JSCE-ASCE Symposium on Infrastructure Resilience
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Structural Design for Infrastructure Resilience

Riki Honda
University of Tokyo/JSCE

To learn from the past

- 1989 Loma Prieta EQ
  - Collapse of highways, liquefaction
- 1994 Northridge EQ
  - Near fault EQ, collapse of highways
- 1995 Kobe EQ

Collapse of Highway
(Kobe EQ)

- 2003 Indian Ocean EQ
  - Huge tsunami
- 2007 Chuetsu-oki EQ
  - Damage of Nuclear Power Plant
- 2010 Chile EQ
  - Mw 8.8, Tsunami
- 2011 Tohoku EQ

Overwhelming Tsunami
(Tohoku EQ)

Operation Comb (2011 Tohoku EQ.)

- Contribution to resilience
  - In Tohoku area, more than half of 1,500 bridges under the Ministry's charge suffered damage.
  - Road access to the severely damaged area was recovered in four days.

- Elements of Operation Comb
  - [Management] Quick and clear decision about the rehabilitation strategy.
  - [Resources] Local construction companies devoted their resources.
  - [Infrastructure] Retrofit of bridges prevented un-recoverable damage.

(Tokuyama 2012)

https://www.fhwa.dot.gov/publications/publicroads/12mayjune/04.cfm

Consideration of Tsunami

- Concept of *L2 (highly risky) tsunami* for design and disaster management.
  - For seismic design L2 Ground motion had been employed in 1991 (and updated after 1995 Kobe EQ)

Definition	Frequency	Target
L1 (for disaster prevention)	Once in decades to hundreds of years.	To save life To protect resources To continue economic activities (esp. ports and harbors)
L2 (for disaster mitigation)	Once in hundreds to thousands of years.	To save life To mitigate economic damage To prevent secondary disaster To recovery quickly

- Elaborate tsunami simulation to determine the height of sea walls.
- After L2, issues are passed to the community, such as urban design etc.

Factors of Design for Resilience

- 4R: Robustness, Redundancy, Resourcefulness, Rapidity (Bruneau et al. 2003)
  - Resourceful: capable of devising ways and means (Merriam Webster)
- Anti-Catastrophe: Consideration of extreme events
  - *Close to "failsafe" or "robustness" but AC considers more severe damage and social context.*
  - Extend the scope in:
    - Phase :Preparation for unexpected situations.
    - Time : Contribution to the recovery process of the community.
    - Domain/Scales :Functionality in various scales: devices, structures, transportation networks, and community.

