Twenty Two Years after Kobe and Six Years after Tohoku – A Japanese Way toward Establishment of Resilient Cities

September 4, 2017

by

Masayoshi Nakashima

President of Kobori Research Complex (KRC)
Counselor, Kajima Corporation
Professor Emeritus, Kyoto University
President-Elect, International Association for Earthquake Engineering (IAEE)

Major Earthquakes in Japan (after 1995)

Date of Occurrence	Name	Magnitude
1995, Jan. 17	Kobe (Hanshin-Awaji)	7.3
2000, Oct. 6	Tottori-Ken Seibu	7.3
2001, Mar. 24	Geiyo	6.7
2003, Sep. 26	Tokachi-Oki	8.0
2004, Oct. 23	Niigata Chuetsu	6.8
2007, Mar. 25	Noto Hanto	6.9
2007, July 16	Niigata chuetsu-Oki	6.8
2008, June 14	Iwate Miyagi Nairiku	7.2
2011, Mar. 11	Tohoku	9.0
2016, Apr. 14-15	Kumamoto	7.3

Problems Surfaced out from Past Large Earthquakes

1995 Kobe (Hanshin-Awaji)

Collapse, Seismic Retrofit
→ Strong Motion（K-Net）
→ Shaking Table
(E-Defense)

2000 Tottori-Ken Seibu
2001 Geiyo
2003 Tokachi-Oki
2004 Niigata Chuetsu
2007 Noto Hanto

2007 Niigata Chuetsu-Oki
2008 Iwate-Miyagi

Business Continuity（BCP）
→ Long-Period Ground Motion

2011 Tohoku

Huge Tsunami
→ Resilience
→ Seabed Motion（S-Net）
→ SIP

2016 Kumamoto

Repeated Shakings
→ Judgment of Safety

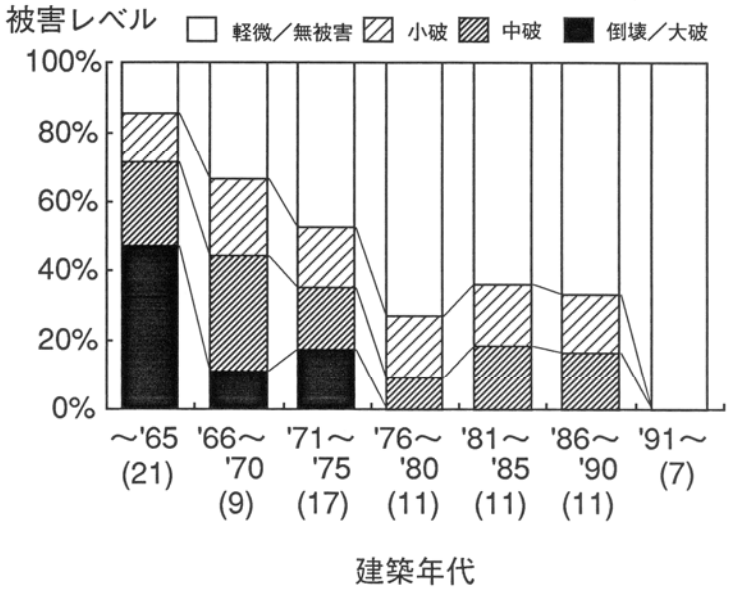
Building Damage in 1995 Kobe

Structural Damage in 1995 Kobe Earthquake

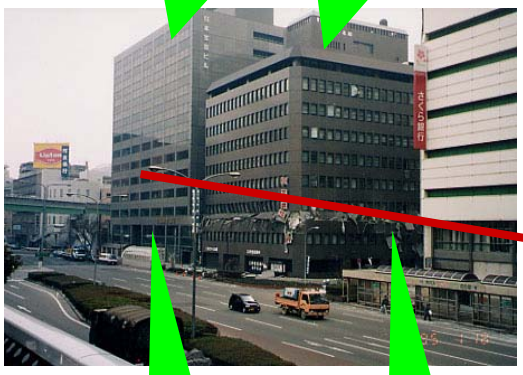




Notable Difference in Damage Level: Correlation with Building Age



Clear Contrast of Damage to RC Buildings



Wall damage
- Acceptable -

"Learning from Earthquakes"

Earthquake engineering has a long history of "learning from actual earthquakes and earthquake damages." That is, we first understand problems by actual damage; then develop engineering to patch them.

