 1995

Implementation of Steel Jacketing was initiated since 1989, prior to the 1995 Kobe Earthquake



2.4m x 2.4m x9m tall column with steel jacketing

Metropolitan Expressway

During the 2011 Great East Japan earthquake, shear failure at cut-off still occurred at RC columns which have not yet been retrofitted

Fuji Bridge, Iwate-ken

Bridges which were retrofitted in accordance with the post-1990 code suffered virtually no damage

Steel jacketing was effective

Replacement of vulnerable steel bearings with elastomeric bearings was effective

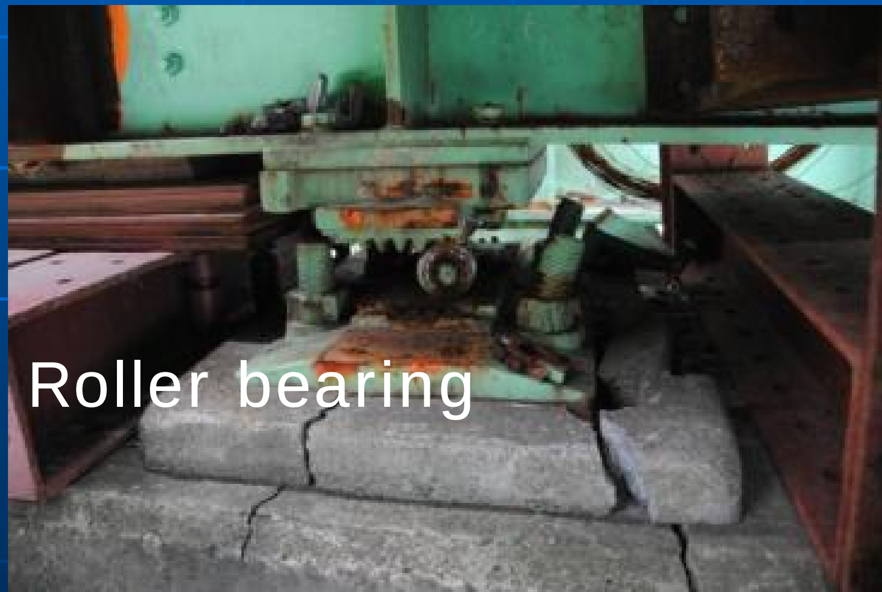
Steel bearings and their support which suffered damage during 1978 Miyagi-ken-oki earthquake suffered damage again