Severe damage: Tough Problems

(a) The substructures were left sound

(b) The substructures were pulled down

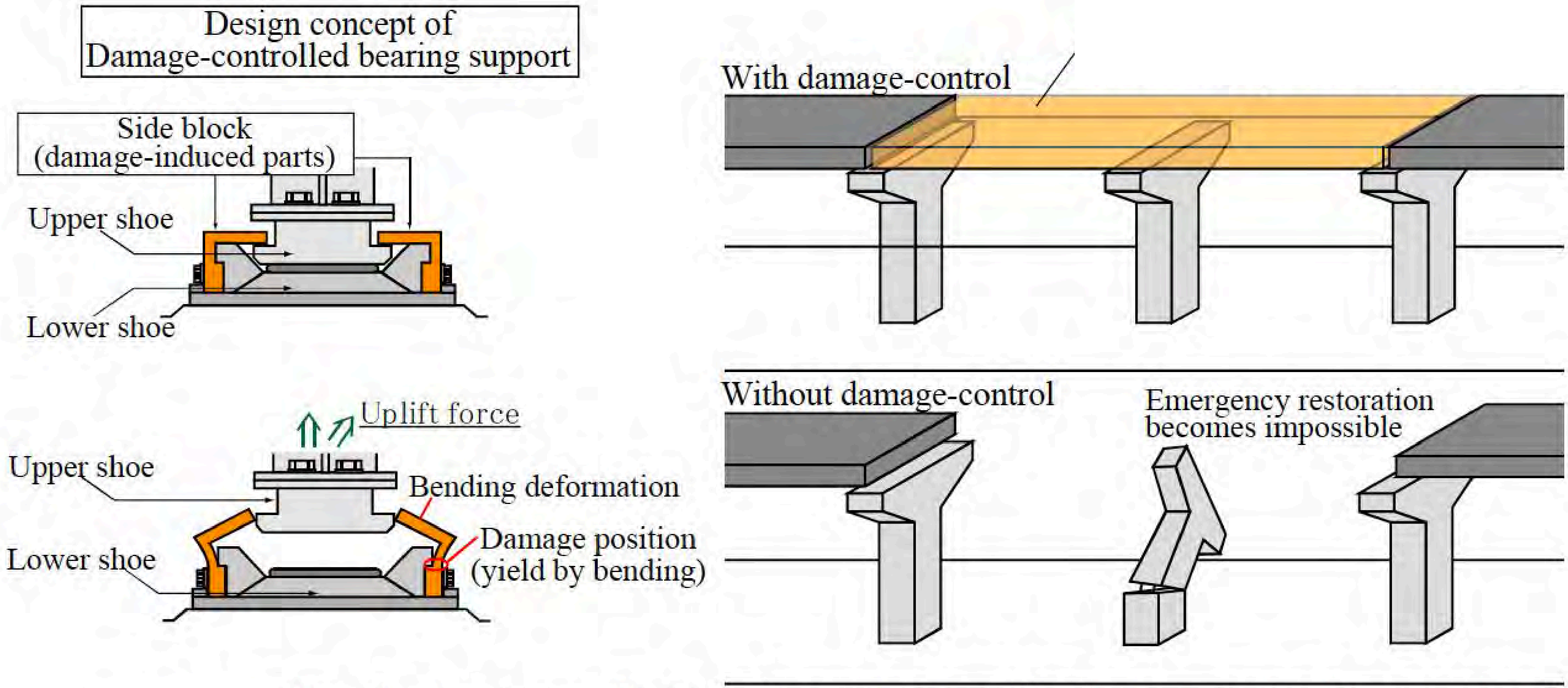
How damaged bridges lost functionality after 2011 Tohoku EQ (MLIT)

Photo by Prof. Takahashi Kyoto University

Damage by the second hit of 2016 Kumamoto EQ was prevented?

Device: Damage Controlled Bearing Support

(MLIT)



The damage-controlled bearing support and its damage controlling mechanism.

Structure System: Consideration of Fault Displacement

(MLIT)

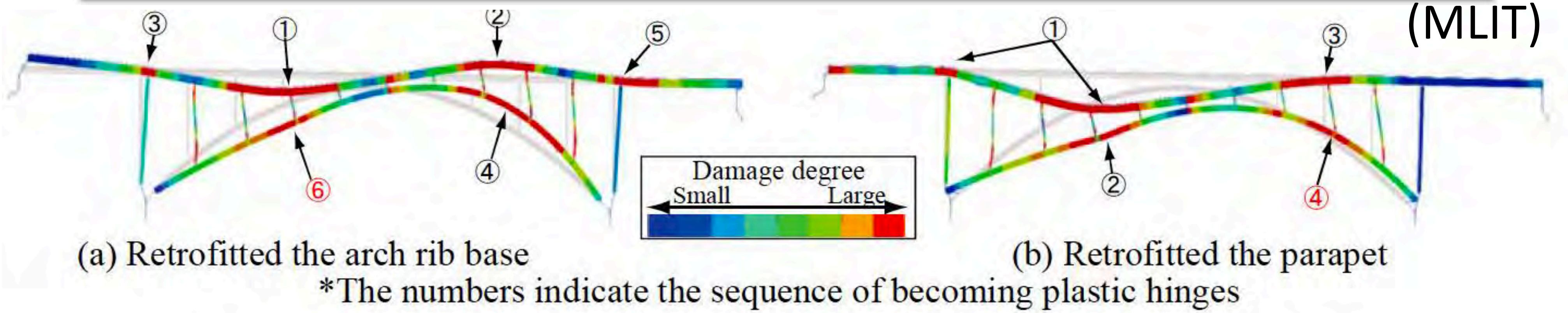


Fig. 10 Damage states of major elements of the arch bridge just before collapsing.