1964 Niigata

Liquefaction

1968 Tokachi-oki

RC Shear Failure

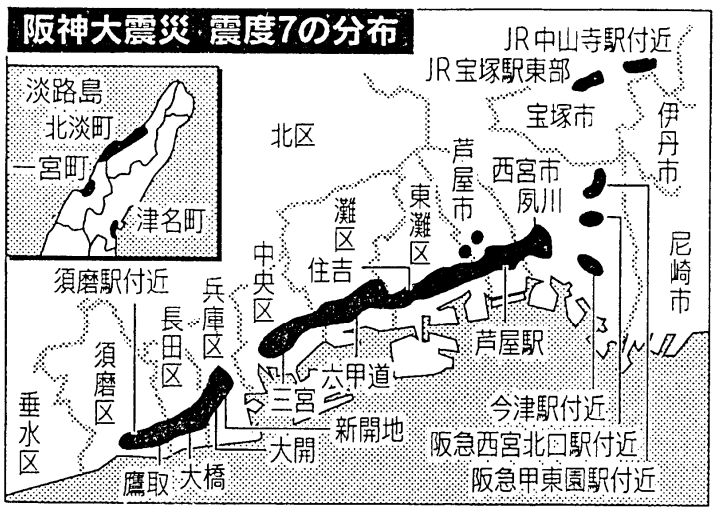
1995 Kobe

Seismic Retrofit

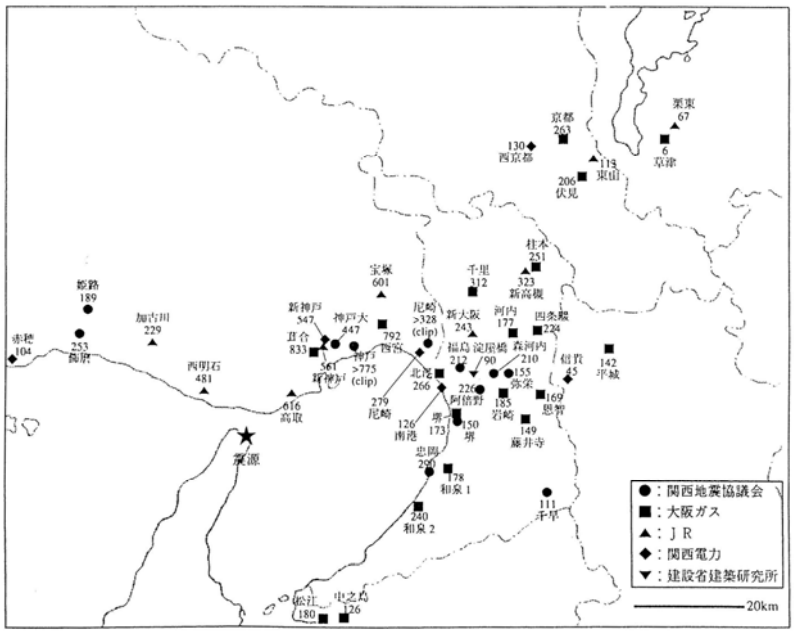
Investment Inspired by 1995 Kobe
Deployment of Network of Strong Motion Recording

