International Conference on Earthquake Engineering

CISMID: 40 Years of Science, Innovation and Infrastructure Assessment for Resilient Cities

History of Japan's Seismic Regulations and the New Damage Detection System

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Disasters in Japan: Earthquakes

1995 Kobe Earthquake

Disasters in Japan: Earthquakes

1995 Kobe Earthquake

Disasters in Japan: Tsunami

2011 Tohoku Earthquake

Disasters in Japan: Volcanos

2019 Sakura Jima, Japan

Ichihara Laboratory, ERI

Disasters in Japan: Tornedo

2012, Tornedo, Tsukuba, Japan

Disasters in Japan: Typhoon

2018, Typhoon No.9, Okayama, Japan Tokyo Metropolitan Fire department

Disasters in Japan: Heavy snow

2014, Tokyo

Ministry of Land, Infrastructure, Transport and Tourism

Code requirement

- Earthquake load
- Snow load
- Wind load

Are the major three load for structural calculation.

Earthquake load is the predominant load for buildings (H<200m).

History of regulations in Japan

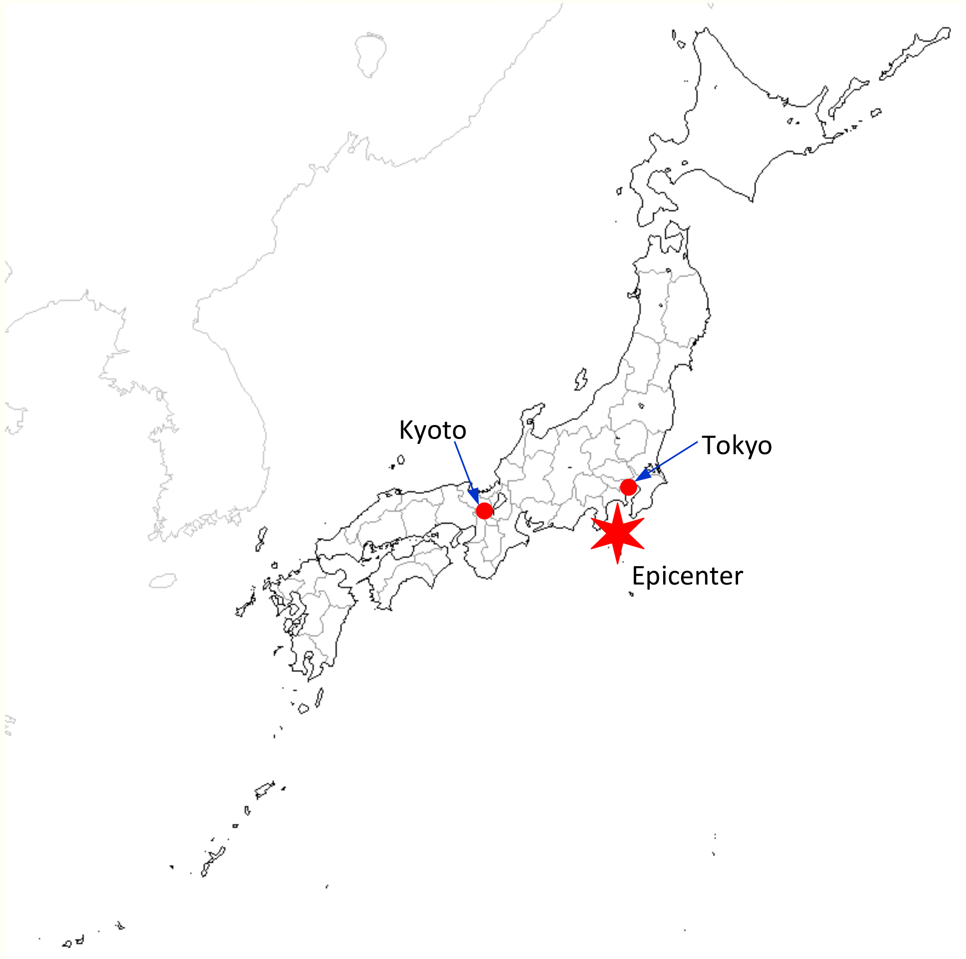
Prof. Toshikata SANO

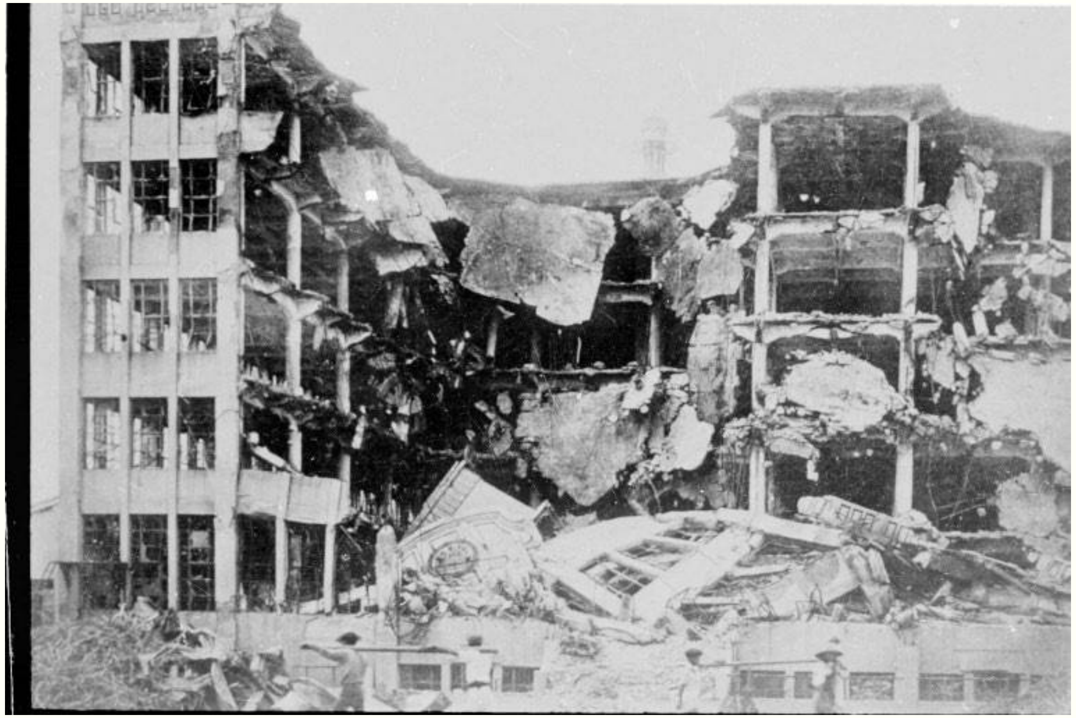
- Doctoral thesis “Seismic structure of buildings” in 1914.
- He studied the damage due to 1855 Great Ansei Earthquake.
- He estimated the maximum PGA in down town and hillside were 0.30G and 0.15, respectively.
- He pointed out that not only the strength, but also stiffness and ductility of buildings are important for seismic design.