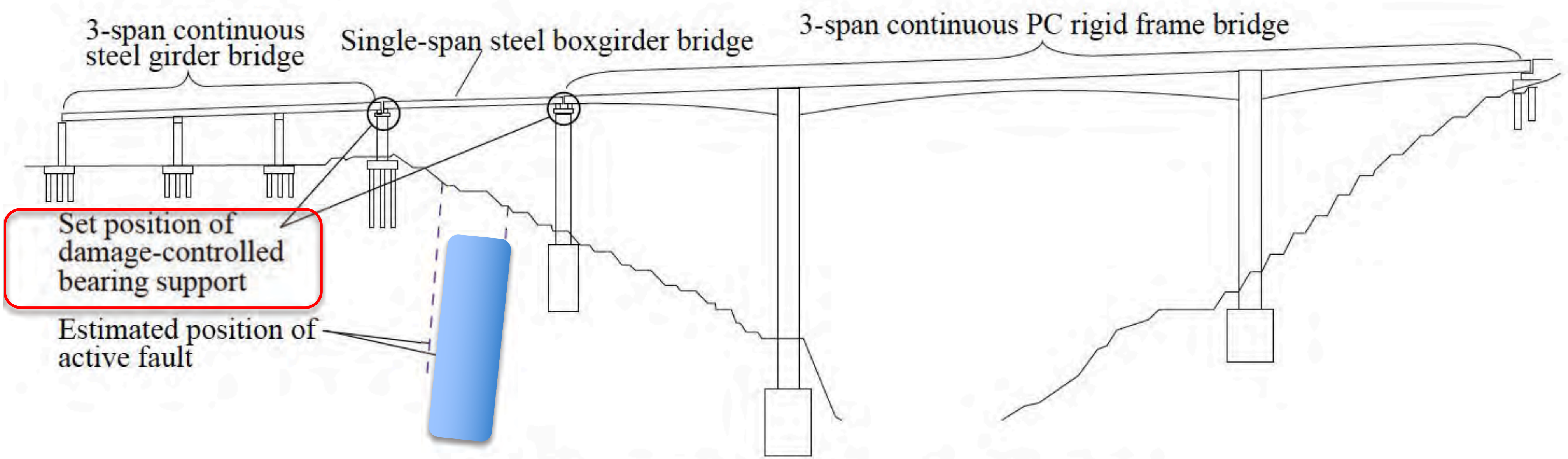


Fig. 15 Side view of the new Aso-Ohashi bridge.

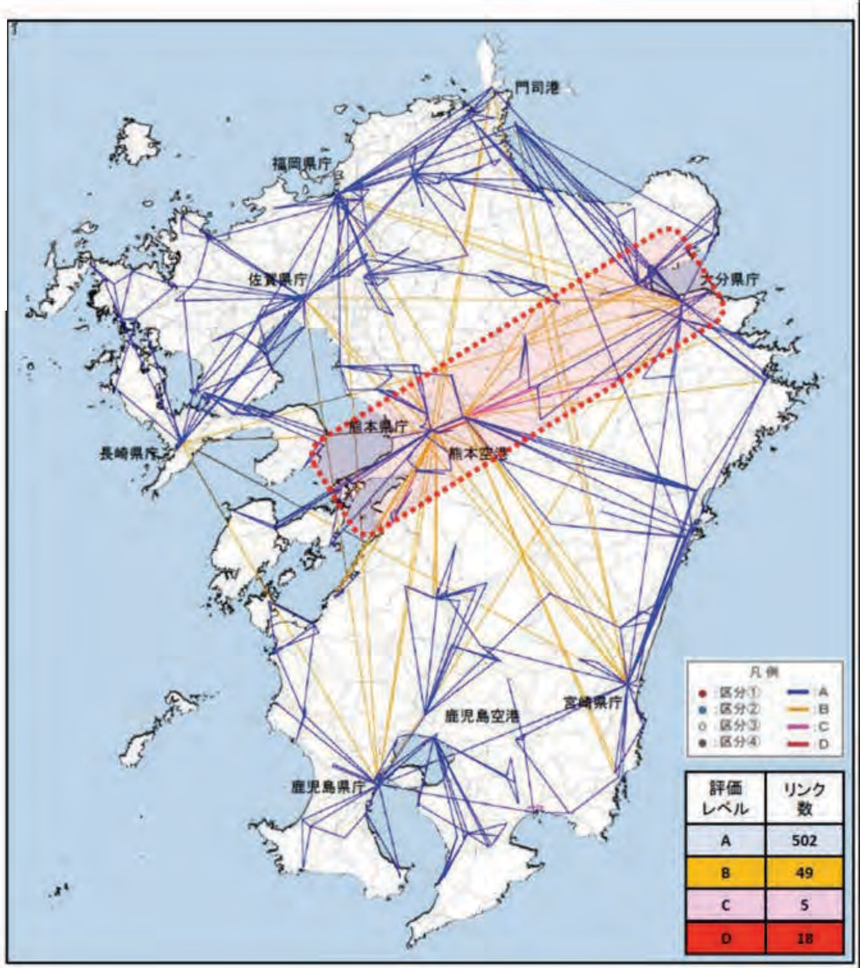
Actual design procedure is to be discussed.