Shaking of 1995 Kobe

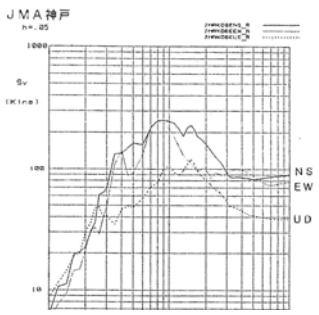
Distribution of Shindo 7

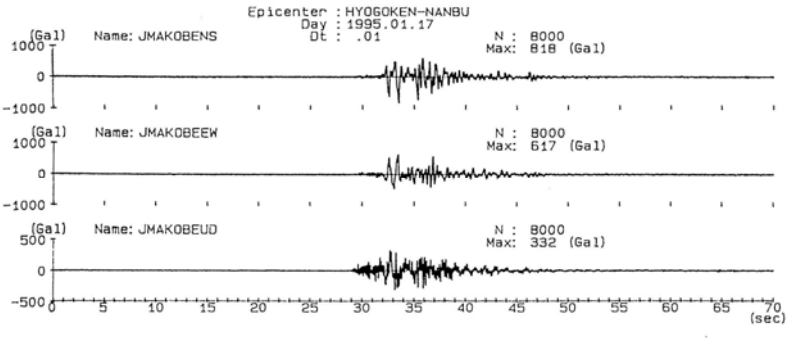


Distribution of Seismographs at 1995 Kobe

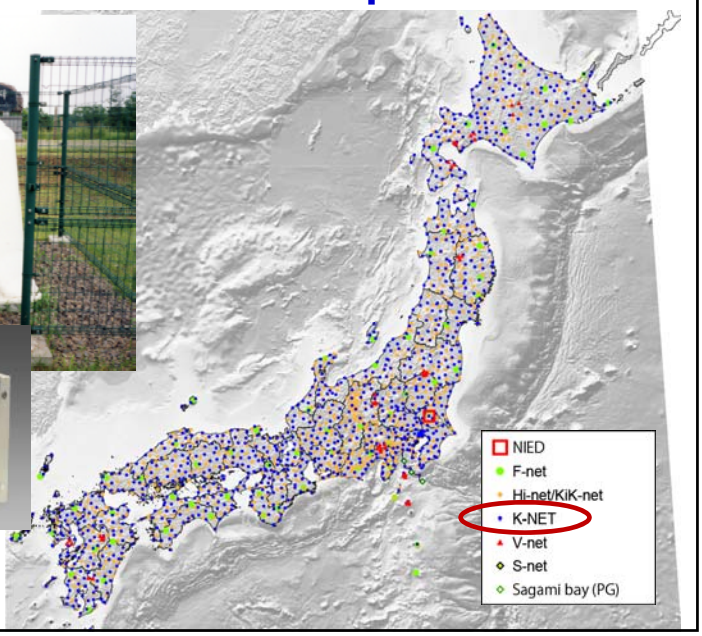


Records obtained at JMA Kobe

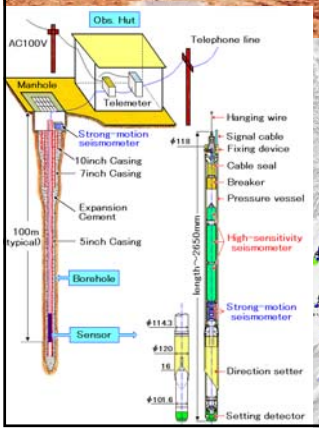


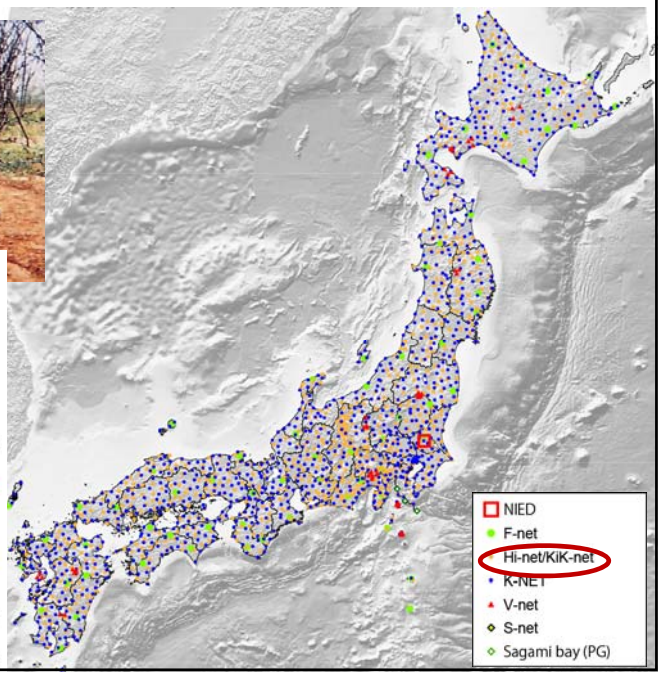


