Damage of Infrastructures due to 2011 Great East Japan Earthquake

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- Overview of infrastructure damage
  - Sediment-related disasters
  - Waste water systems
  - Dams
  - Road geotechnical works
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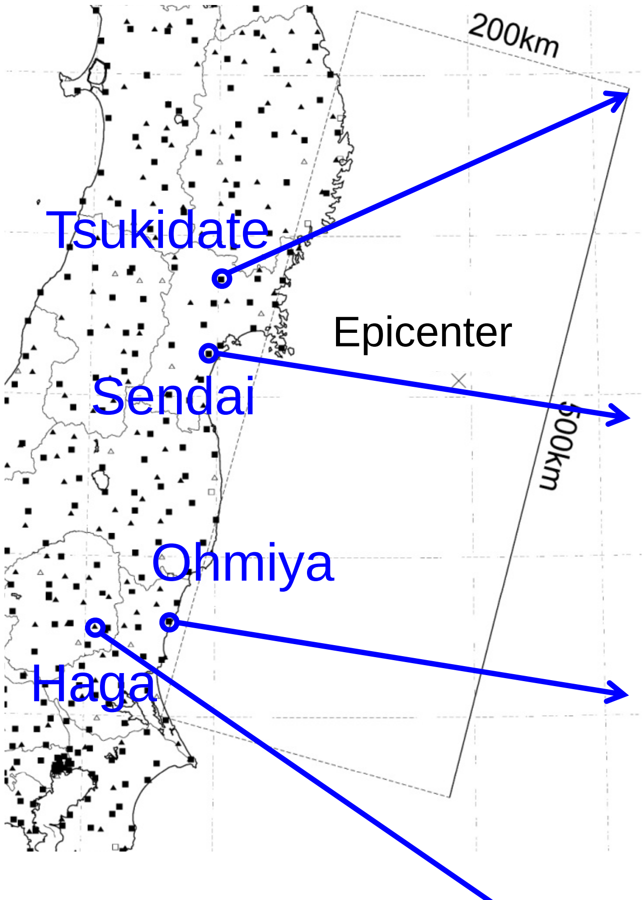
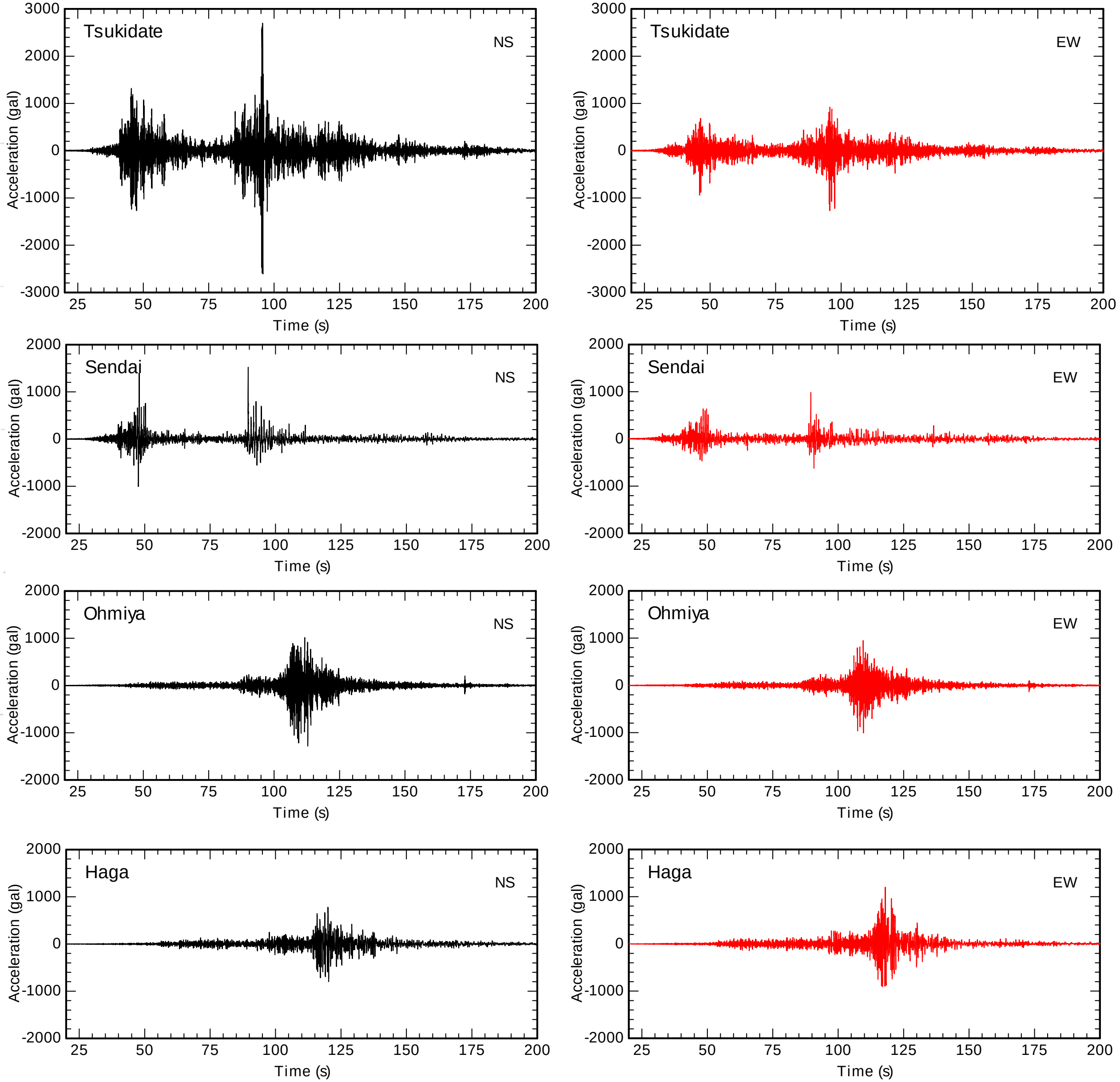
- Conclusion