Urban Buildings Law

- Developed in 1919 and enforced in 1920.
- The applied cities were defined by royal command.
  - Tokyo, Kyoto, Osaka, Yokohama, Kobe, and Nagoya cities.
- Allowable stress: $\sigma_{\mathrm{B}}/3$ for concrete, $\sigma_{\mathrm{y}}/2$ for steel.
- Maximum height: 20m for residential areas, 30m for other areas.
- No wind load or seismic load was considered.

Great Kanto Earthquake (1923)





Muto Labo., the Univ. of Tokyo

Great Kanto Earthquake (1923)

- Occurred at 11:58, September 1st, 1923.
- The epicenter was offshore from Sagami Bay (close to Tokyo)
- Magnitude was estimated as 7.9
- Damage
  - Casualty/Missing person: 105,000
  - R/C buildings
    - Collapse: 15, Partial collapse: 20, Severely damaged: 49, slightly damaged: 79, no damage: 551

Seismic design was applied for some buildings

- Industrial Bank of Japan (1923)
- C_B=0.067
- Almost no damage

The first seismic design code

- The Urban Building Law was amended in 1924.
  - C_B=0.10
  - No response amplification was considered (PGA and maximum response acceleration were assumed to be the same).
  - Working stress method was adopted.
  - The allowable stresses for concrete and steel were defined.
- Prof Sano recommended applying the ultimate strength method with C_B =0.30, but it was not adopted.
- AIJ developed the “AIJ standard for Structural Calculation of Reinforced Concrete Structure” in 1933.

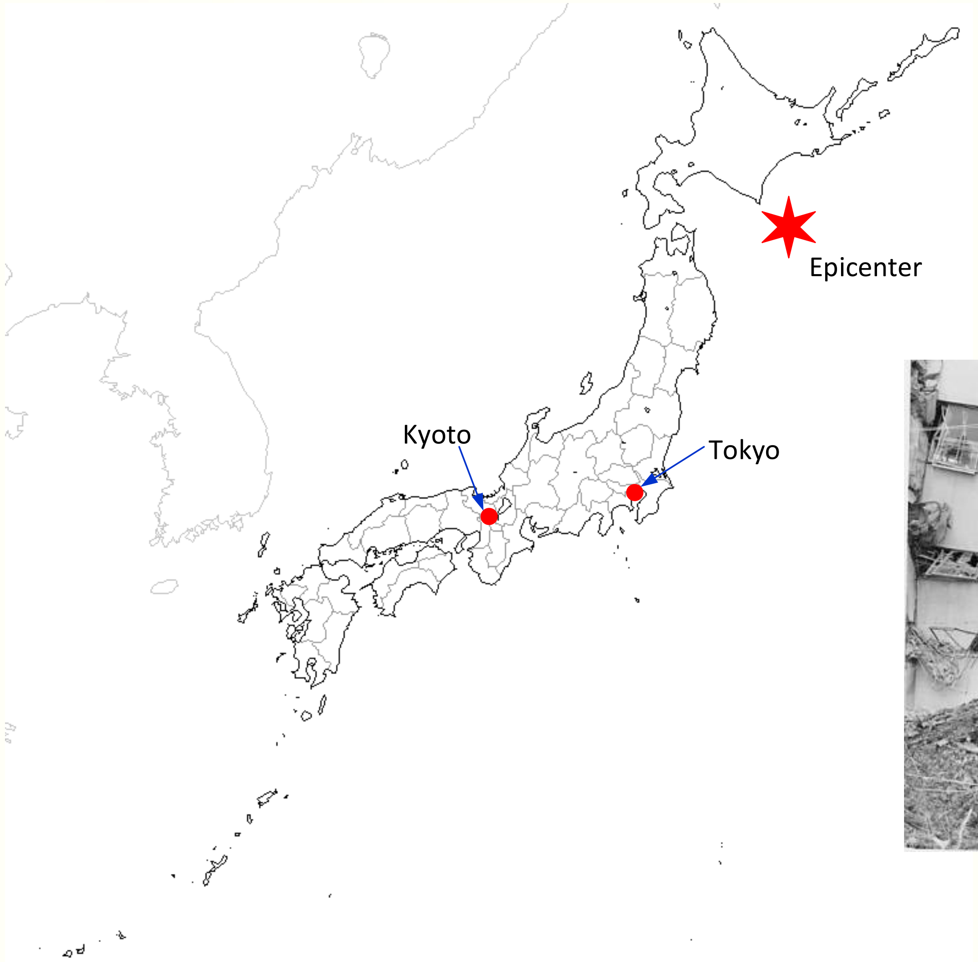
During the World War II

- The Urban Building Law was suspended due to World War II.
- Many regulations were eased due to the war, but the building law was not eased.
- The allowable stress was amended.
  - The safety margins for gravity load and seismic load with the same allowable stress depend on the combination of gravity and seismic loads.
  - The allowable stress for seismic load was defined as double, and C_B was increased from 0.10 to 0.15.