Deployment of K-net System (1,000 stations) After 1995 Kobe Earthquake

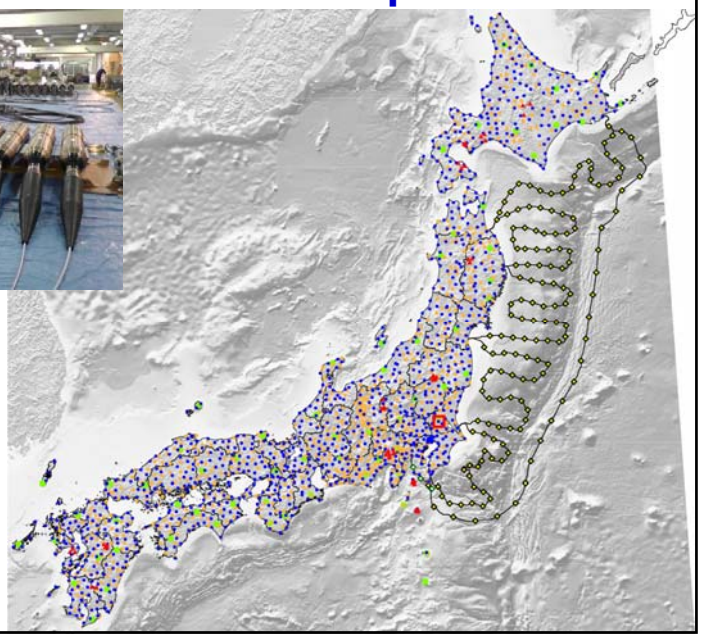


Deployment of Kik-net (about 700 stations）



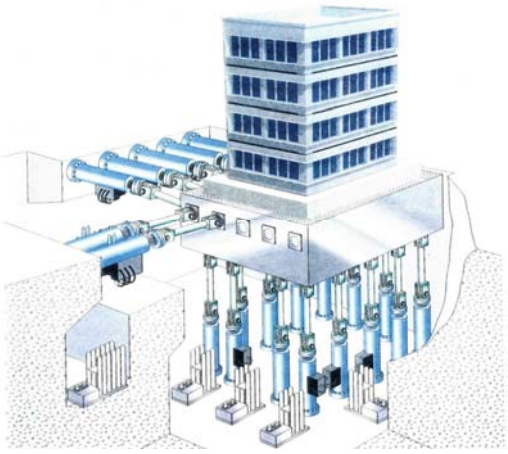


Deployment of S-net System (150 stations) After 2011 Tohoku Earthquake



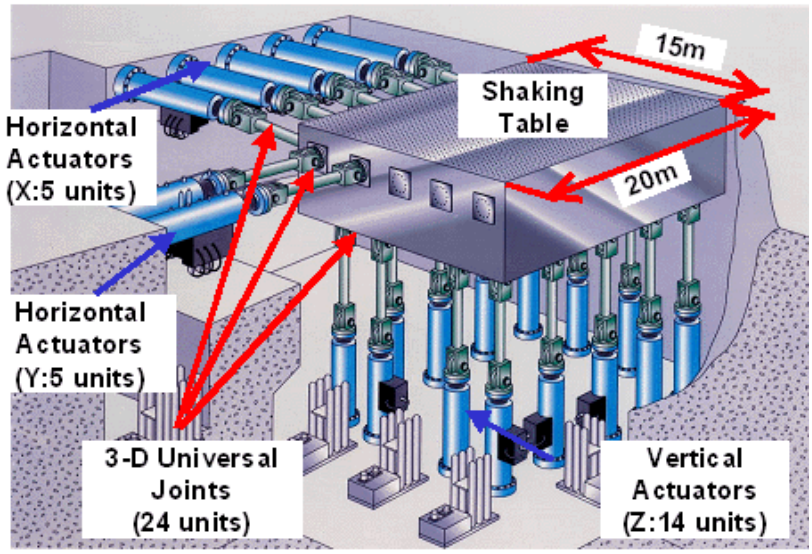
Investment Inspired by 1995 Kobe E-Defense

What is E-Defense?