Tennoh Bridge, National Road 45

1978 Miyagi-ken-oki

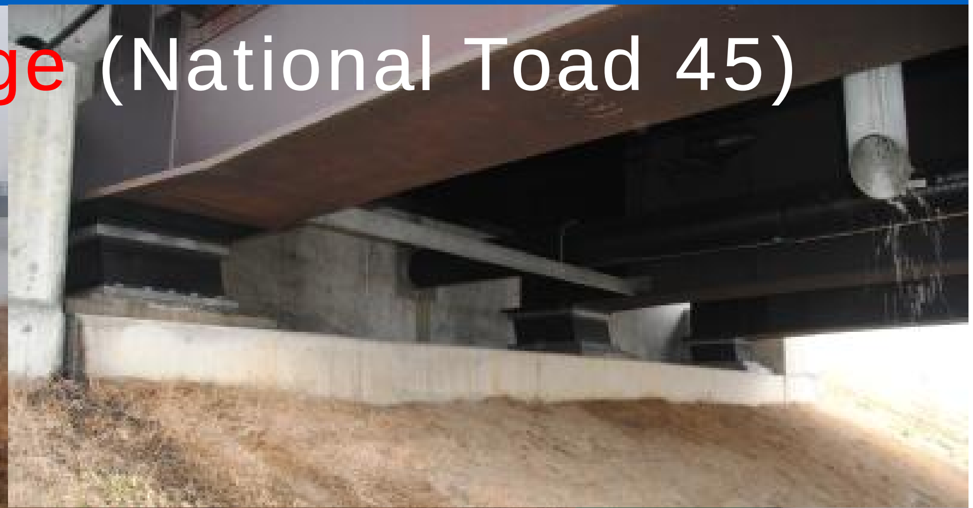
2011 Great East Japan

Bridge was about to collapse if an aftershock was stronger



Bridges designed based on the post-1990 design code suffered no damage

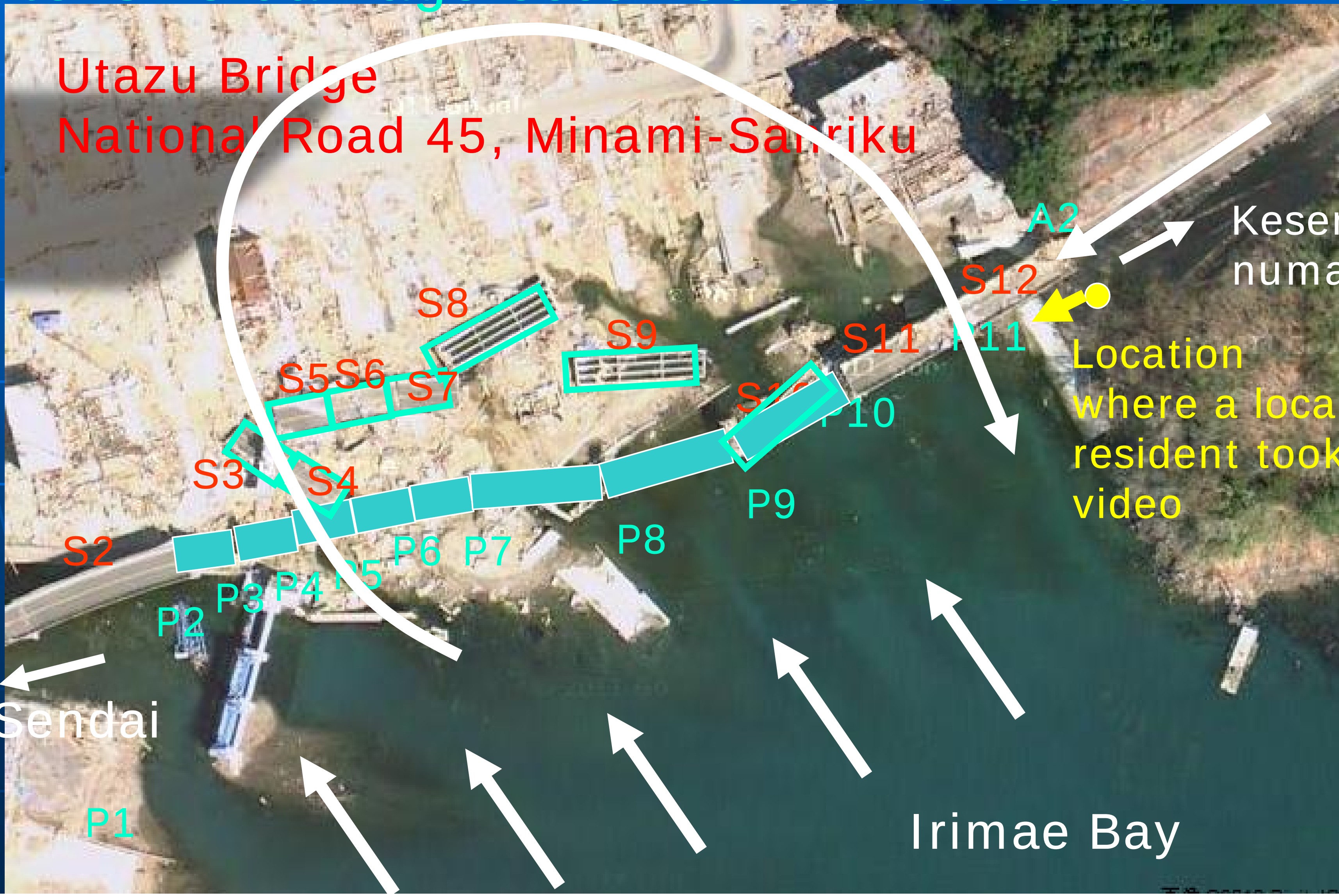
Higashi Matsuyama Bridge (National Toad 45)



Shin-Tenno Bridge (Sanriku Expressway)