After the World War II

- Japan accepted the Potsdam Declaration in 1945.
- Meiji Constitution, which was based on the imperial system, was eliminated.
- New Constitution of Japan, which is based on democracy, was developed.
- All laws based on the imperial system were also eliminated, including the Urban Building Law.
- Building Standard Law of Japan (BSL) was enforced in 1950.

Tokachi Oki Earthquake, 1968

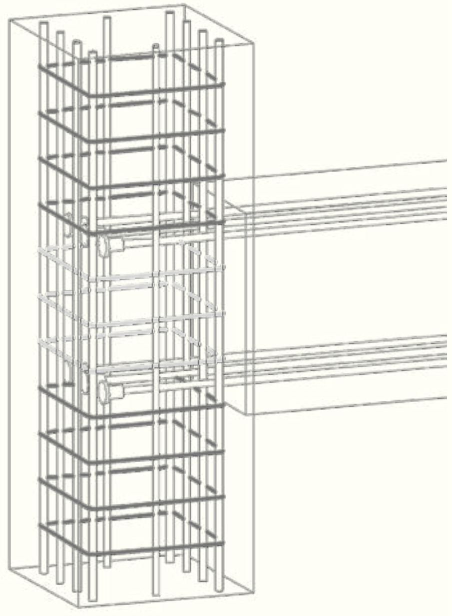


Many columns failed in shear.

Okada Labo., the Univ. of Tokyo

Tokachi Oki Earthquake, 1968

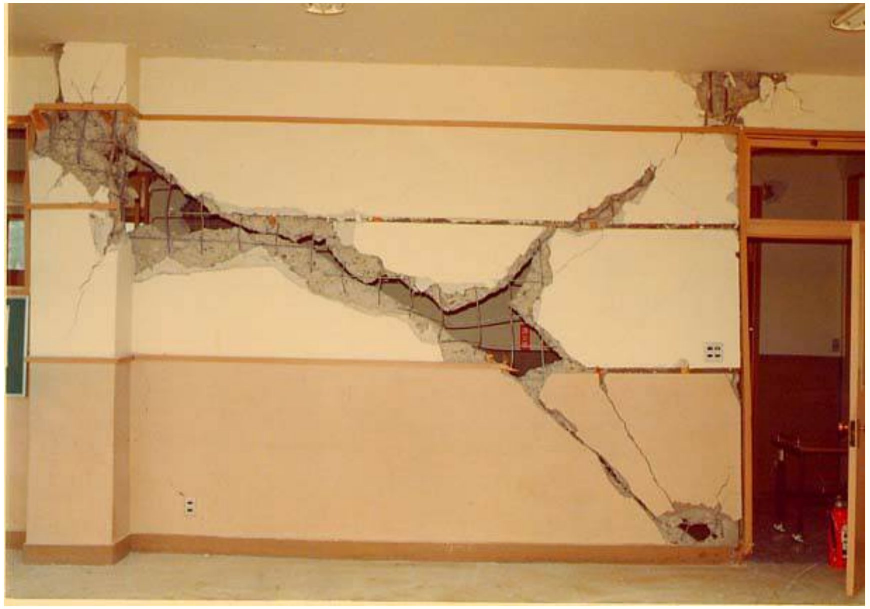
- Occurred at 9:48, May 16th, 1968.
- The epicenter was offshore from Tokachi.
- Magnitude was estimated as 7.9
- Damage
    - Casualty: 52
    - R/C buildings
        - Collapse: 673, Partial collapse: 3,004
    - A tsunami hit the affected area.
- Minimum hoop pitch was reduced from 30cm to 15cm.



Tasai-Kusunoki Labo

Miyagi Ken Oki Earthquake, 1978

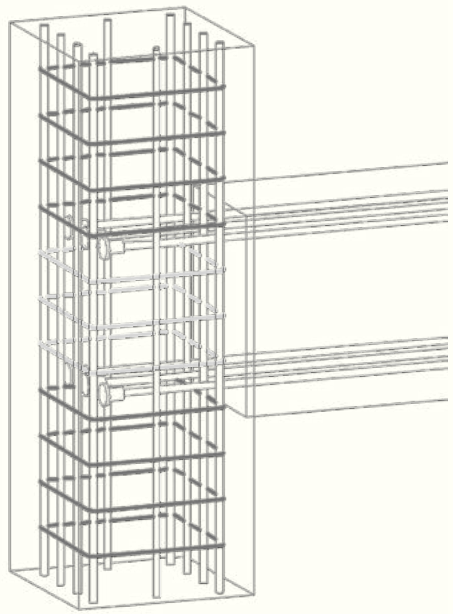
Many columns failed in shear again.