Infrastructure System : Road Network

Vulnerability of the transportation network in Kyushu Area had been evaluated considering volcanos and heavy rainfalls (not earthquake).

Vulnerability estimation (right) and Actual Damage by Kumamoto EQ. (bottom)

Road Traffic Closed
(1) Kyushu Highway
(2) Oita Highway
(3) Routes No. 57 and No. 352

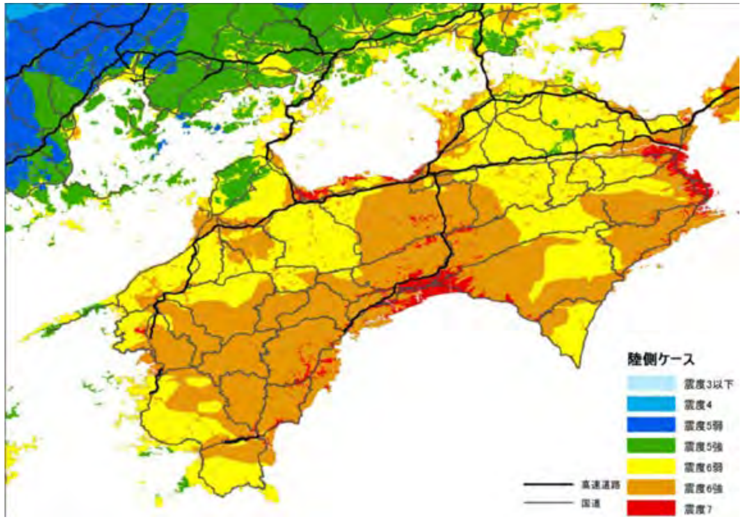


（JSCE repots after Kumamoto EQ.）

*1) http://www.mlit.go.jp/policy/shingikai/road01_sg_000269.html

Community Level: Collaboration with Regional Plan

- Shikoku Island has a concrete disaster management plan, expecting suffering severe damage by the Nankai Trough Earthquake.



Estimation of Seismic intensity in the Nankai Trough Earthquake

(Japanese Cabinet Office)