Ground motion characteristics

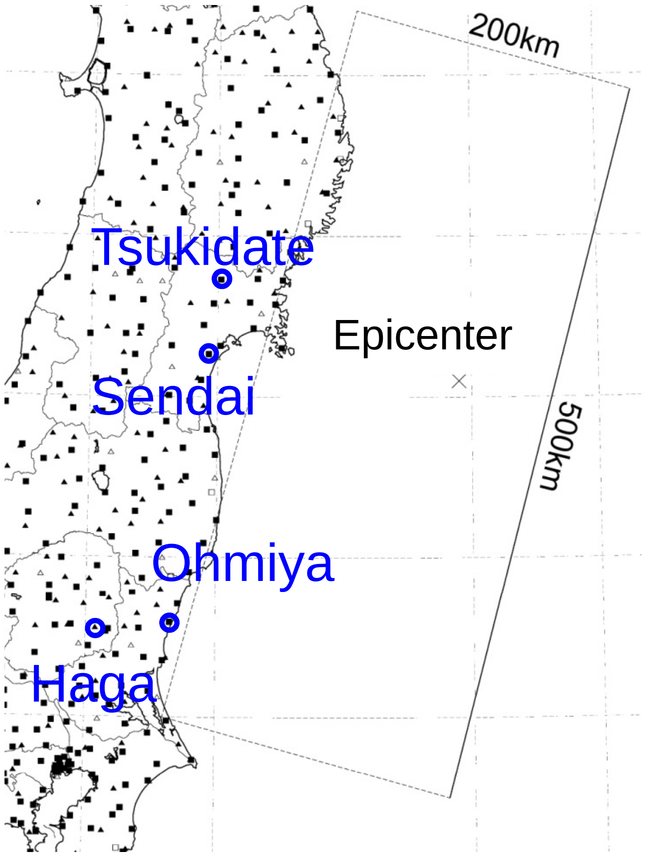
Typical strong motion records

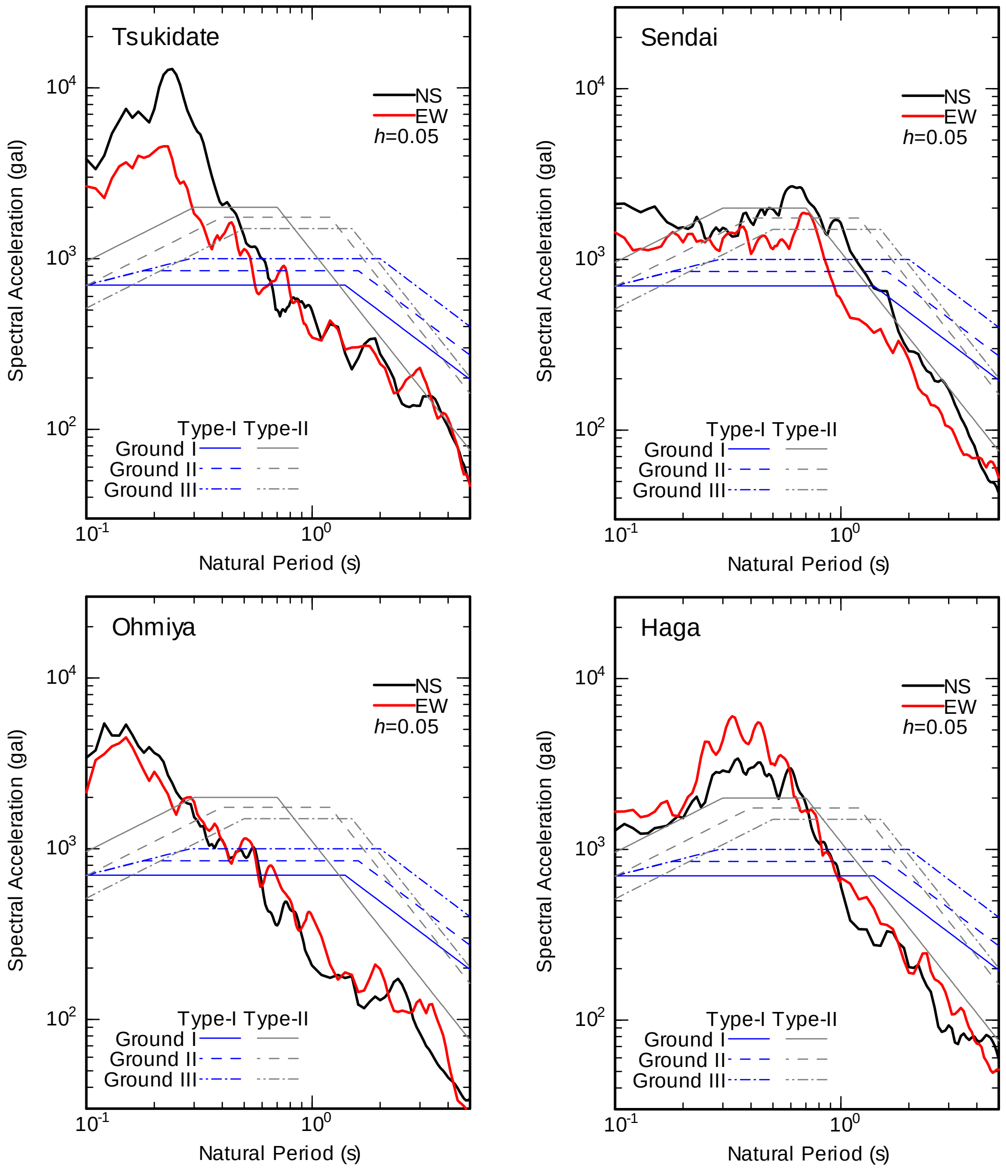




Source: National Research Institute for Earth Science and Disaster Prevention

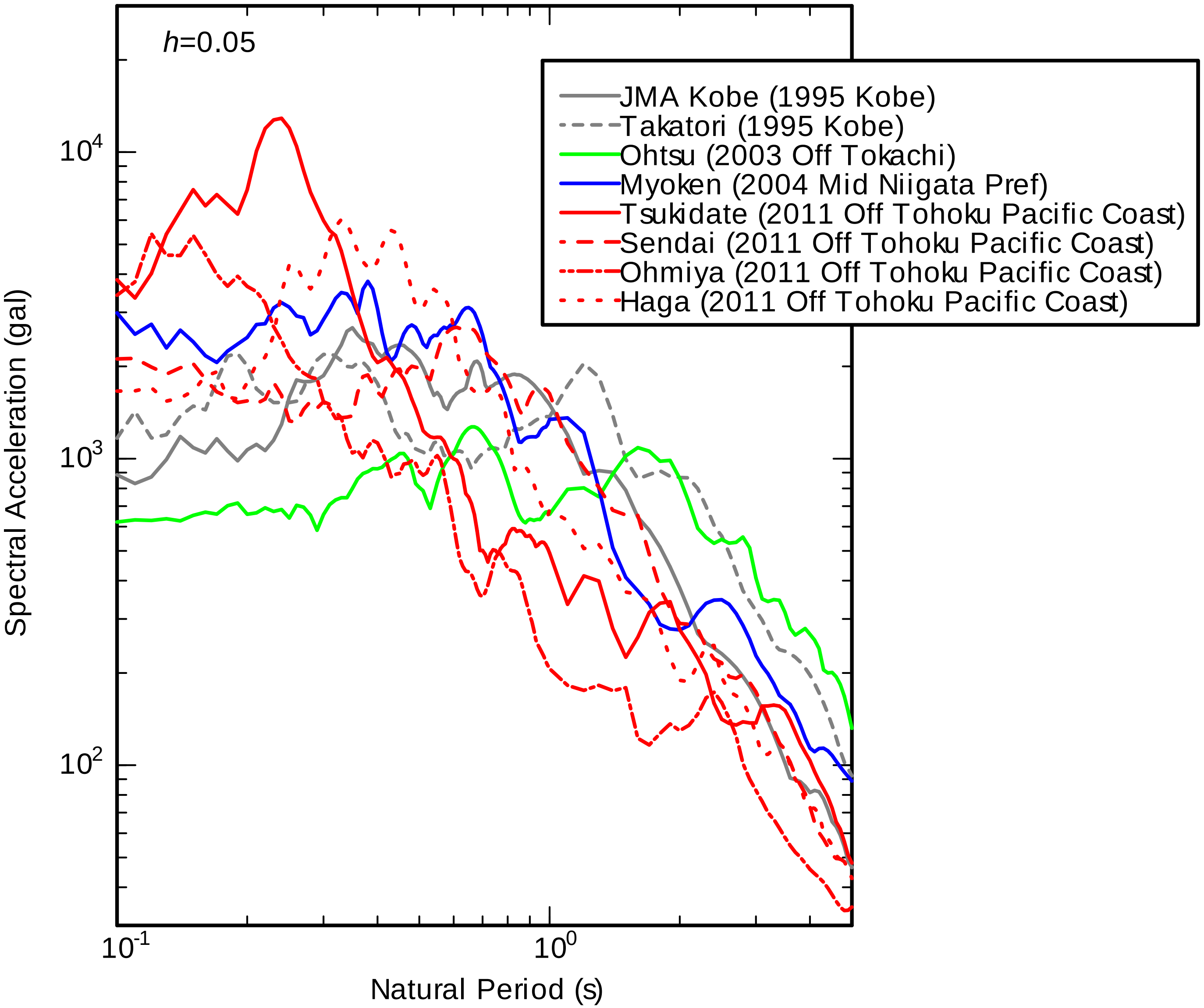
Acceleration response spectra





Source: National Research Institute for Earth Science and Disaster Prevention

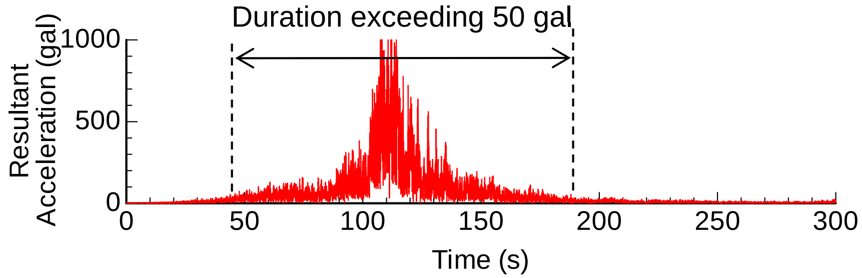
Comparison of acceleration response spectra

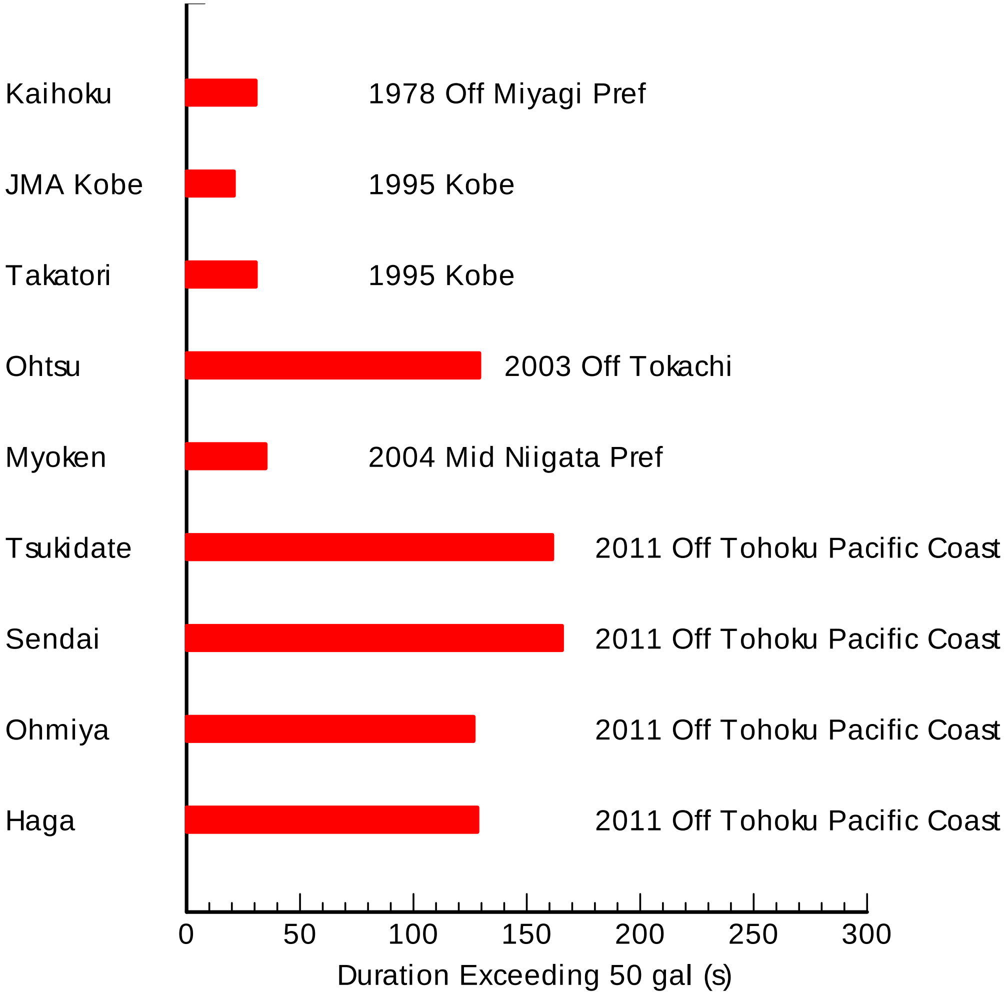


Duration of strong ground motion

Definition of strong motion duration

- Compute the resultant of two horizontal acceleration components.
- Define "duration" as an interval between the times when the resultant acceleration first exceeds 50 gal and it lastly becomes less than 50 gal.





Overview of infrastructure damage

Sediment-related disasters

- The number of sediment-related disasters was rather small, even though strong motions, i.e., seismic intensity of 5+ or larger were widely observed.
- The 2008 Iwate-Miyagi Nairiku Earthquake caused approximately 3,500 sediment-related disasters including river course blockages.

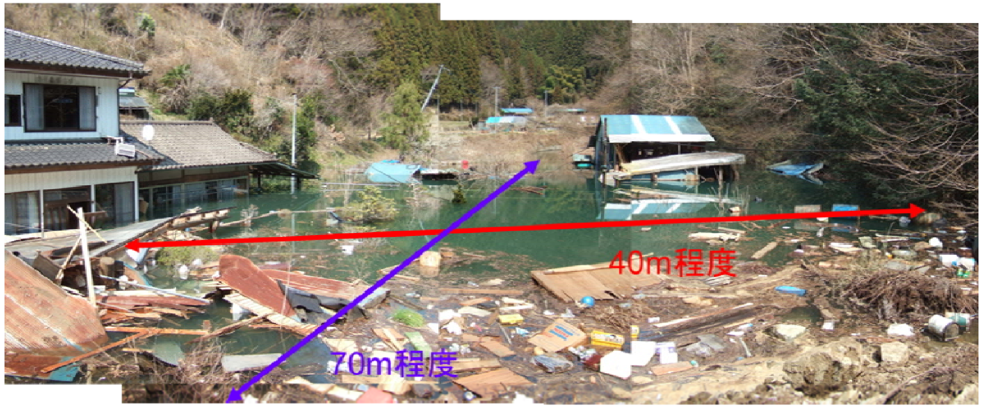
Hanokitaira, Shirakawa City
- Width: 70m, Length: 160m
- 13 deaths, 10 destroyed houses
- Mainly consists of aeolian deposit of volcanic ash soil.

Okanouchi, Shirakawa City
- Width: 50m, Length: 100m
- 1 death, 1 destroyed house
- Mainly consists of aeolian deposit of volcanic ash soil.

Sediment-related disasters by aftershock

- An aftershock (M7.1) occurred on April 11. Maximum seismic intensity was 6-.
- Induced slope failures and landslides.
- In Tabito, Iwaki City, a landslide destroyed 3 houses, caused 3 deaths, and generated a landslide dam.