Okada Labo., the Univ. of Tokyo

Miyagi Ken Oki Earthquake, 1978

- Occurred at 17:14, June 12th, 1978.
- The epicenter was offshore from Miyagi Prefecture.
- Magnitude was estimated as 7.4.
- Damage
    - Casualty: 28
    - R/C buildings
        - Collapse/Partial collapse: 7,621
    - A tsunami hit the affected area.
- Minimum hoop area ratio was defined as 0.2%.



Tasai-Kusunoki Labo

National Project to develop a new structural calculation method

- A new structural calculation method was required to consider the ductility and evaluate the ultimate stage of the structure during an extremely strong earthquake.
- Duration: 1972-1976.
- Due to the 1978 Miyagi Ken Oki Earthquake, the developed method was added to BSL in 1980 and enforced in 1981.

Check the ultimate collapse mechanism, how to collapse the building: Total yielding mechanism, partial yielding mechanism, or brittle failure mechanism.

The method was added to the Building Standard Law of Japan in 1981.

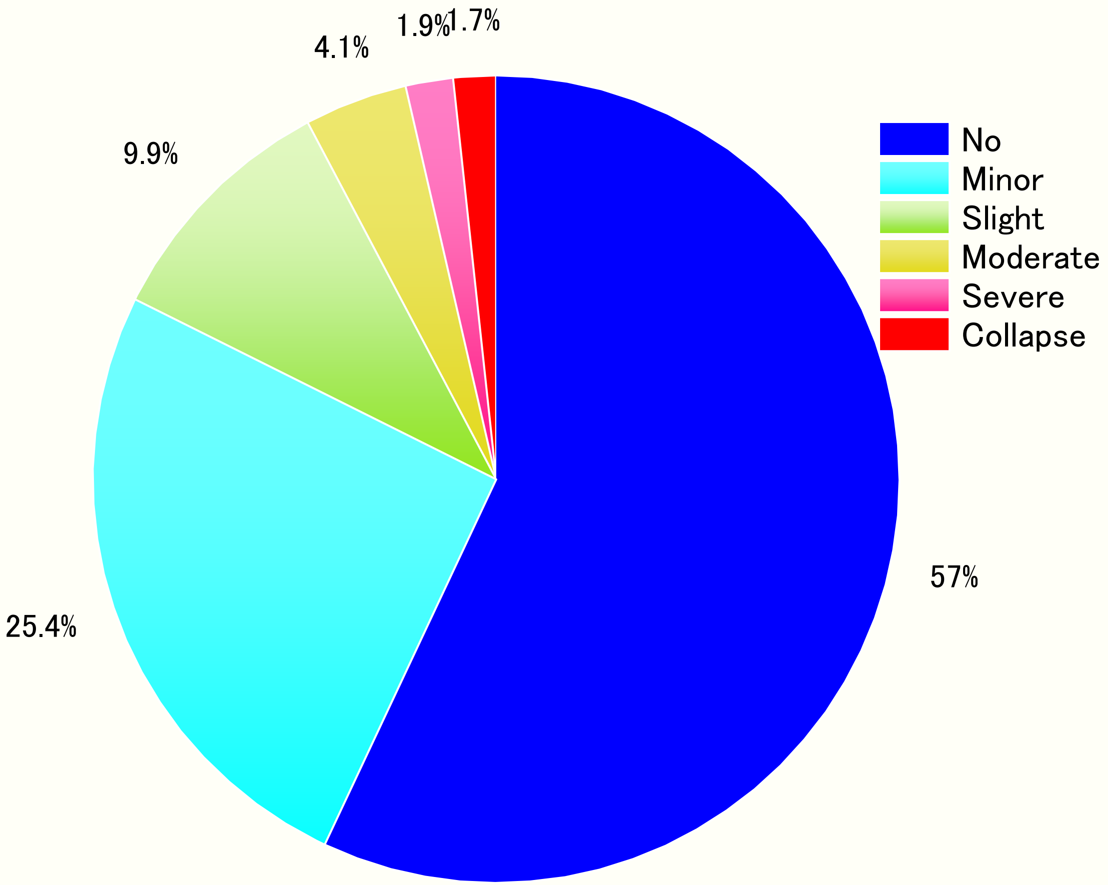
Hyogo Ken Nambu Earthquake, 1995

Okada Labo., the Univ. of Tokyo

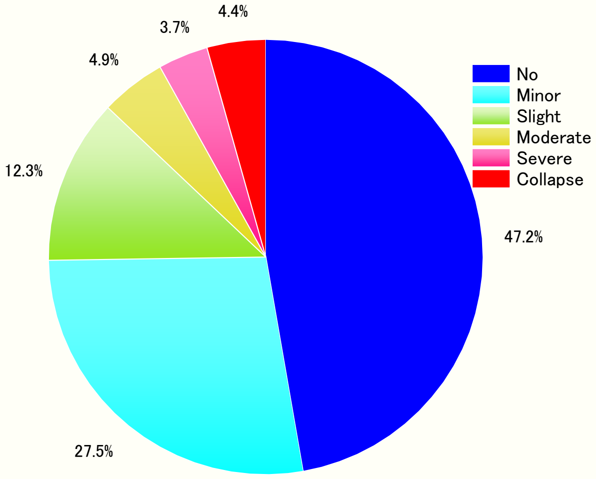
So called “Kobe Earthquake”

- Occurred at 5:46, January 17th, 1995.
- The epicenter was Awaji Island.
- Magnitude was estimated as 7.3.
- Damage
  - Casualty: 6,434, Missing person: 3, Injured: 43,792
  - About 689,776 buildings were damaged.