It is a jumbo shaking table
of 20 m by 15 m in plan, activated in 3D
Owned by National Research Institute for Earth Science and Disaster Prevention and open in 2005

Shaking Table and Actuator System



Collapse Reproduction Applied to Wooden Houses (November 21 to 24, 2005)

Test click here

Activities of E-Defense

Since 2005, E-Defense has completed forty some full-scale (or large-scale) tests for various structures.

Four-story Base-isolated Hospital

Six-story RC Frame

Two-Story Wooden House

Four-story Steel Frame

Pile Foundation

Six-story Wooden House

Damage Disclosed in Niigata Chuetsu-Oki Earthquake

Problems Surfaced out from Past Large Earthquakes

1995 Kobe (Hanshin-Awaji)

Collapse, Seismic Retrofit
→ Strong Motion（K-Net）
→ Shaking Table (E-Defense)

2000 Tottori-Ken Seibu
2001 Geiyo
2003 Tokachi-Oki
2004 Niigata Chuetsu
2007 Noto Hanto

2007 Niigata Chuetsu-Oki
2008 Iwate-Miyagi

Business Continuity（BCP）
→ Long-Period Ground Motion

2011 Tohoku

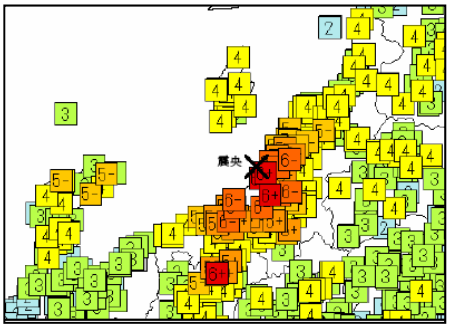
Huge Tsunami
→ Resilience
→ Seabed Motion（S-Net）
→ SIP

2016 Kumamoto

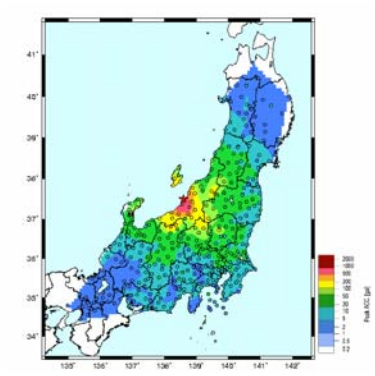
Repeated Shakings
→ Judgment of Safety

2007 Niigata-Chuetsu-Oki Earthquake

Occurrence at 10:13 of July 16, 2007
Epicenter of Niigata Chuetsu-Oki, with the depth of 17 km
Magnitude of 6.8



Distribution of Shindo Intensity (6+plus as Maximum)



Distribution of Maximum Accelerations over 500 gal

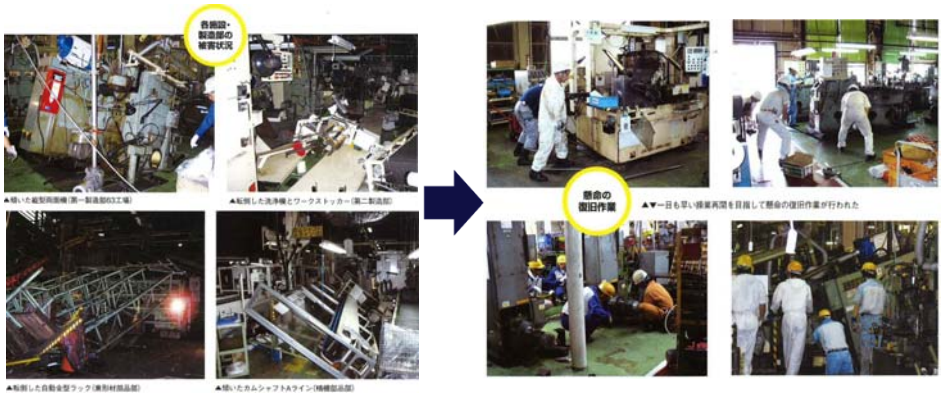
Damage to Factory A

Serious damage into buildings and production facilities due to 2004 Niigata-Chuetsu earthquake