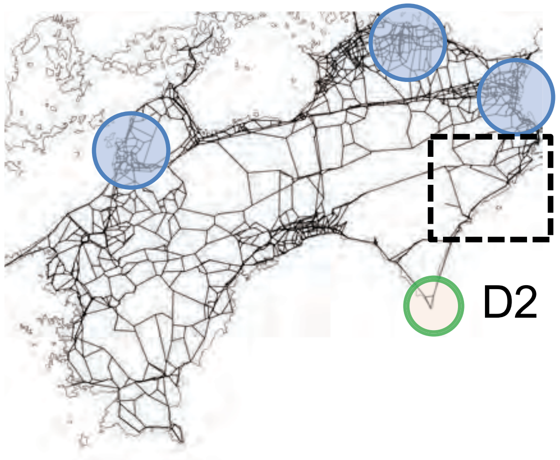
Emergency route

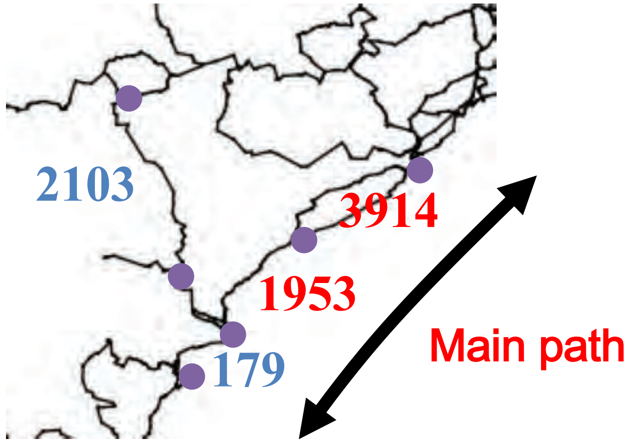
(Shikoku Regional Development Bureau)

- Information exchange and flexible adaptation
- Protection of emergency route is focused on, but protection level of ordinary roads is not mentioned.

Critical Links for Different Damage Level

- Critical links change depending on degradation level because probability characteristic changes