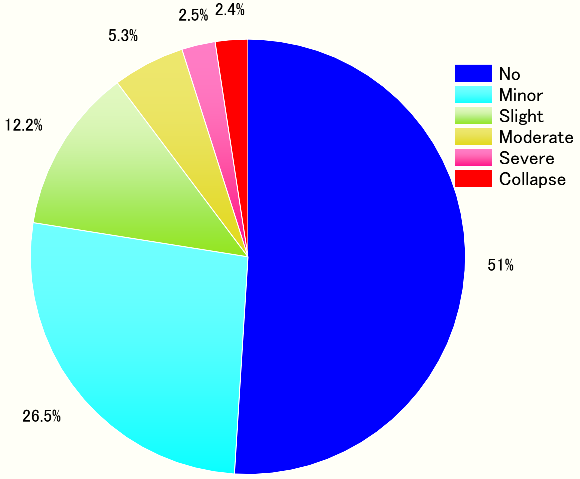
Damage of R/C due to Kobe EQ



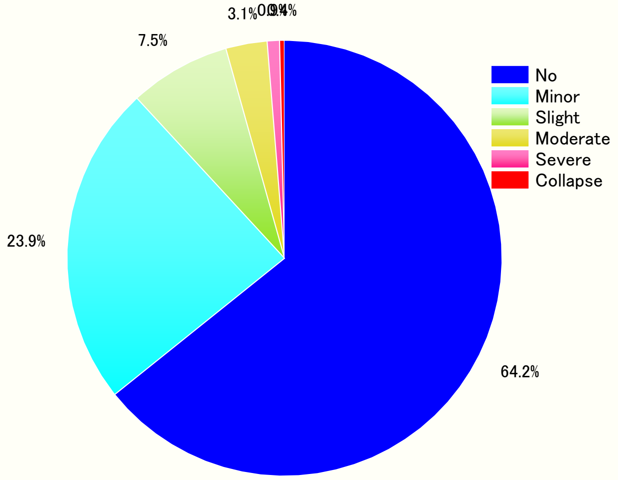
Damage of R/C due to Kobe EQ



Before 1971



1971-1981



After 1981

- Current structural calculation system worked well.
- The existing old buildings designed according to the old building codes suffered damage.

Design with 1G seismic force?

Building can dissipate earthquake energy by being “safely” damaged.

→Ductile structure can reduce the demand

Total yielding mechanism

Building during an earthquake

- Even though the building is designed according to the current building code, there is a possibility of damage.
- The current building code allows buildings damaged to dissipate input energy.
- The earthquake itself may exceed the code requirement.

- The safety and functionality of the buildings need to be evaluated right after an earthquake.

Quick Inspection

- After an earthquake…

Residual seismic capacity should be evaluated

Without adequate residual seismic capacity

To reduce enormous harm due to an aftershock

With adequate residual seismic capacity

To reduce the number of refugees

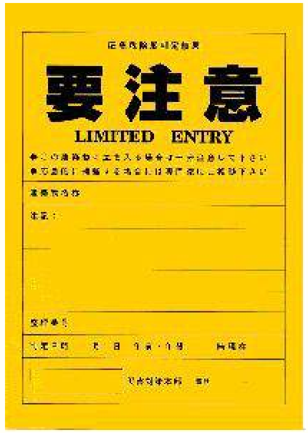
When an earthquake happens....

- Is your house, office, school, hospital, market, station, and etc. are safe to use continuously?
- We need to conduct the **Rapid Inspection** to evaluate the safety of the damaged buildings.
- It is based on the visual inspection.
- It takes time...

Two major problems of current method

- It takes time
  - People need to stay at the shelters for long time.

- Many “Limited entry” judgements are made.
  - We need to evaluate the damage according to only residual cracks and inclination angle.



Waiting for the inspector…

Date	Earthquake	Duration	Volunteer	Buildings	Inspected	Caution	Unsafe
1995.1.7	Kobe	23 days	6,466	46,610	30,832	**9,302**	6,476
2000.12.6	Tottori West	24 days	332	4,080	2,138	**1,499**	443
2001.3.25	Geiyo	19 days	636	1,763	674	**921**	168
2003.7.26	Miyagi North	8 days	743	7,245	3,804	**2,181**	1,260
2004.10.23	Niigata Cyuetsu	18 days	3,821	36,143	19,778	**11,122**	5,243
2005.3.20	Fukuoka	19 days	444	3,148	1,500	**1,131**	517
2007.3.25	Noto	６ days	391	7,600	4,800	**1,571**	1,229
2007.7.16	Niigata Cyuetsu	８ days	約2,800	34,048	20,150	**8,943**	4,995
2008.6.15	Iwate-Miyagi	10 days	475	2,978	2,197	**564**	217
2011.3.11	Tohoku						
	Miyagi Prefecture	2 months	2,955	50,721	37,968	**7,553**	5,200
	Fukushima Prefecture	2.5 months	2,053	15,807	5,775	**6,718**	3,314

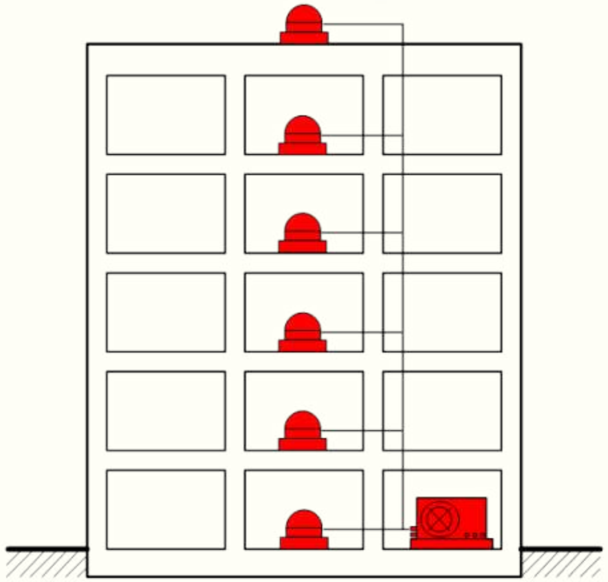
Rapid inspection with sensors using the Capacity Spectrum Method