Tabito, Iwaki City
• Hight: 170m, Width: 50m



Landslide dam
• Blocked a stream 3m deep and 3m wide.
• Landslide dam: 40m wide, 70m long and 2m deep

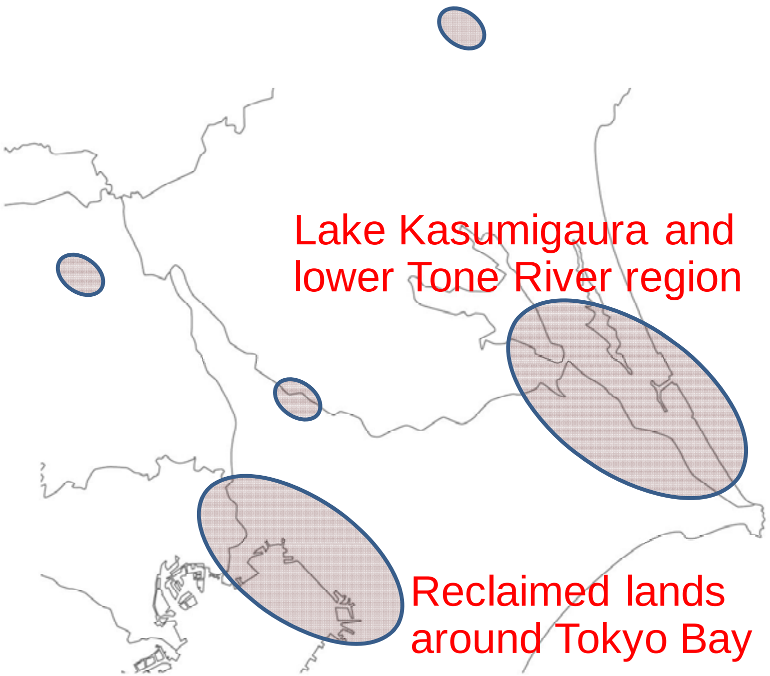
Damage of waste water treatment plants

- 16 waste water treatment plants were suspended and 38 were damaged as of August 8.
- Plants not impacted by tsunami resumed shortly, while those in tsunami inundation areas were severely damaged.
- Liquefaction caused uplifts of pipes and manholes, and subsidence of road surface in 138 municipalities over a wide area. In Tokyo metropolitan area massive liquefaction in addition to liquefaction of backfill soils affected piping systems.

Pumping plant damaged by tsunami (Sendai City)

Machinery damaged by tsunami (Tagajoh City)

Damage of waste water pipes due to liquefaction



Waste water pipe damaged area due to liquefaction

Damage of dams

- Cracks were generated at dam crest and/or spillway, and leakage/seepage increased.
- No severe damage affecting dam safety was reported.

Surikamigawa Dam
- Earth core rockfill dam
- Dam height: 105m
- Year of completion: 2006

Damage
- Increase in leakage from 70 l/min to 100 l/min
- 17cm settlement at dam crest
- Cracks on dam crest pavement

Damage of dams

Ishibuchi Dam

- Concrete Face Rockfill Dam
- Dam height: 105m
- Year of completion: 1953

Damage

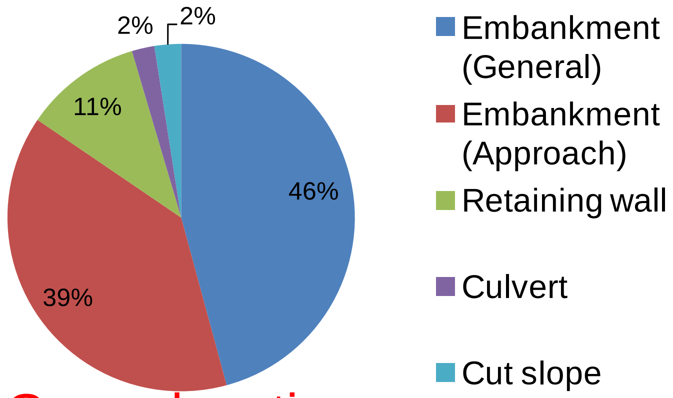
- Leakage increase in the river bed from 2,000 l/min to 3,000 l/min.
  *Imperfection of flow measurement.
- 1cm settlement at dam crest

2011 Great East Japan Earthquake

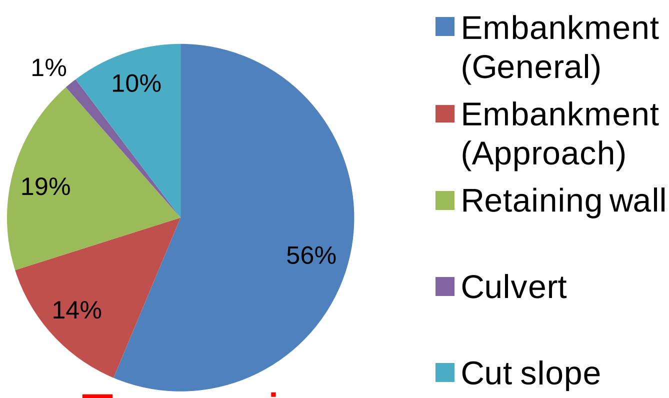
2008 Iwate-Miyagi Nairiku Earthquake

Damage of road geotechnical works (National highways)

	Embankment (General)	Embankment (Approach)	Retaining wall	Culvert	Cut slope	Total
Ground motion	130	110	31	6	7	284
Tsunami	49	12	16	1	9	87



Ground motion



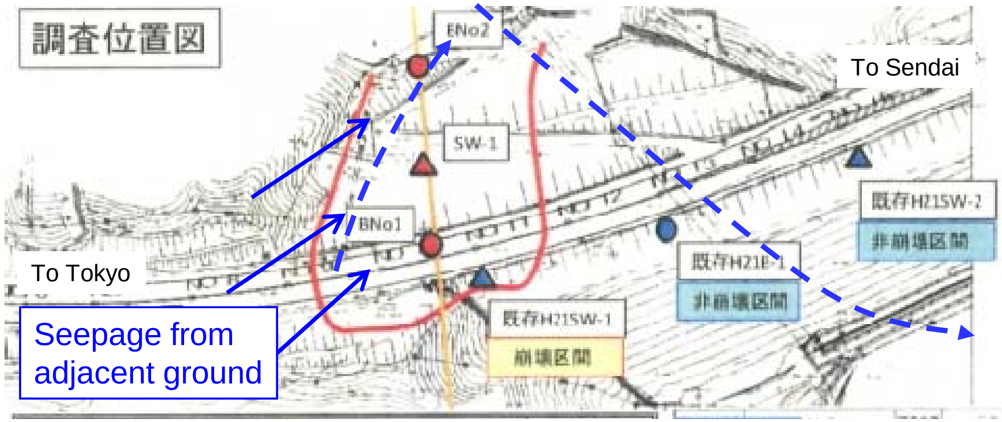
Tsunami

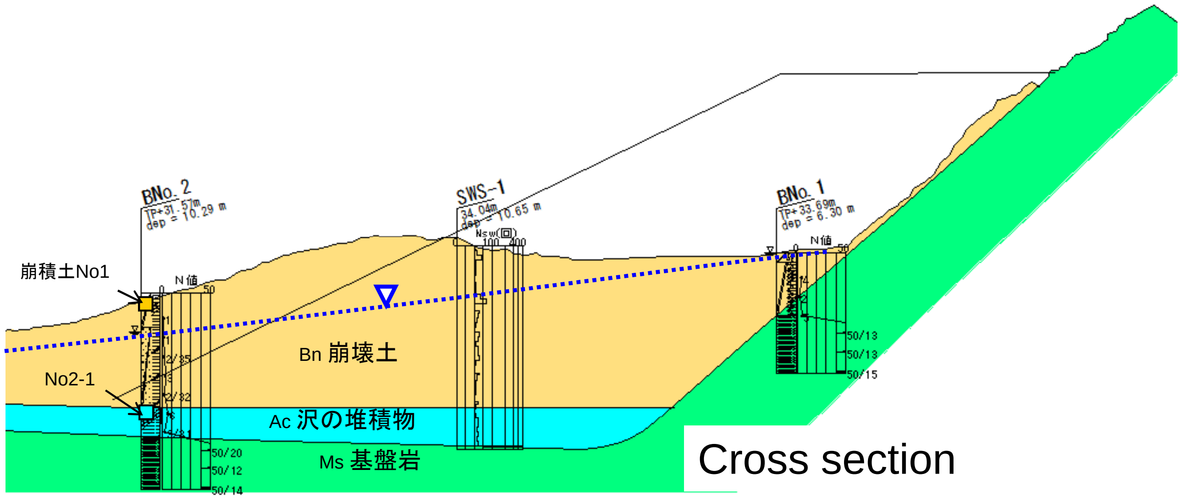

Wash out of embankment


Collapse of embankment

Settlement of approach

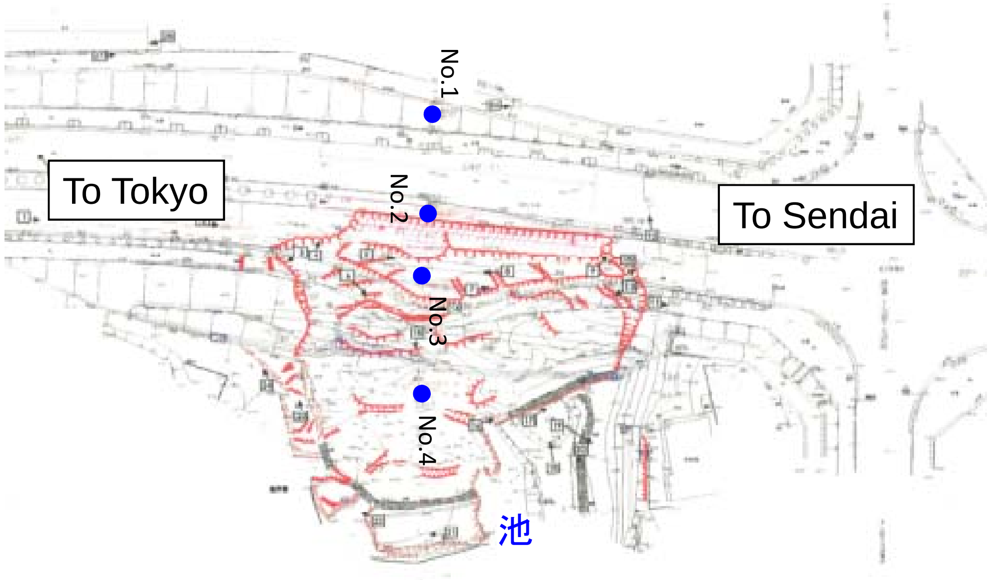
Damage of road embankment due to high groundwater table in embankment body



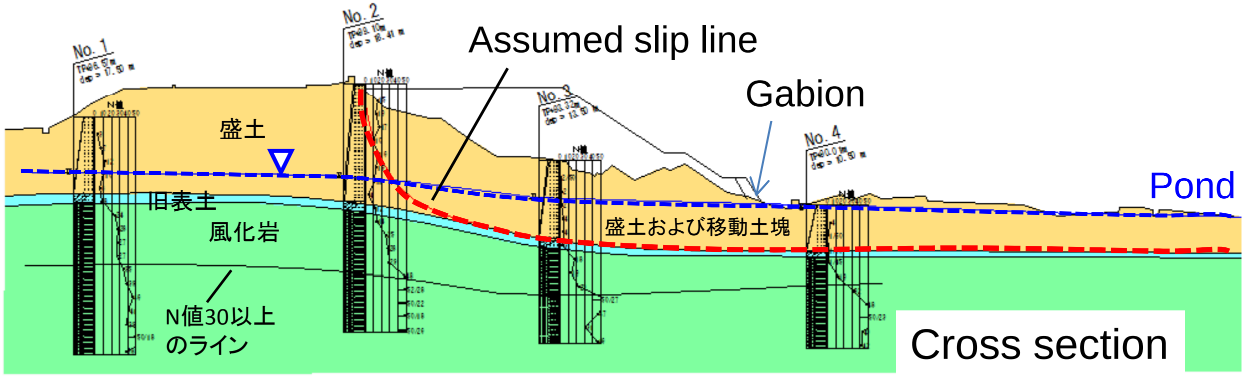


- Constructed by filling up a valley.
- Spring water seeps from upper portion of embankment.
- Groundwater table in embankment is high.