Two months needed for Re-Opening

Damage to Factory B

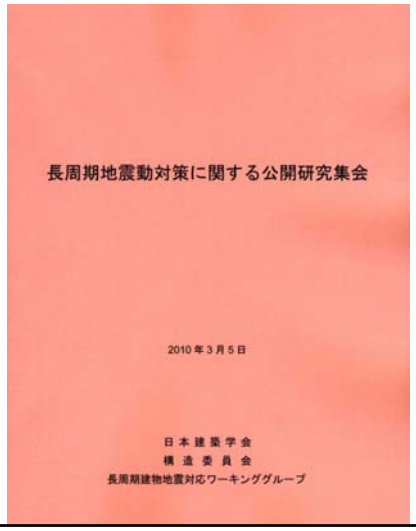
Serious damage into buildings and production facilities due to 2007 Niigata-Chuetsu-Oki earthquake



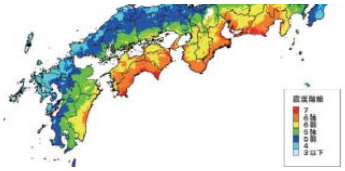
Opened after one week, with assistance of over 10,000 manpower from affiliated firms

Business Continuity Plan (BCP) and Long Period Ground Motions

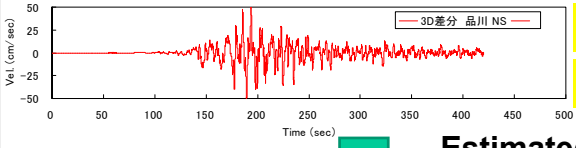
Investigation into Counter Measures for Large Long Period Ground Motion
AIJ's Report (2007 to 2011), subsidized by Cabinet Office of Japan



Long Period Ground Motion Anticipated by Rupture of Nankai Trough



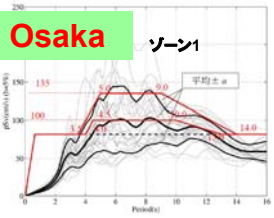
Estimation of strong motion



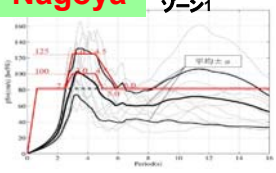
- Power in long period
- duration of 300 s

Estimated design seismic forces

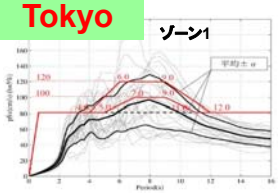
Osaka ゾーン1



Nagoya ゾーン1



Tokyo ゾーン1



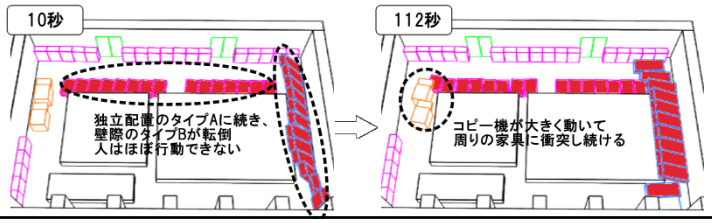
Responses of High-Rises Subjected to Nankai Trough

■ Expected loss to high-rises

Zone	Tokyo1	Nagoya1		Osaka1	Osaka2	
Building	50 - S Office	30 - S Hotel	40 - RC Residence	50 - S Office	50 - S Office	50 - S Office
Functionality	Need Check	Serious	Serious	Good	Need Check	Need Check
Member Damage	Medium	Medium	Slight	Serious	Serious	Slight

Need detailed investigation before operation　　Need repair before operation

■ Nonstructural components and building contents are also expected to aggravate damage.



Duration Expected for Safety Check of High-Rises

$$\text{Days of Safety Check} = \frac{\text{\# of High-Rises}}{\text{\# of Investigators x Efficiency}}$$

0.5～0.25 building/man/day
← based on 2011 Tohoku

About 220 engineers（Year: 2008）
← JSCA Registered Engineers = 2557 engineers, Efficiency of about 0.1 (no high-rise experiences, other inspections, etc.)