No single word about “Tsunami” had been described in the codes

Extensive damage occurred due to tsunami



Video showing submerging of Utatsu Bridge

Before Tsunami Attack

Tsunami rose up to the bottom of the bridge

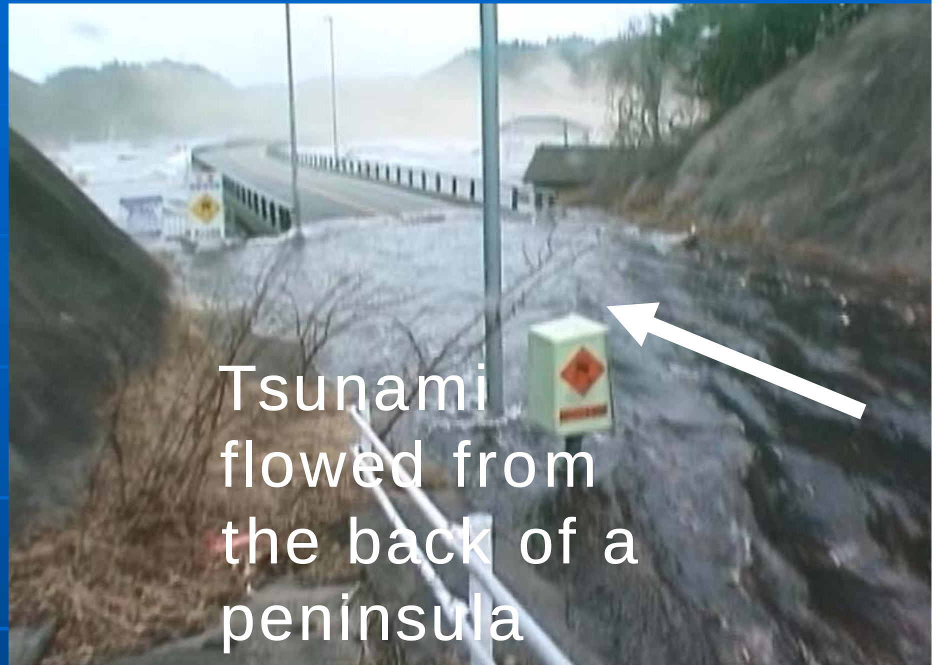
Center of Utatsu Town

Still peoples were chatting & watching see

Houses are being floated

Courtesy of Mr. Katsuya Oikawa

Rising Up of Tsunami




Utasu Town was disappearing
by 14 m tall tsunami
Utatsu High
School
Utatsu Junior
High School
Center of Utatsu Town
Utatsu Bridge
Courtesy of Mr. Katsuya Oikawa