Damage of road embankment due to liquefaction of foundation layer



Plane view

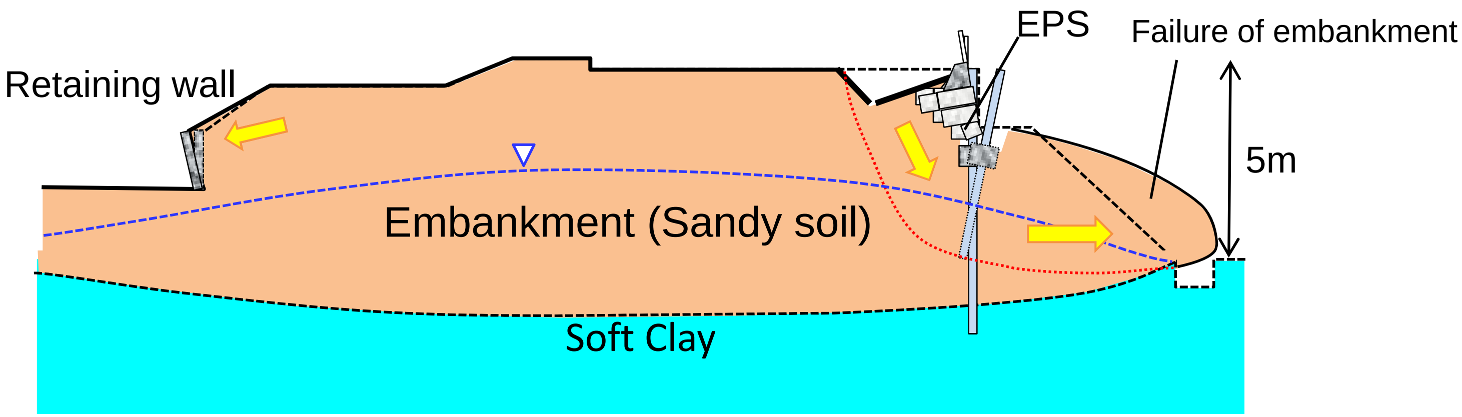


Cross section

- Embankment adjacent to a pond laterally spread about 20m.
- Foundation layer was judged to liquefy.
- Safety factor by circular arc method was less than 1.

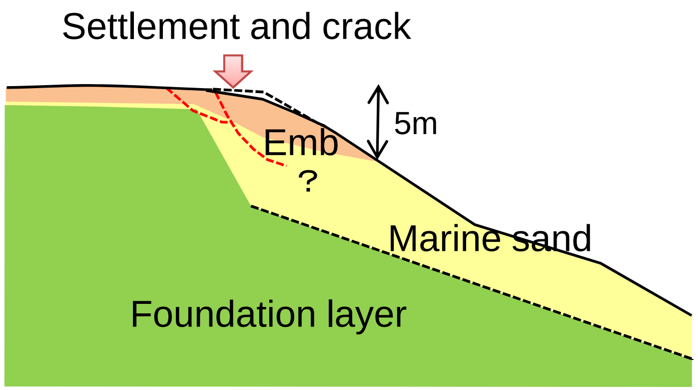
Damage of road embankment due to liquefaction of embankment body

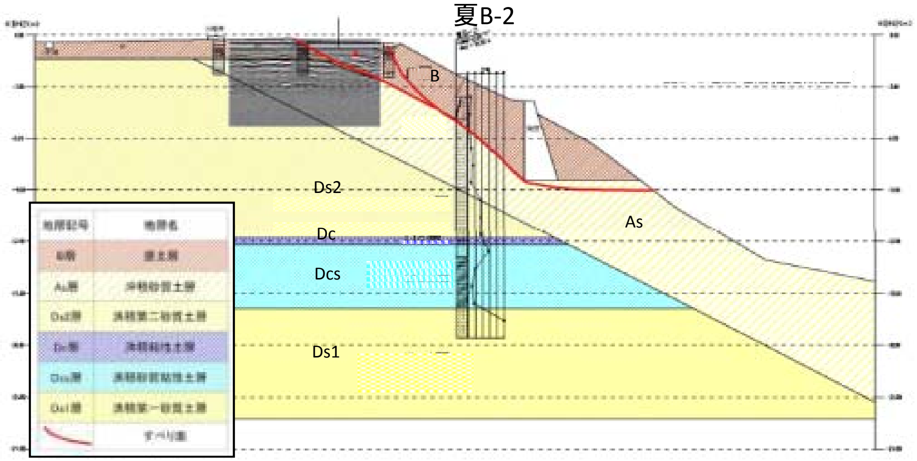
- Constructed on soft clay layer with sand mat method.
- Groundwater table exists within embankment body.
- Embankment beneath groundwater level and sand mat were assumed to liquefy.



Damage of road embankment constructed on unstable slope ground

- Constructed on edge of marine sand deposited on slope ground.
- No design consideration was given to construction of embankment or retaining wall on slope ground.



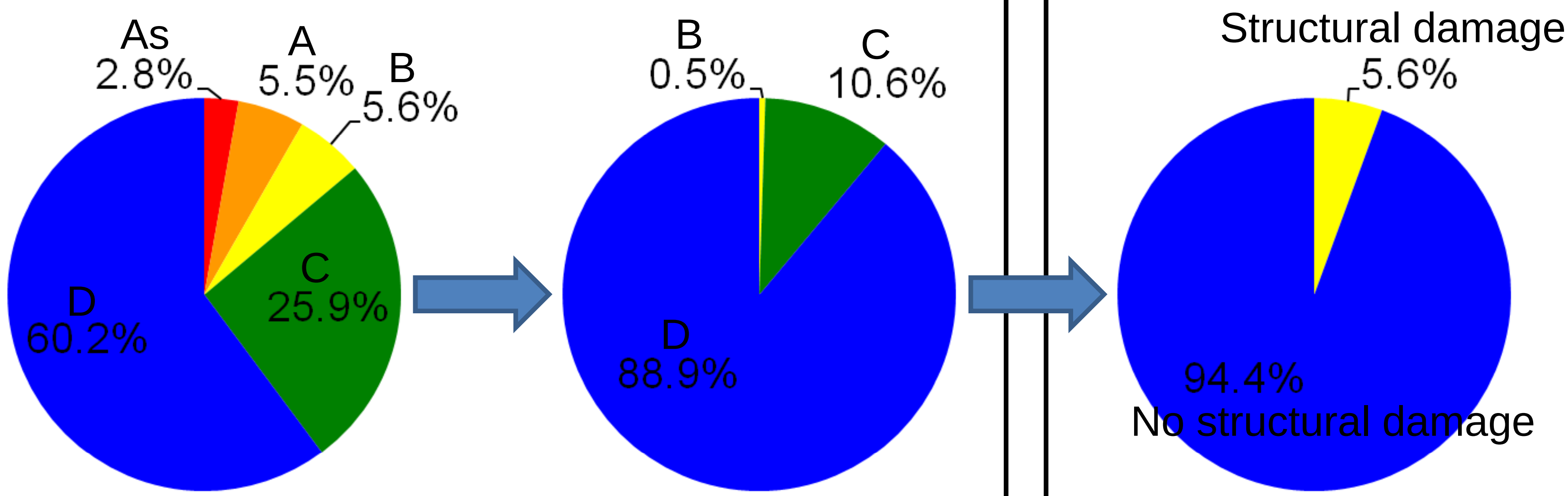


Damage of highway bridges

Revision of seismic design code and improvement of seismic performance

Damage of RC piers
1995 Kobe Earthquake

Damage of bridges
Great East Japan Eq

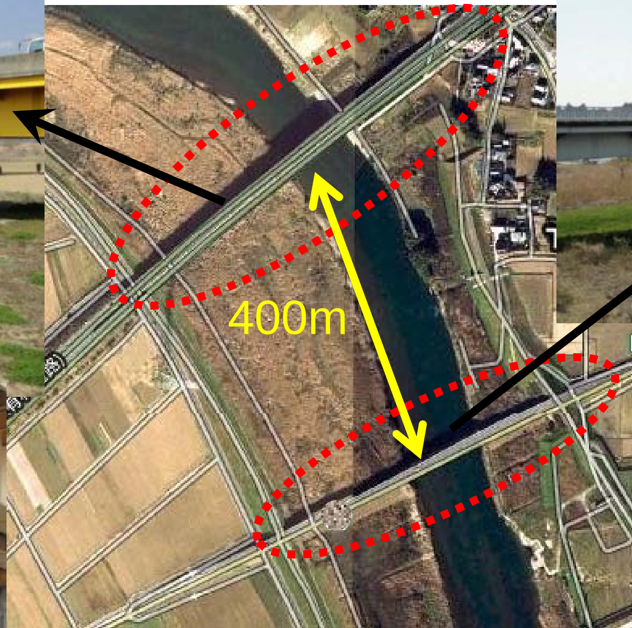


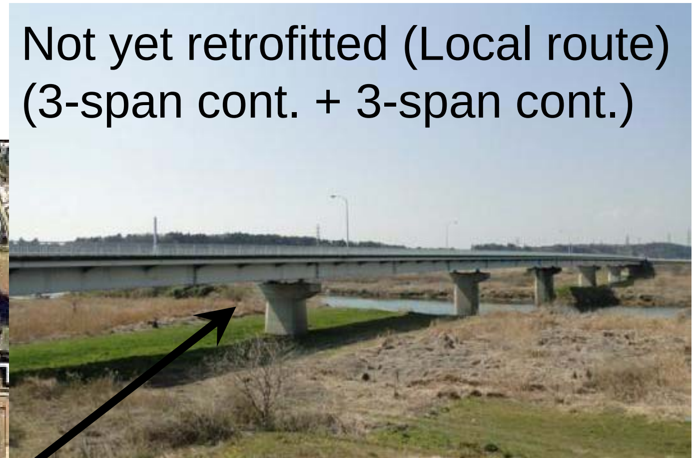
1971 Code or former | 1980 or 1990 Code | 1996 Code or later

As: Collapse, significant damage
A: Broken reinforcement, significant deformation
B: Partial buckling of reinforcement, partial peeling of cover concrete
C: Crack, local peeling of cover concrete
D: No damage, minor damage

Damage of superstructure, substructure or bearings due to ground shaking.