Performance and demand curves are measured

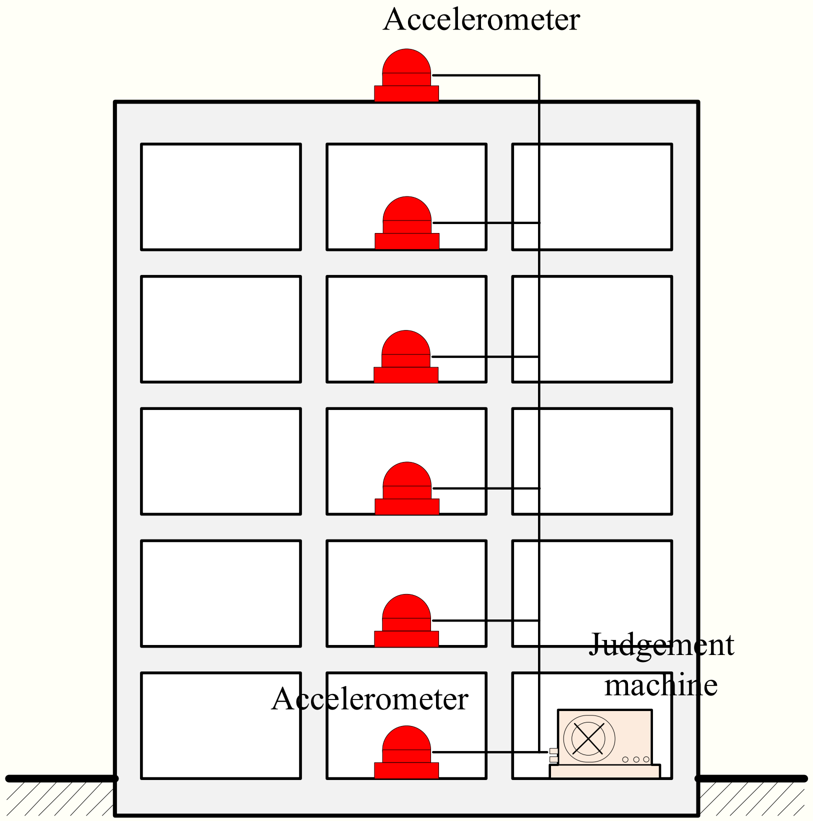
Place few inexpensive accelerometers

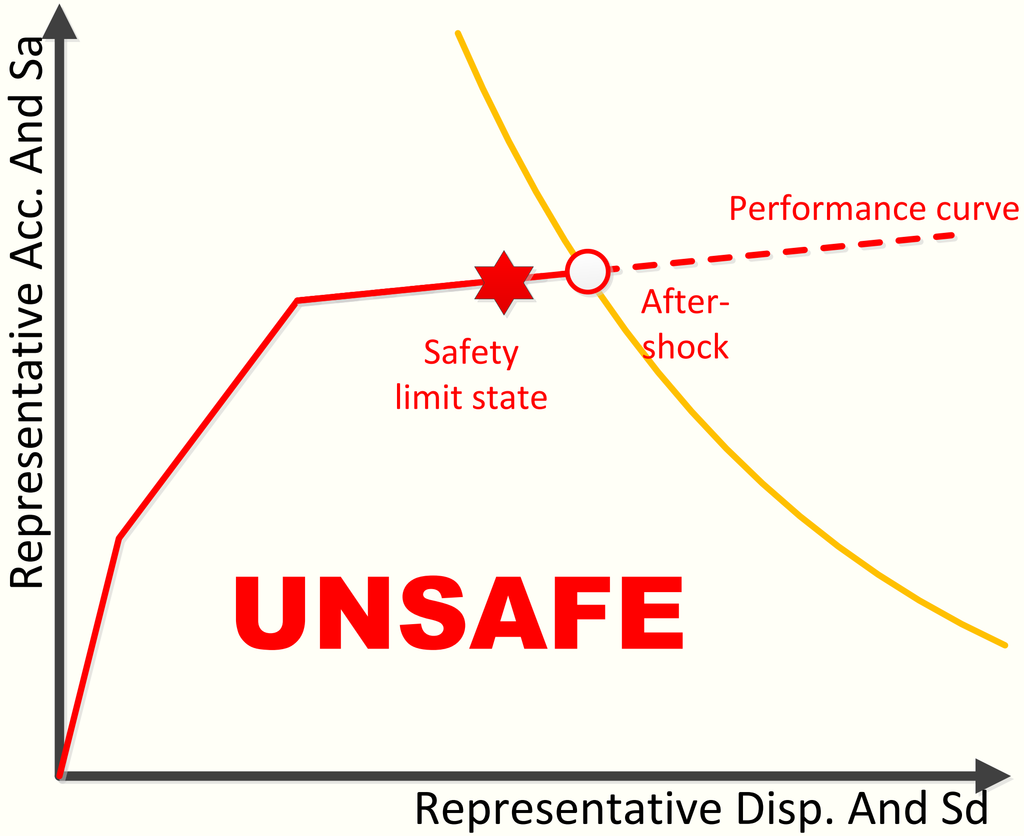
Derive displacement from measured acceleration