PC girder decks floated by tsunami

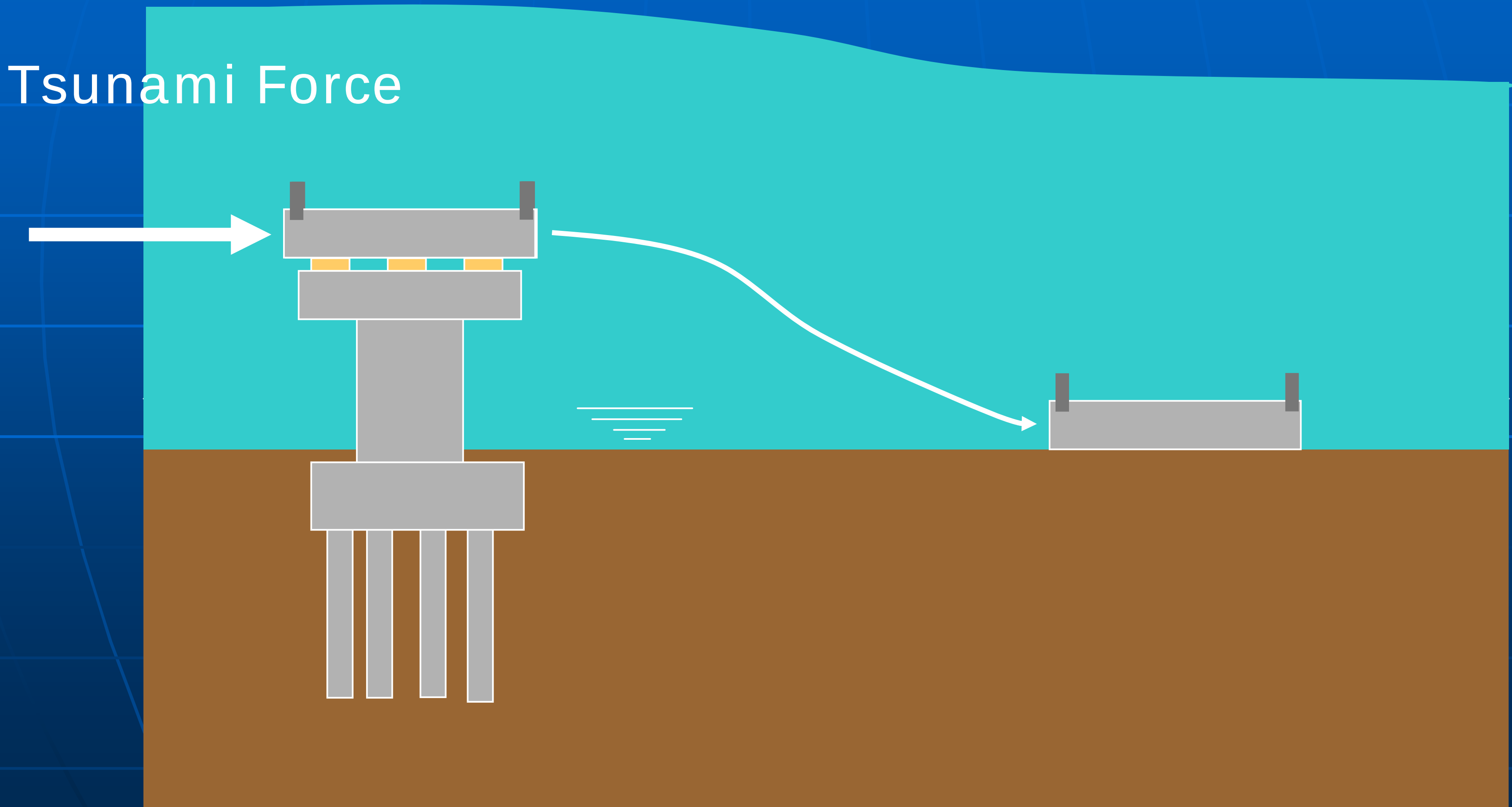
Utazu Bridge, Route 45, Rikuzen-Takada City