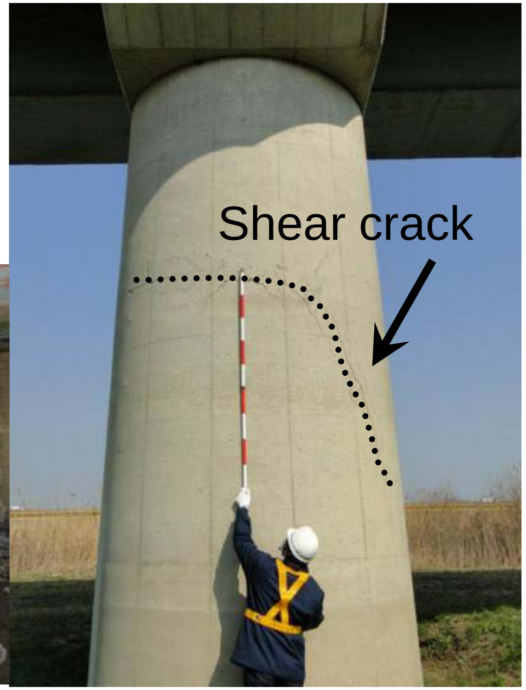
Effectiveness of seismic retrofit





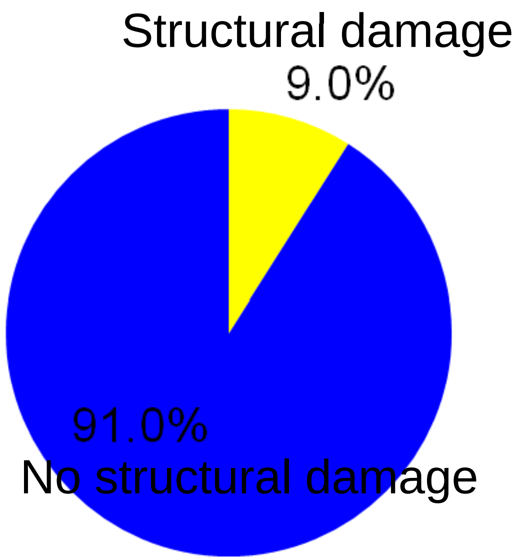
No damage to piers
or bearings

Damage to cut-off
section of long. rebars



Retrofitted bridges with structural damage due to ground motion

*Retrofitted bridges on national highways.



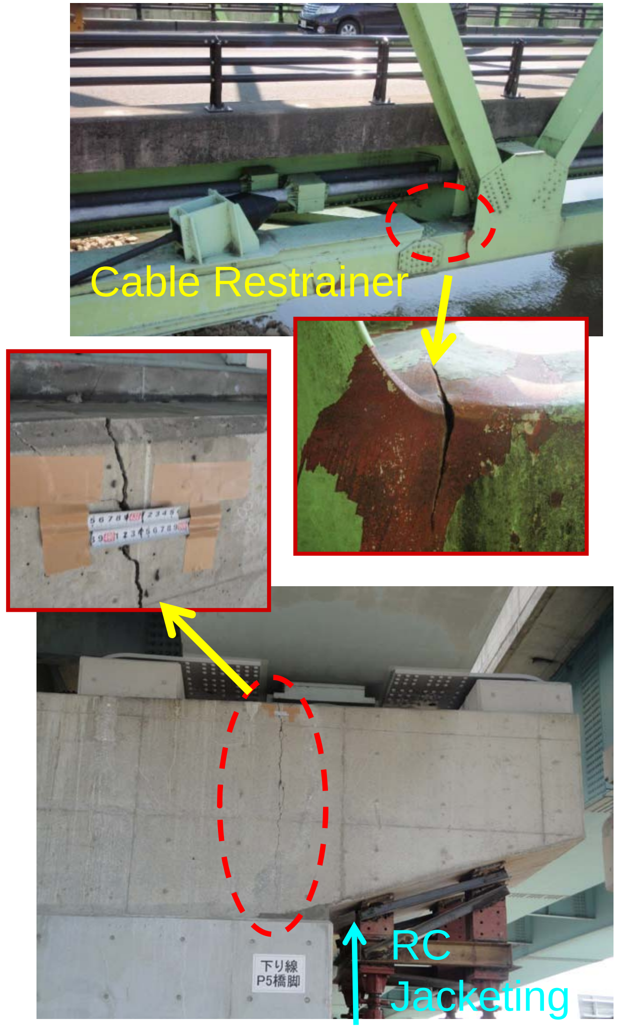
Damaged section

1. Bearing and attachment (6.4%)
- Bolts, side stopper for bearing
- Attachment for damper/shear key

2. Member of superstructure (1.3%)
- Crack on lower chord member
- Crack on girder near bearing
- Shortening of deck-end gap

3. Beam section in T-shape pier (0.7%)
- Vertical crack on beam section
- Crack on pier column-beam connection

4. Backwall of abutment (0.7%)
- Crack

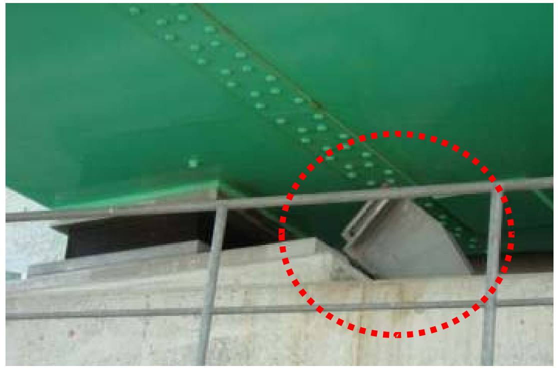


Newly designed bridges with structural damage due to ground motion

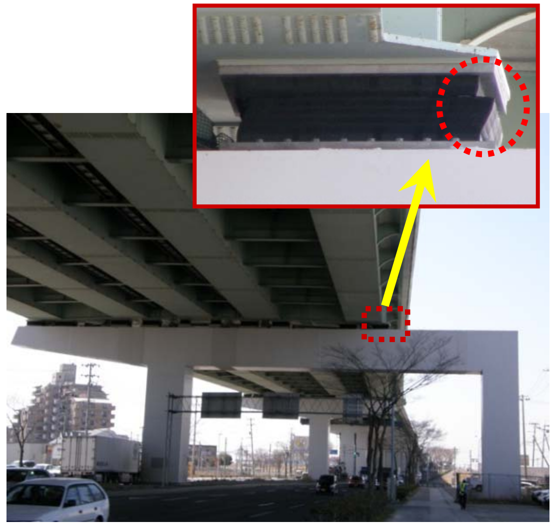
*Bridges designed by 1996 or later code on national highways

Damaged section

1. Bearing and attachment (4.2%)
   - Failure of joint protector
   - Deformation of top shoe plate
   - Deformation of rubber bearing due to movement of abutment
2. Superstructure (1.4%)
   - Shortening of deck-end gap



Rupture of elastomeric rubber bearings



Damage of bridges not yet retrofitted

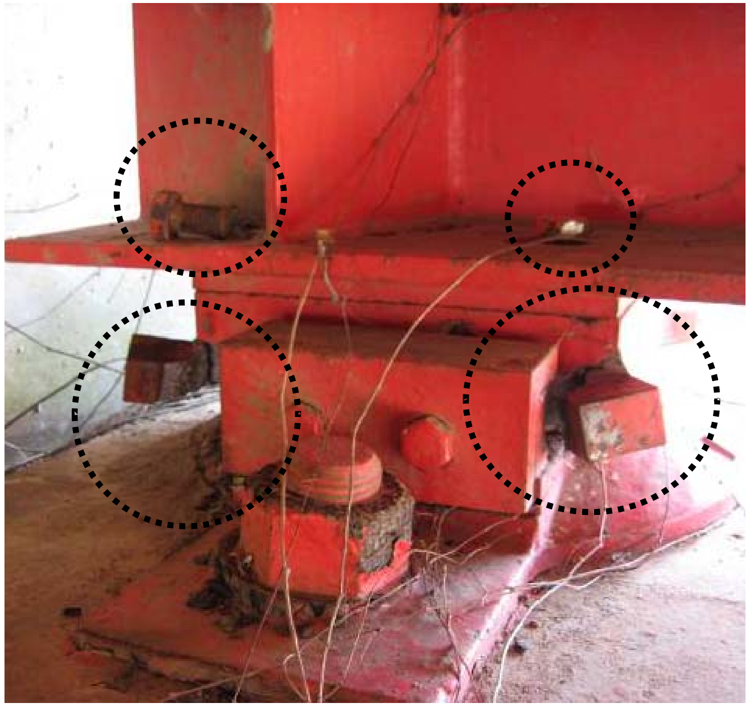
- Damage to RC column with cut-off of longitudinal rebars.
  Shear crack developed from flexural failure at the section of cut-off of longitudinal rebars.