Evaluate by comparing these curves



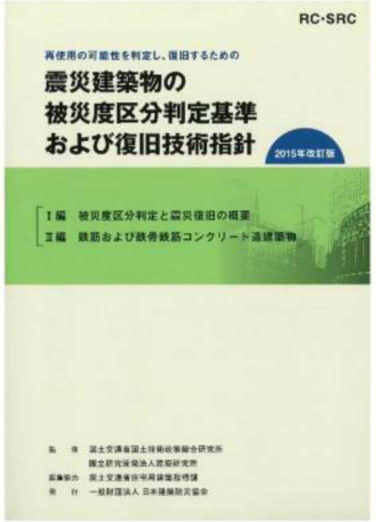
Evaluate the damage class with sensors

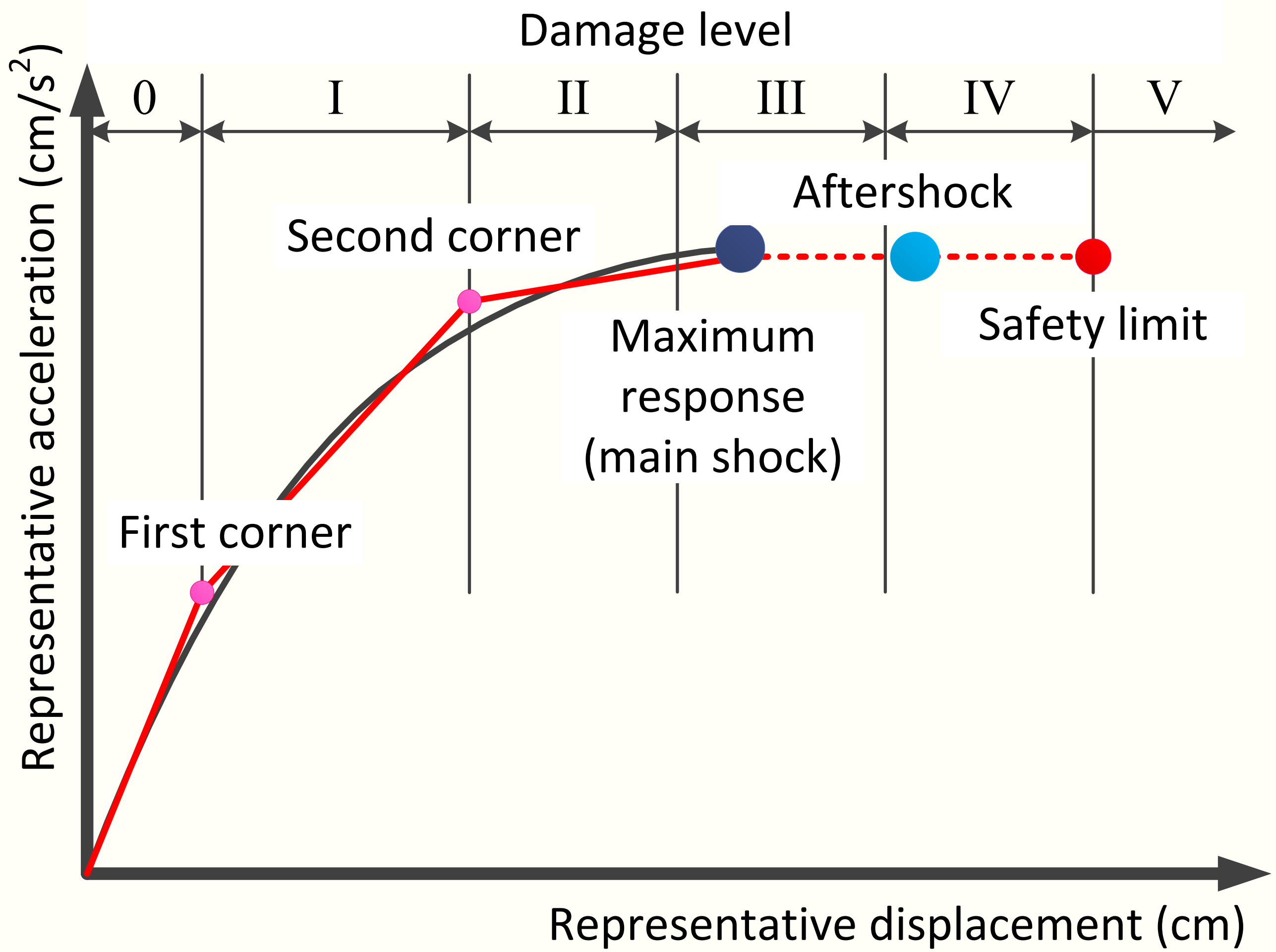




Put sensors to evaluate the damage based on the capacity spectrum method.