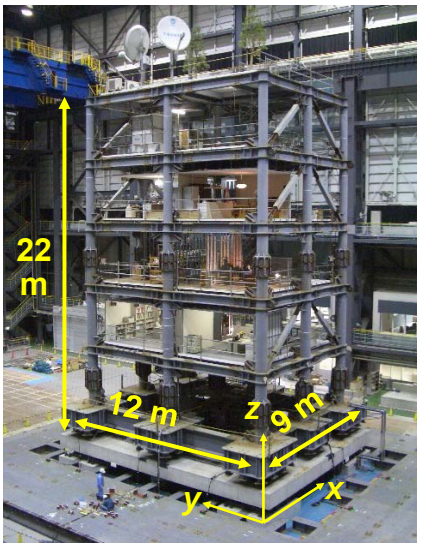
Kanto:8～15 days
Nagoya:7～15 days
Osaka:8～15 days

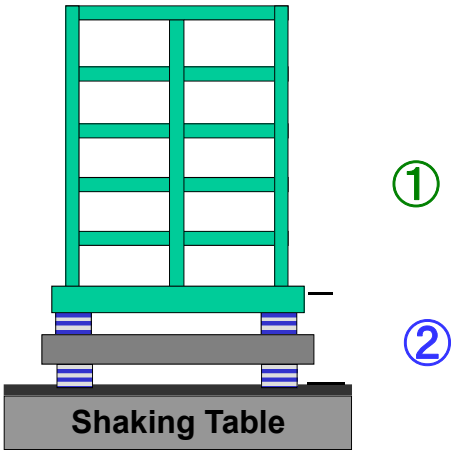
Days required for completion of inspection
→ 14～35 days

Note: 7～20 days added for preparation

■ One month to wait before decision of continuing occupancy
■ One month forced to leave, serious effect on BCPs.

Reproduction of Floor Response of Top Story of High-Rise Building

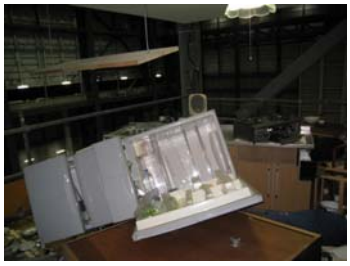




①Steel Frame(Rigid Body)

②Rubber-and-Mass system

Furniture Behavior in Top Floors



Overall Office Living Bedroom

Damage to Buildings and Cities/Towns in 2011 Tohoku

Problems Surfaced out from Past Large Earthquakes

1995 Kobe (Hanshin-Awaji)

Collapse, Seismic Retrofit
→ Strong Motion（K-Net）
→ Shaking Table (E-Defense)