Damage of bridges not yet retrofitted

- Damage to steel bearings

Subsidence of deck end resulting from broken movable bearing

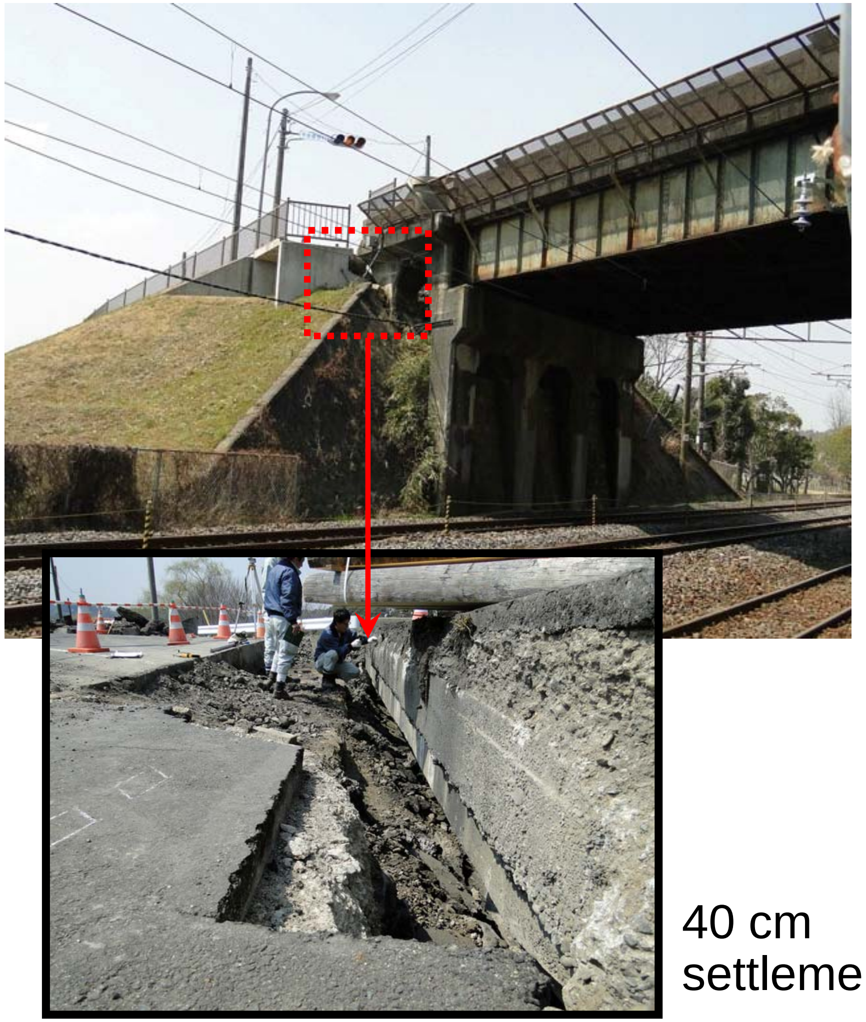
Damage of fixed bearing



Damage to approach of bridge

- Settlement of backfill soil of abutment

Overpass



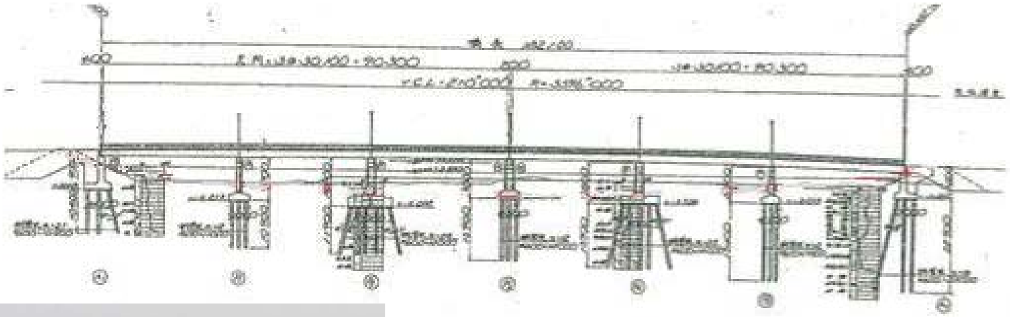
40 cm
settlement

Effects of liquefaction

Liquefaction
at adjacent
levee

Effects of tsunami

- 6-span steel girder bridge (two 3-span continuous girders).
- All spans of girders, one substructure and backfill soil of abutments were washed away.



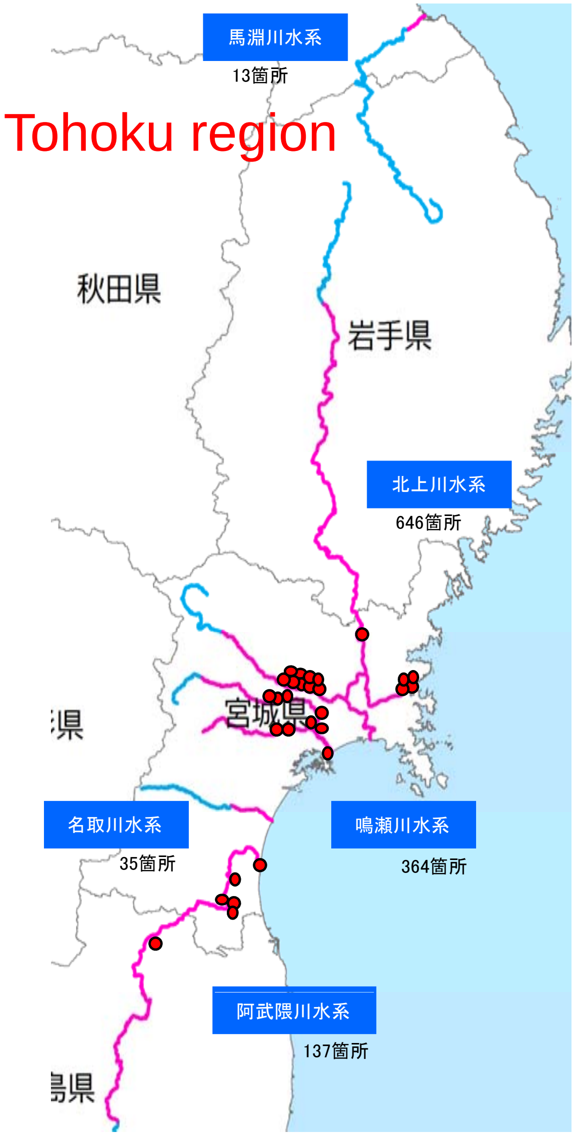
Effects of tsunami

- Bridge structure survived, even though girders were inundated with tsunami.

Damage of levees

Location of levees damaged

- Levees were widely damaged over Tohoku and Kanto regions.
- Damaged levees along the rivers directly administered by MLIT exceeded 2,000.
- Major damage was due to liquefaction.



● Significant damage

：堤防に地震に伴う変状が見られた区域

●：大規模被災箇所（HWLよりも深い堤体の沈下、陥没や、亀裂が発生した箇所）

数字は各水系における被災箇所数

Typical damage of levees

- Typical damage of levees includes crack, settlement, slope failure, etc.