Short span decks were simply dragged by tsunami

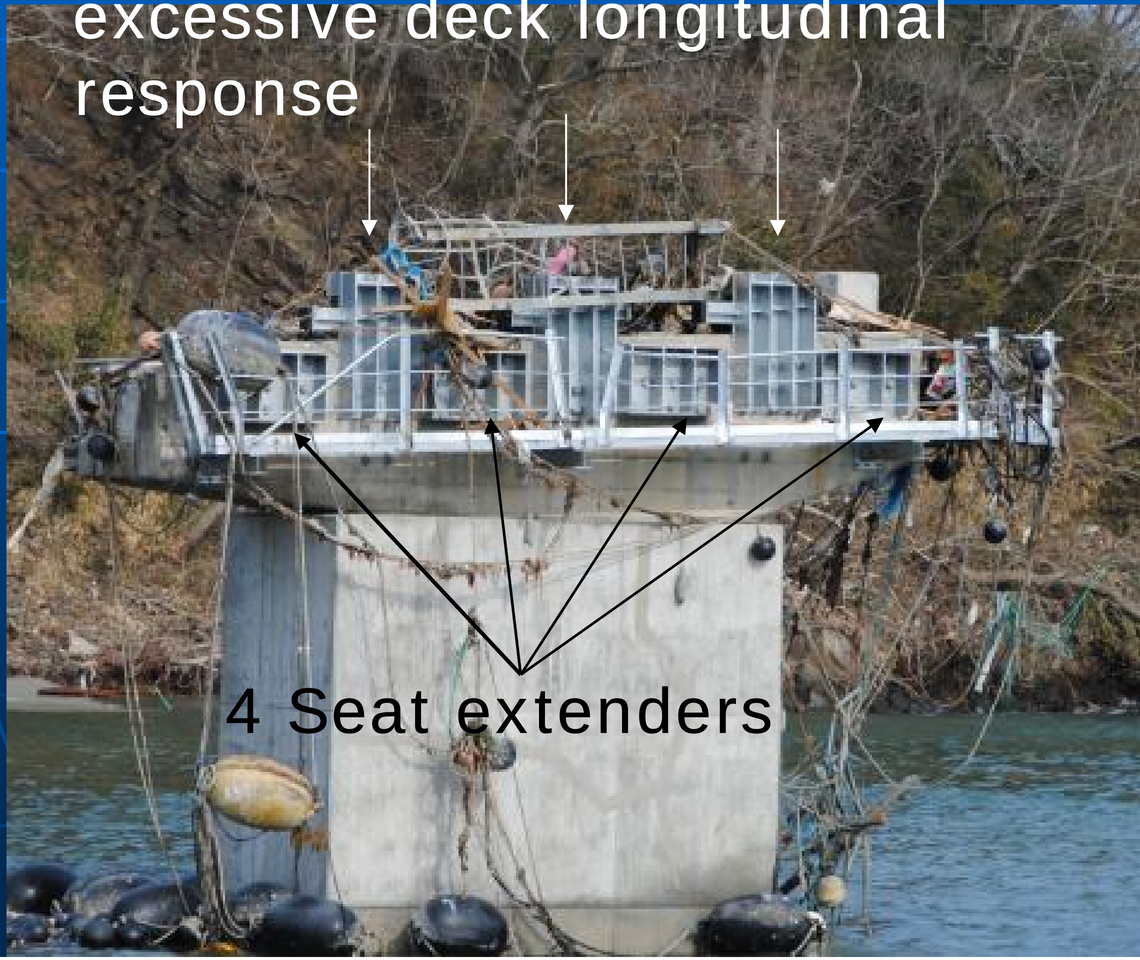
P2

Stoppers for preventing excessive deck displacement in the longitudinal direction

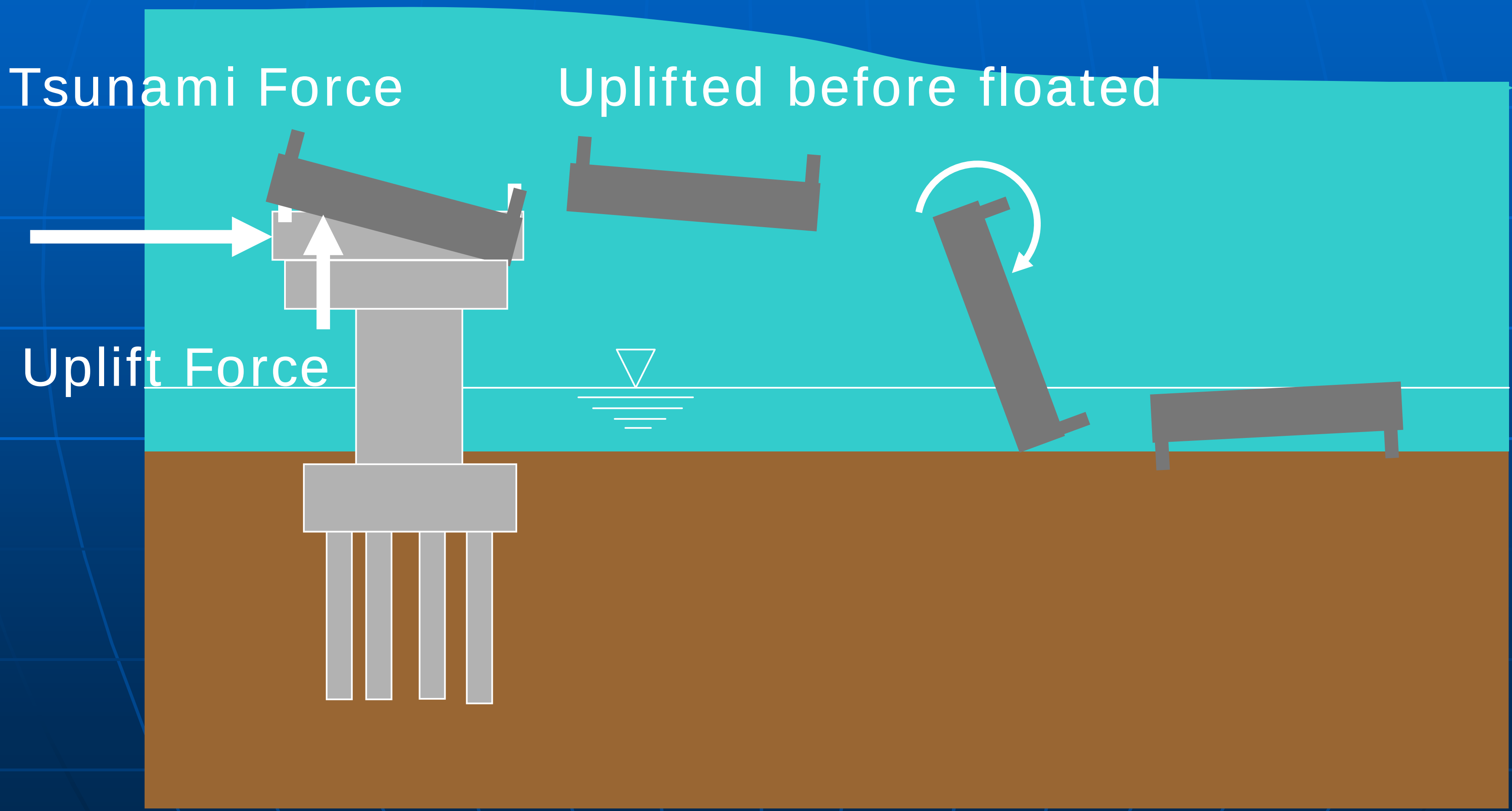
A Possible Failure Mechanism of Short-span Decks due to Tsunami