Damage evaluation

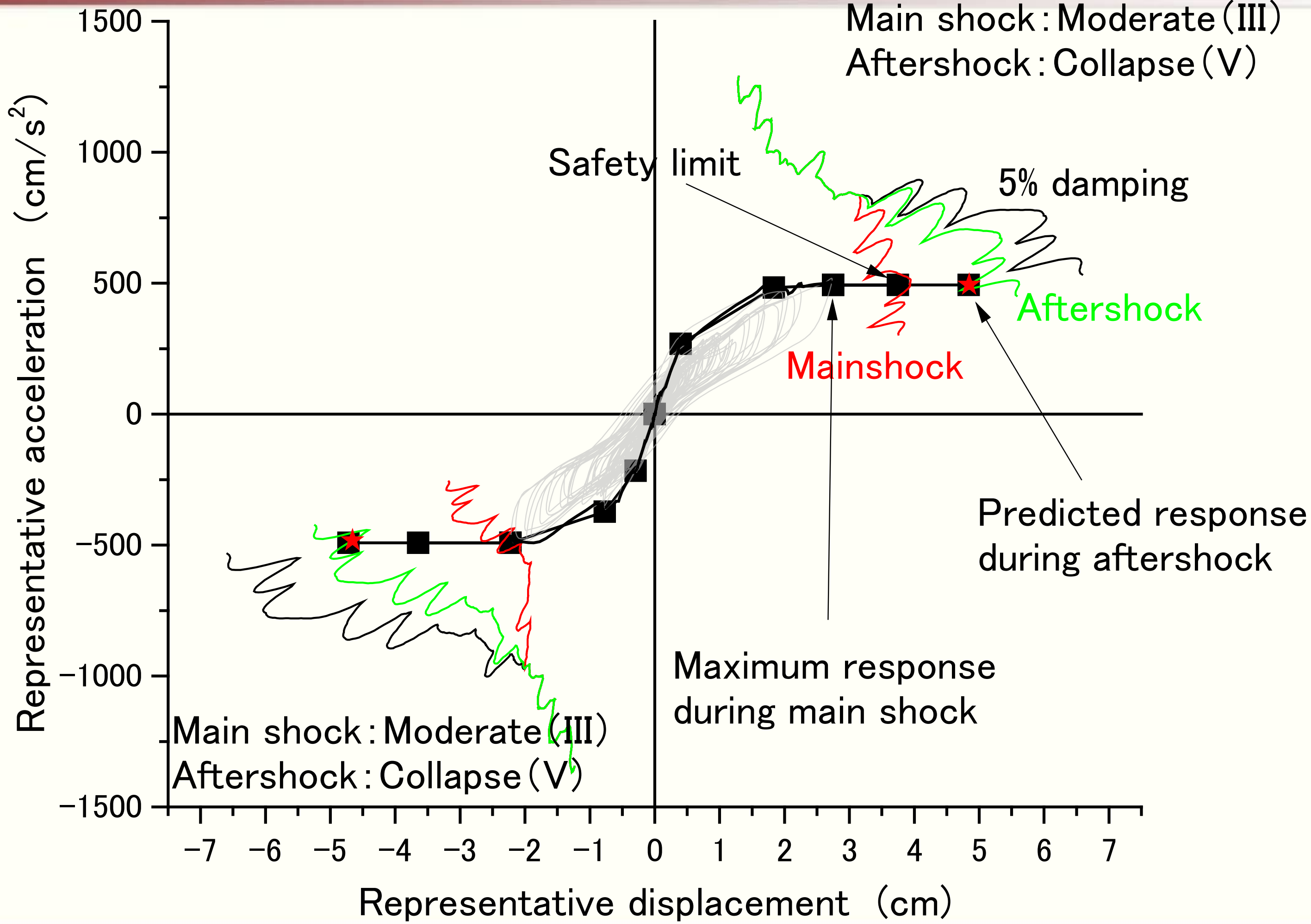




- Damage evaluation is conducted according to the Japanese standard.

Example: E-Defense Shaking Table Test

Level 200% (Pile foundation)

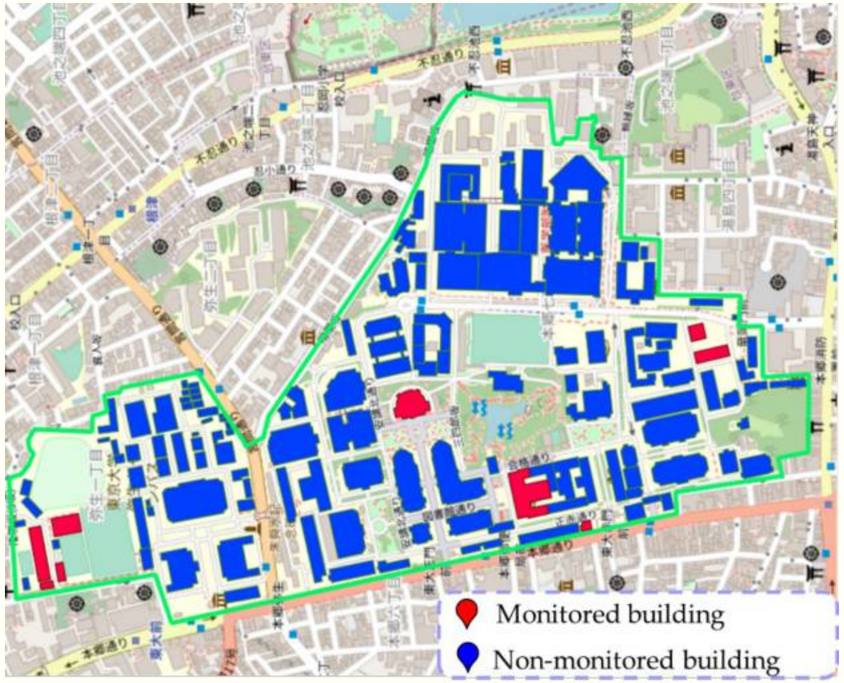


Level 300% (Pile foundation)

Collapsed as predicted!

We are promoting the SHM system

- Instrumented buildings in Japan and in the world



- Buildings on our campus are also instrumented.

Red Gate of the University of Tokyo

Current situation

- Ministry of construction has organized a committee to apply the SHM system for damage evaluation, especially for high-rise buildings.
- The evaluation data will be sent to the local governments of the affected area.
- Recorded vibration data will be stored in the server managed by the Building Research Institute of Japan.
- The response data are supposed to be used for academic research.

Thank you for your kind attention…