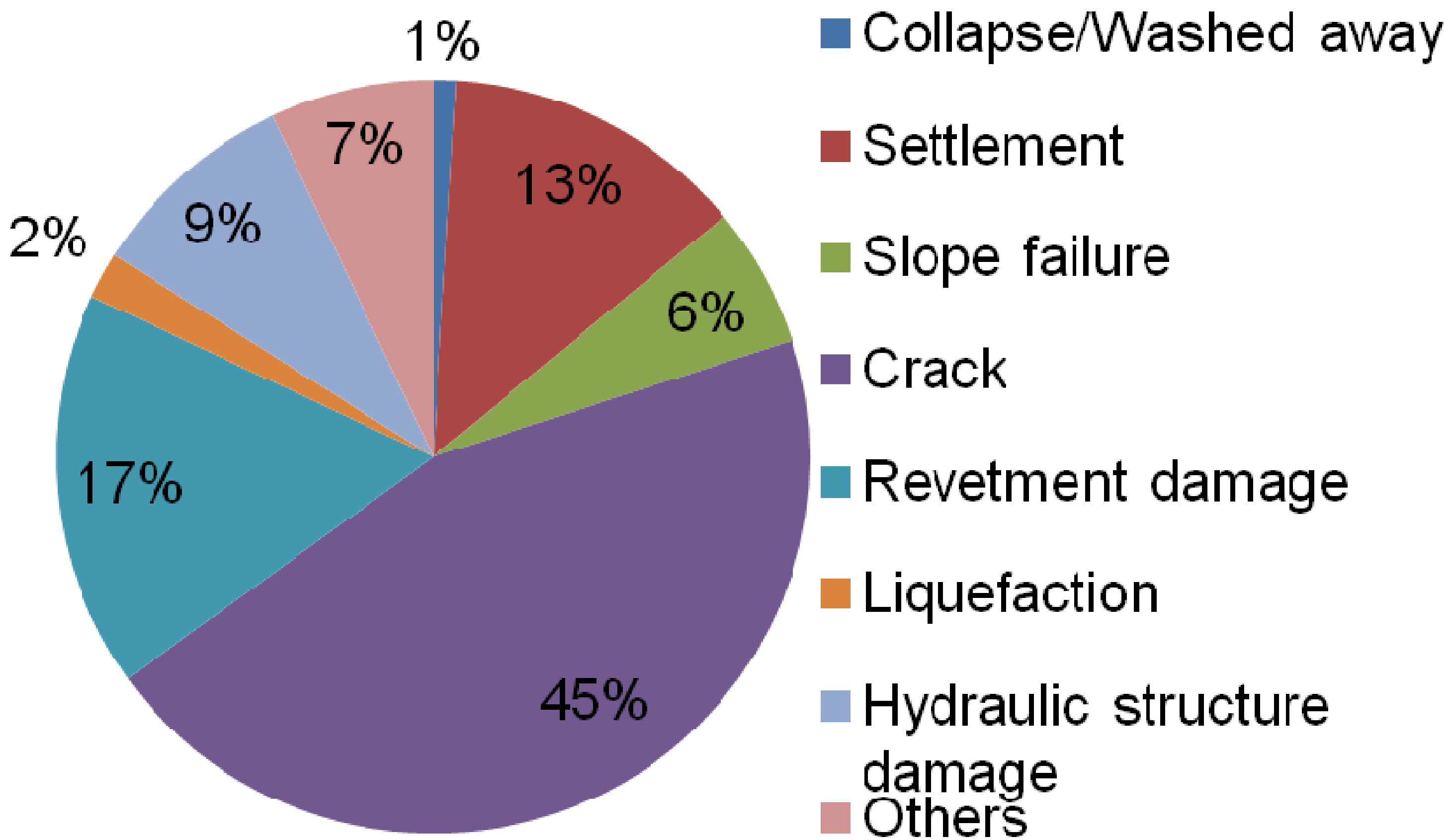
Kokai River, Ibaraki Prefecture

Tone River, Chiba Prefecture

Naruse River, Miyagi Prefecture

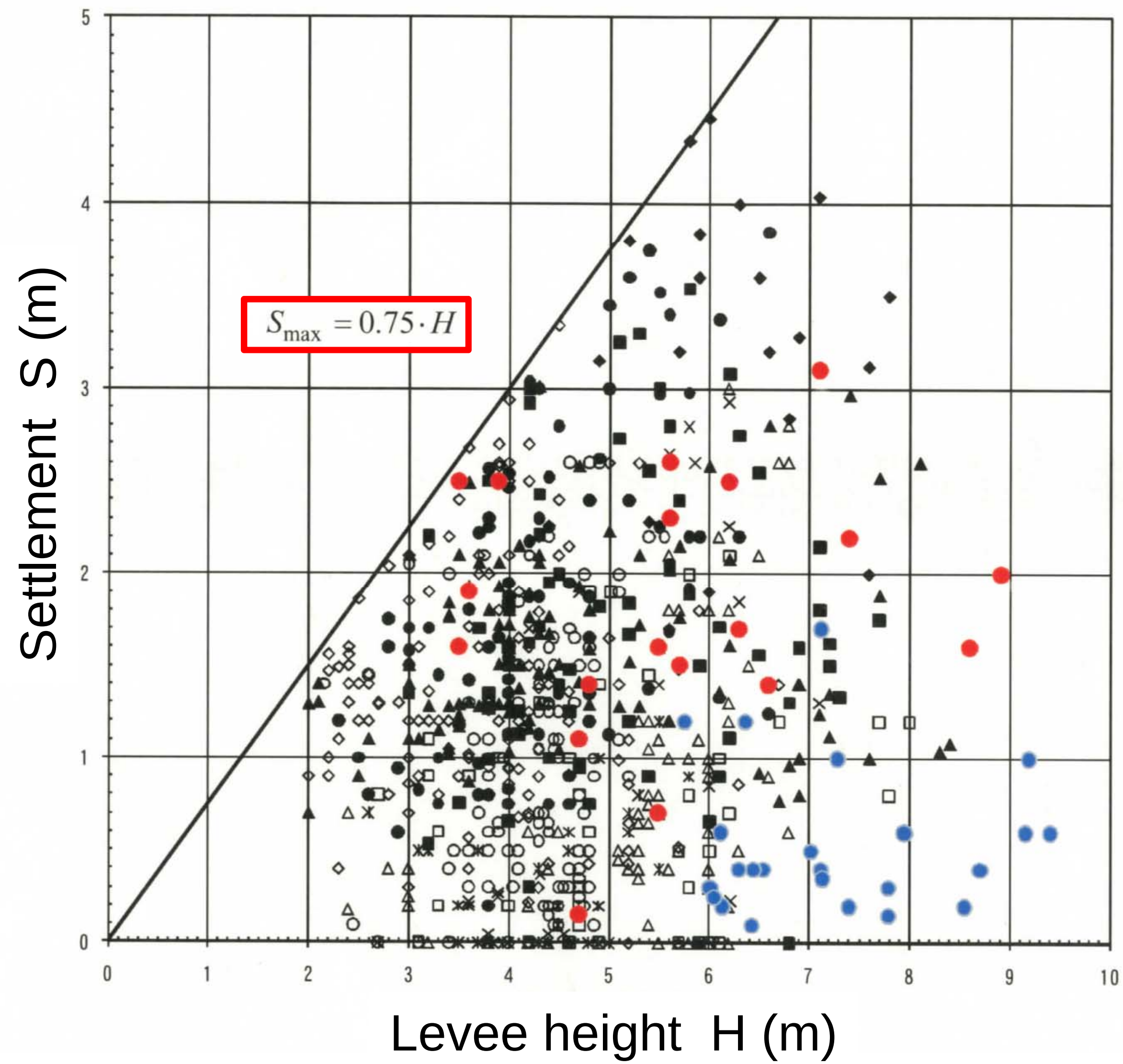
Eai river, Miyagi Prefecture

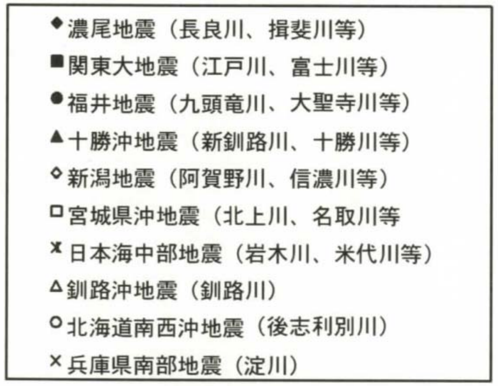
Classification of levee damage

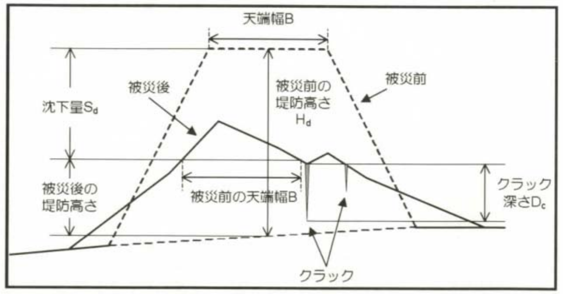


* Rivers directly managed by the Ministry of Land, Infrastructure, Transport and Tourism (MLIT).

Relationship between levee height and settlement

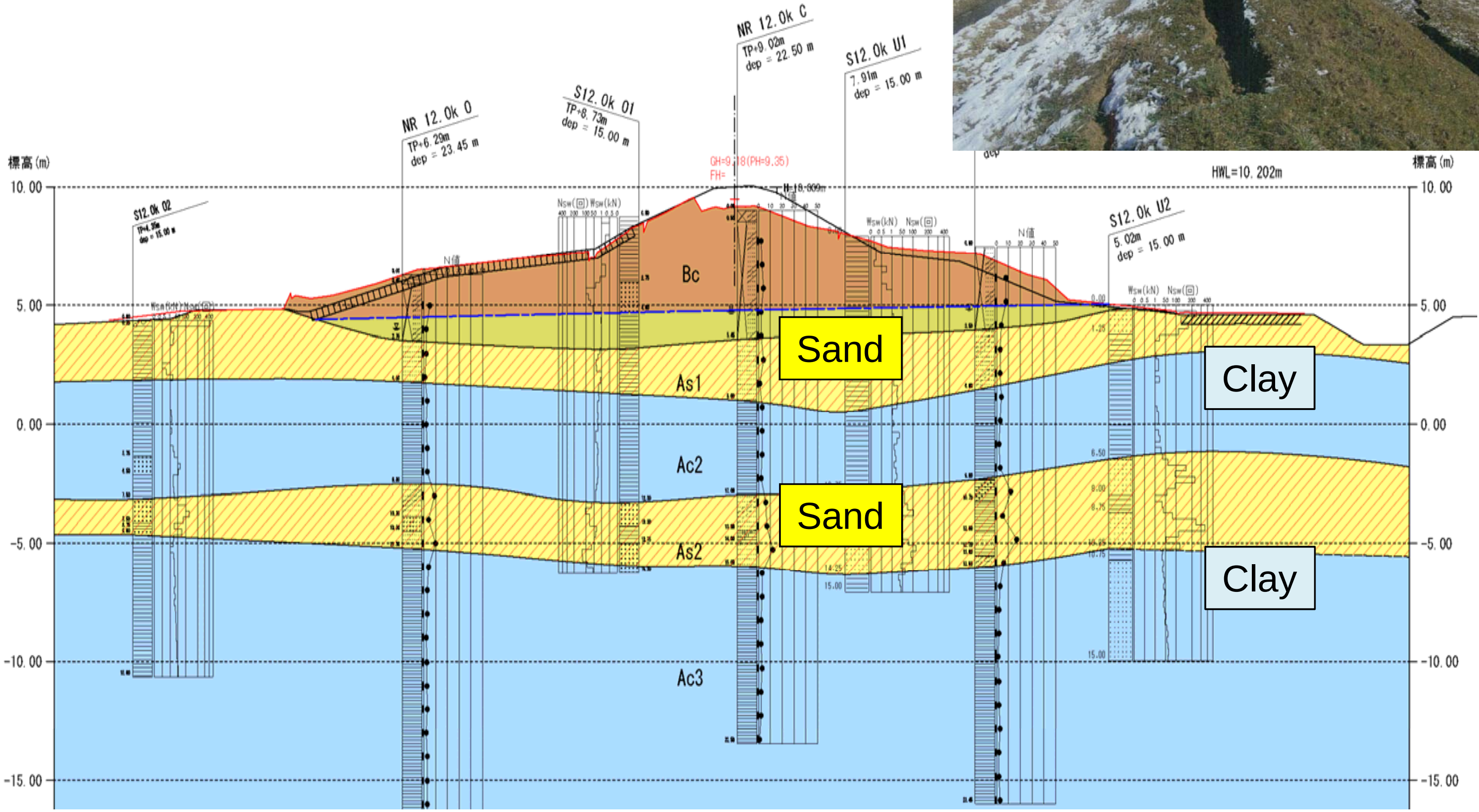






Cause of levee damage

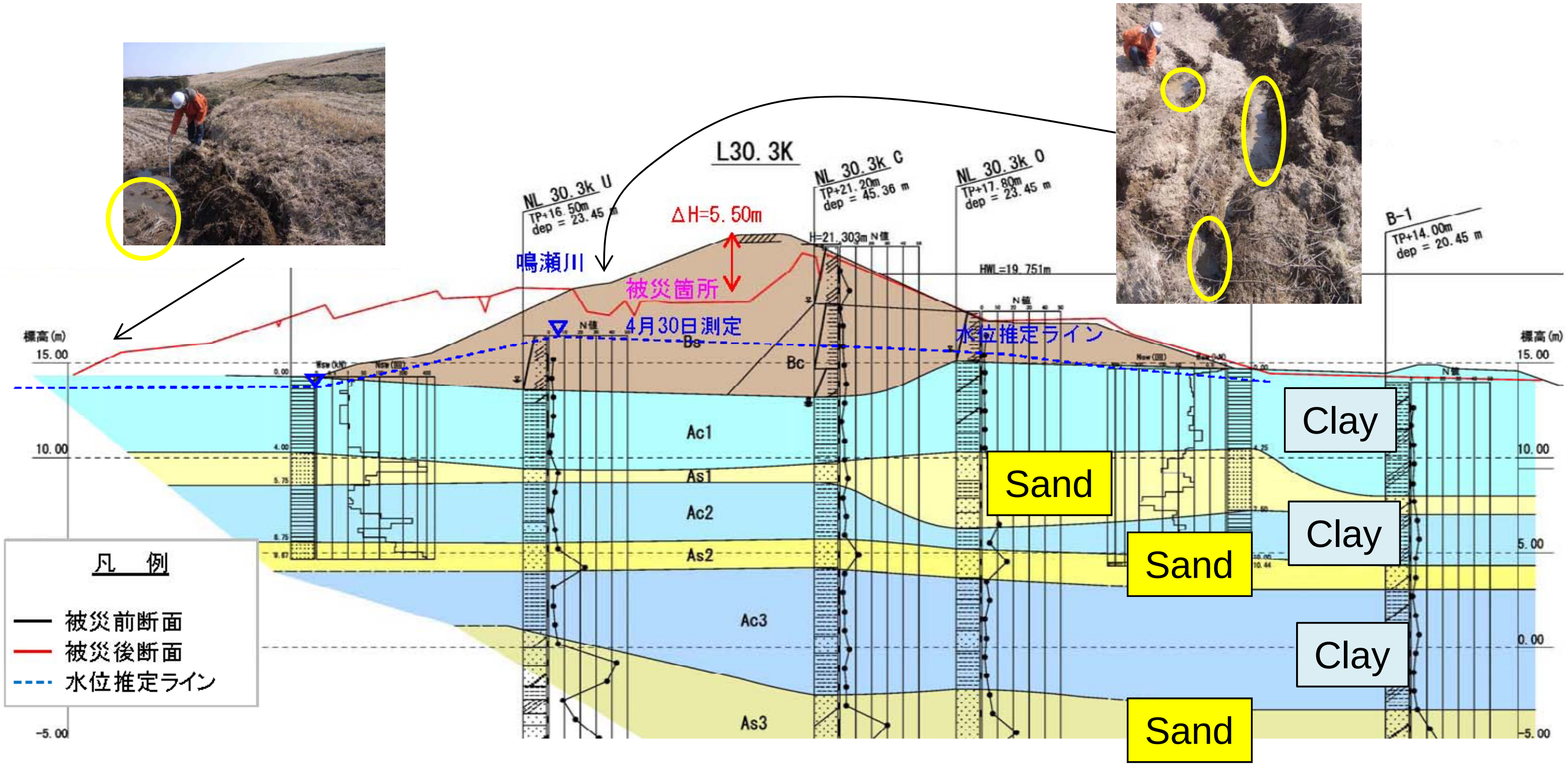
- Sandy layer exists beneath the levee.
- Liquefaction of foundation layer.