Degradation level: Small

Critical links	307, 547, 586, 576, **1953, 3914**

Links which are long and located on a main path is more critical

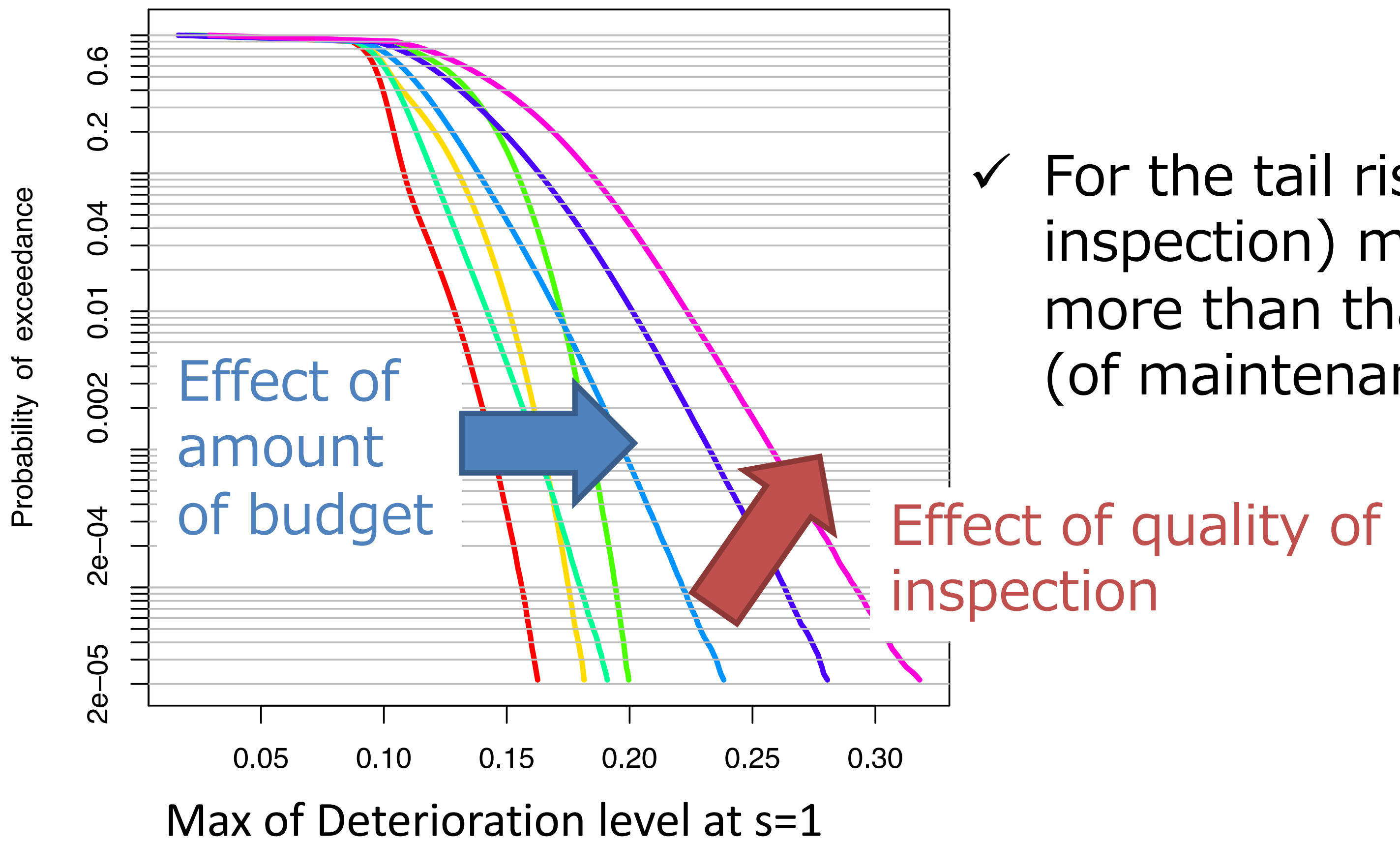
Degradation level: Large

Critical links	307, 547, **179**, 586, 576, **2103**

Links which cause change in topology is more critical

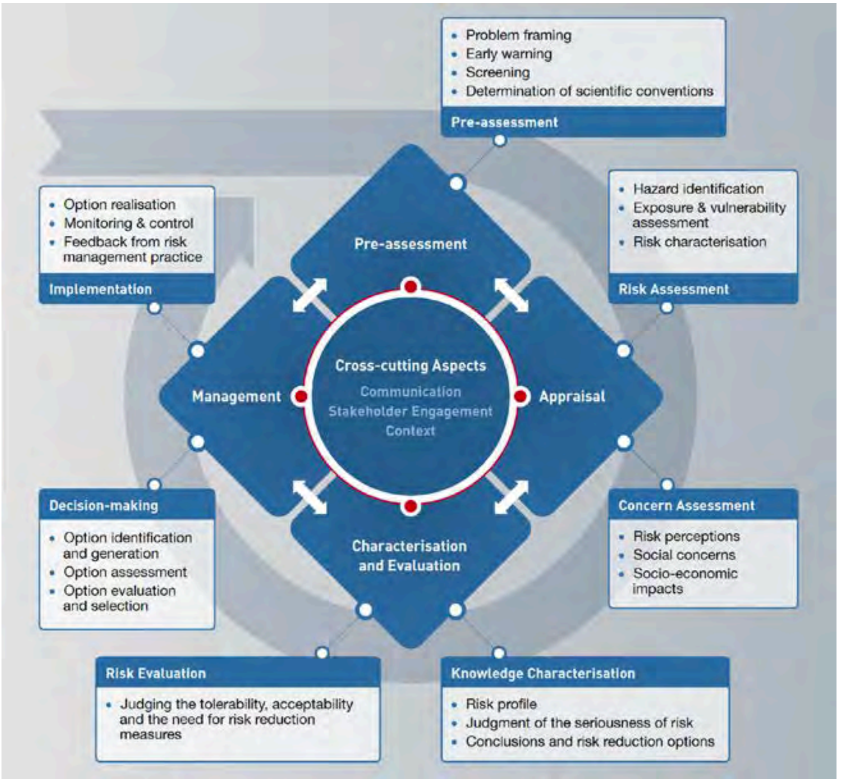
Institution Level: Consideration of Social Factors

Social factors for community
Capacity of national and local governments, local communities, private companies.
e.g. Contract for disaster management, and maintenance.



- ✓ For the tail risk, quality (of inspection) may matter more than than quantity (of maintenance).