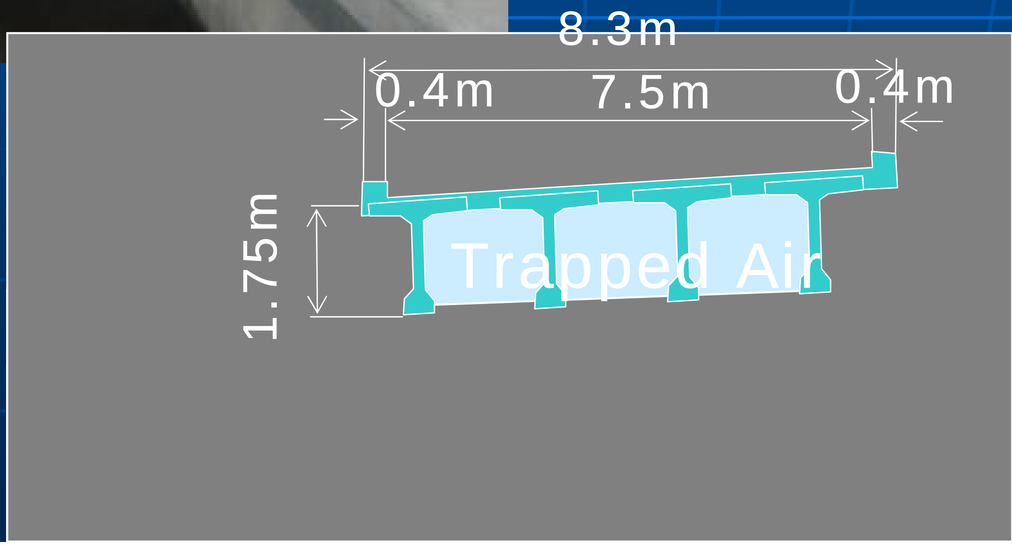
Steel stoppers were provided, but they were ineffective for preventing transverse deck movement & uplift by tsunami