Naruse River (Kimazuka)

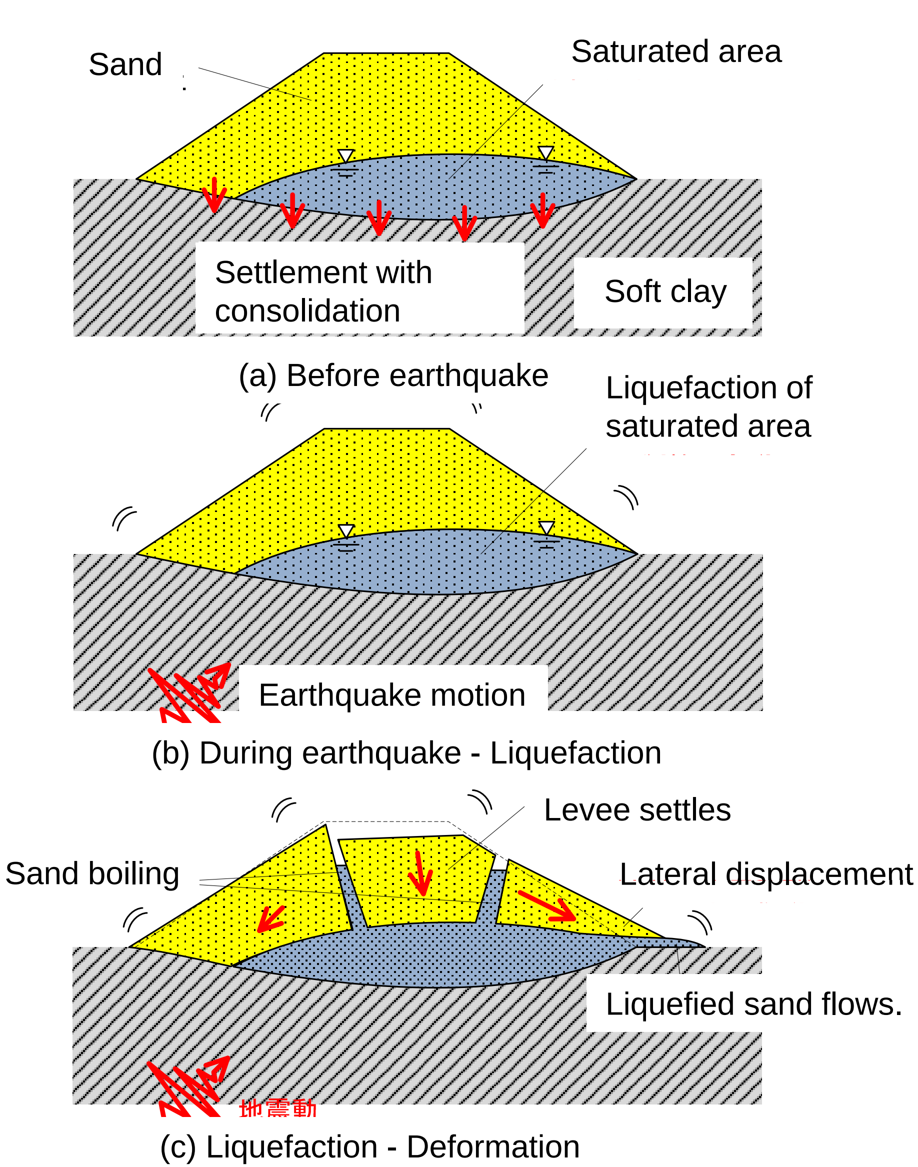
Cause of levee damage

- Sand boils were observed in the cracks of levee body.
- Foundation layer mainly consists of clayey soils, while the damaged portion of levee is of sandy soils and the water table was high.
- Damage resulted from liquefaction of levee body.



Naruse River (Shimo-naknome)

Assumed mechanism of damage by levee body liquefaction



(a) Levee body settled with the consolidation of soft clay foundation layer.
Then, water was easily trapped, and the saturated area has expanded.

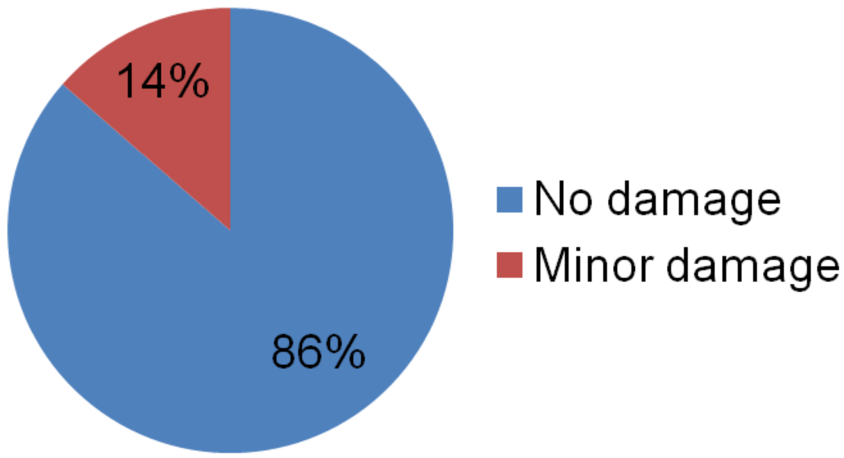
(b) Saturated sand liquefies during an earthquake.

(c) Levee settles and spreads to lateral direction.

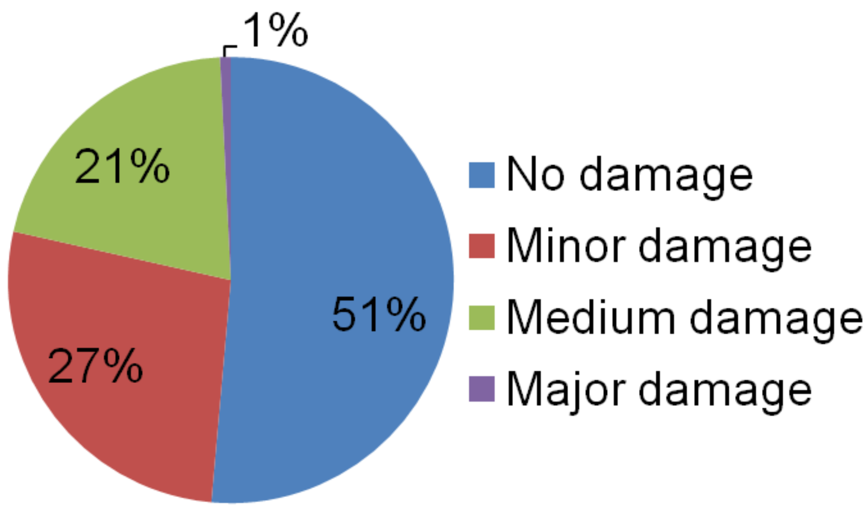
Effectiveness of earthquake countermeasures

- No major damage was reported at the levees measured for liquefaction of foundation layers, which aimed for the level 1 ground motion.
- In Tohoku and Kanto regions, levees over 81.9km long were evaluated to be measured for the level 1 ground motion, and 17.7 km (22%) portion has been completed.

<u>Measured for level 1 ground motion</u>

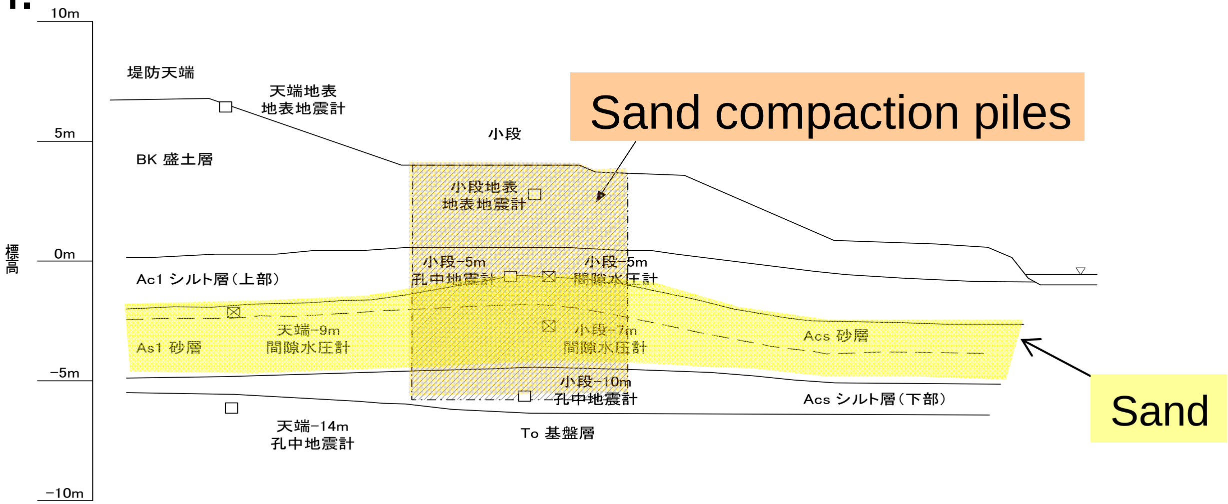


<u>No countermeasure</u>

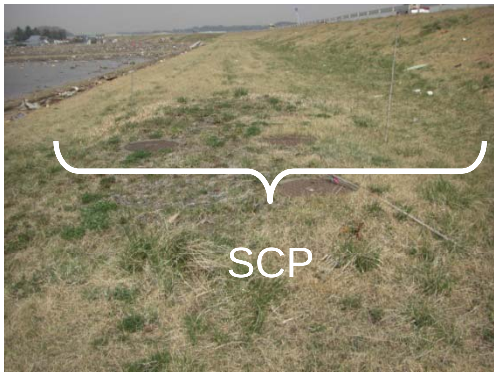


Effectiveness of earthquake countermeasures

- Naruse River (Nakashimo). Improved by sand compaction piles.
- Although the inner side of levee was inundated with tsunami, no settlement or deformation of levee occurred due to ground motion.



Levee crown



Step

Toe of inner slope

Summary

- A magnitude 9.0 earthquake was the largest earthquake ever recorded in Japan.
- Tsunami was more influential than ground shaking in both human and physical damage.
- Ground motion was predominant in the short period range and exceeded design spectra, while it was equivalent to or less than design motion in the intermediate-to-long period range.
- Extensive liquefaction occurred and much affected seismic performance of waste water systems, levees, etc.
- Bridges designed by new design codes or seismically retrofitted performed well. While those not retrofitted suffered similar damage observed in the past earthquakes.
- Levees were damaged by liquefaction of levee body in addition to liquefaction of foundation layer. Countermeasures for liquefaction were effective.