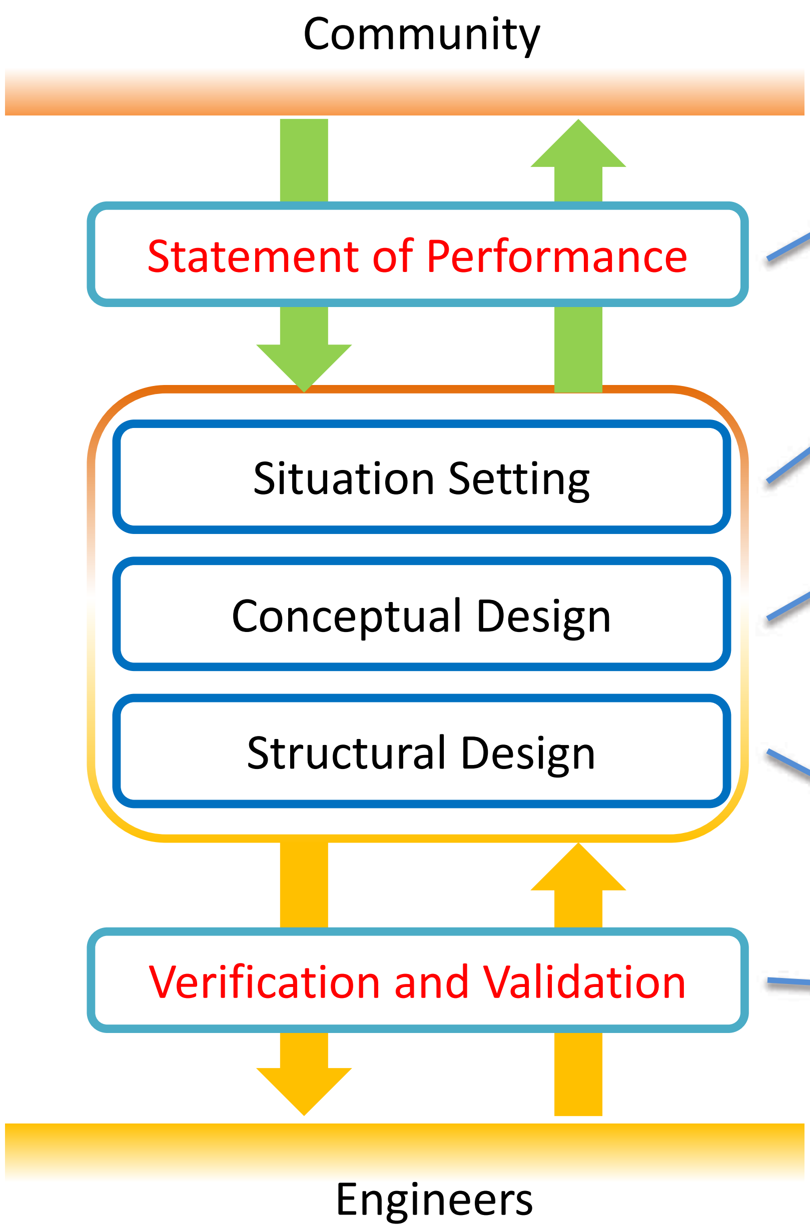
Implementation: Risk Governance



Framework by International Risk Governance Council (IRGC)
https://irgc.org/

- Pre-assessment: How the society *perceives* the risk.
- Appraisal : How the society is concerned.
- Characterization and evaluation: It is tolerable?
- Management: Efficient implementation is essential.
- Communication: To share the risk and responsibility.

Design Scheme to bridge Community and Engineers



Design scheme for engineers and community can share the information

- Plain description of damage and recovery scenarios
- Assume damage scenario (Input GM may not be necessary)
- *Multi-scale discussion*, including regional disaster management plan, etc.
- Advanced and cutting-edge technologies should be utilized.
- Responsibility against scientific facts, not design codes.

Summary

- Not only the resilience of infrastructure, infrastructure for resilience should be recognized.
- Anti catastrophe: consideration of damaged situation
  - Difficult engineering problems for various scales:
  - Device level
  - Structural level
  - Infrastructure system level
  - Community level
  - Institution level
- Implementation with the concept of risk governance
  - Design bridging community and engineers
- ASEC-JSCE research collaboration over these issues should be promoted.

Thank you for your kind attention.