Most Probable Failure Mechanism of Medium-span decks due to Tsunami



Uplift due to Air Trapped under a PC Deck



Many bridges survived whereas they were completely submerged by tsunami

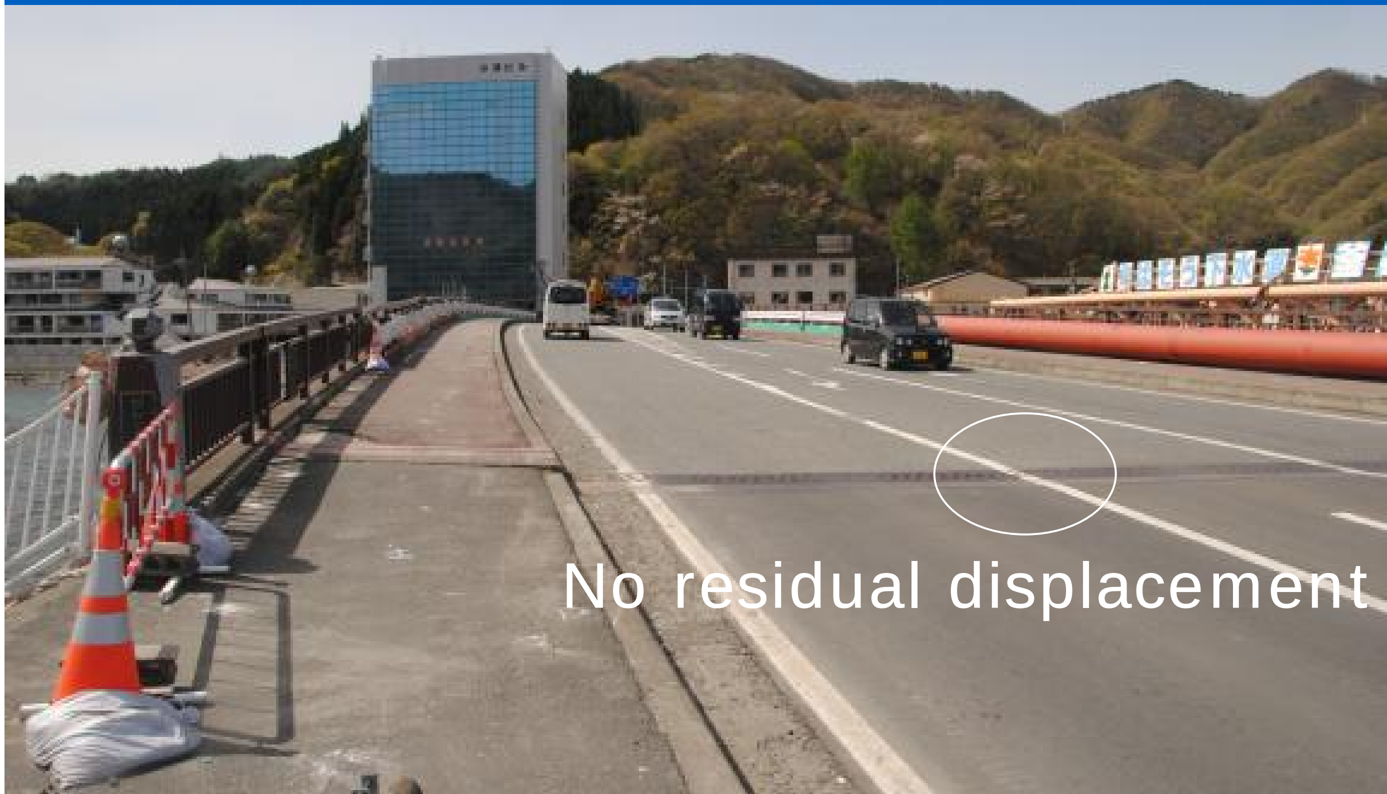
Yanoura Bridge,Kamaishi

Kamaishi City

National Road 45

After Kozo Sawada, Sunday Maichi, Special Issue for E-J EQ, No.2

Yano-ura Bridge after the earthquake



Conclusions

- It was a great success that ground-motion- induced damage of bridges which had been designed or retrofitted in accordance with the post-1990 design codes was generally limited. This was resulted from the recent advancement of seismic design practice and implementation of seismic retrofit.
- New challenges which were identified are securing seismic performance under more stronger ground motions and mitigating tsunami-induced-damage.

Thank you for your kind attention

A young pine tree which survived tsunami