2000 Tottori-Ken Seibu
2001 Geiyo
2003 Tokachi-Oki
2004 Niigata Chuetsu
2007 Noto Hanto

2007 Niigata Chuetsu-Oki
2008 Iwate-Miyagi

Business Continuity（BCP）
→ Long-Period Ground Motion

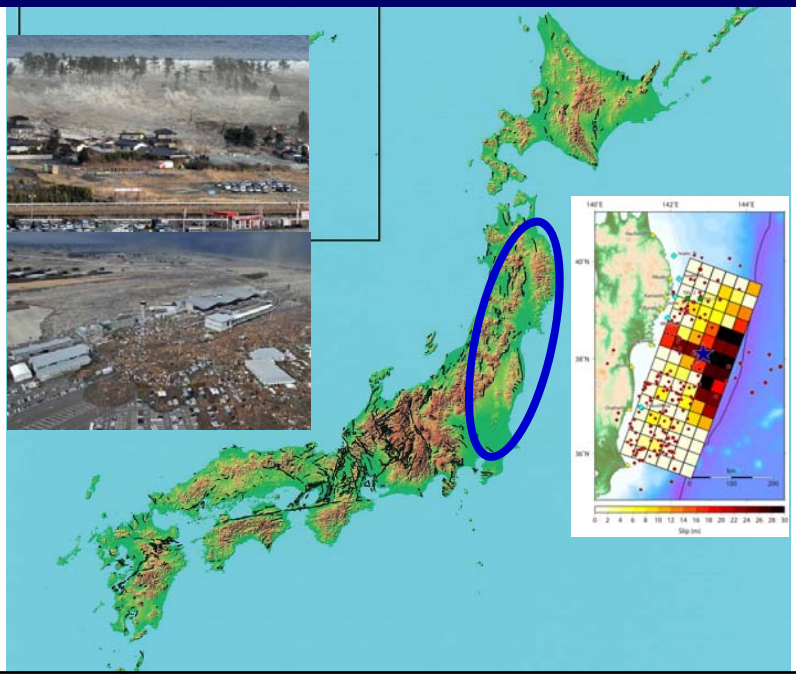
2011 Tohoku

Huge Tsunami
→ Resilience
→ Seabed Motion（S-Net）
→ SIP

2016 Kumamoto

Repeated Shakings
→ Judgment of Safety

2011 Tohoku Earthquake (March 11, 2011)



Urban damage, such as observed in Sendai

Collapse of First Story in Two-Story RC

Downtown Sendai Right After Qauke

Shear Failure of RC Columns

Failure of House by Landslide

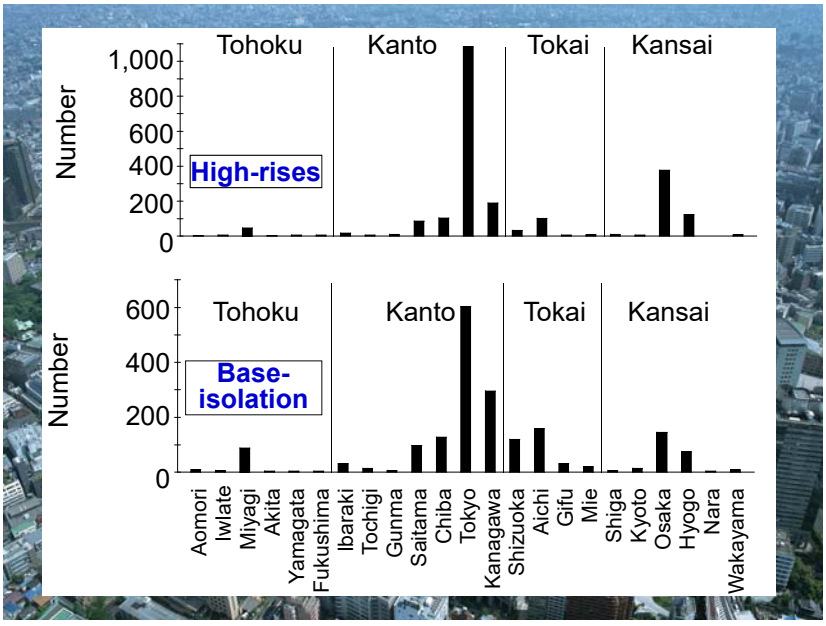
Nonstructural Damage

Behavior of High-Rise in Sendai

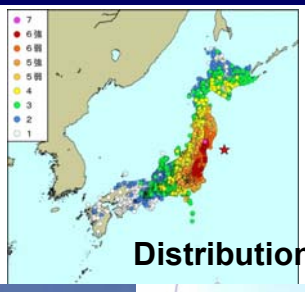
Constructed: 1998 (31 stories)
Type of Structure: SRC, with passive mass dampers

- **Difficulty in standing;**
- **Partitions overturning;**
- **Books thrown horizontal and fell to floor with a parabolic orbit;**
- **No human injured;**
- **Inhabitants evacuated orderly using stairs;**
- **Cars in ground parking areas moved;**
- **Those who watched the building thought that it might break in the middle of the building;**
- **Seismograph in the building showed Shindo 7.**

Performance of hundreds of high-rises and base-isolated buildings in the Tokyo metropolitan area



Shinjuku Right After Quake (March 11, 2017)



Distribution of Shaking

Blue Sky in Shinjuku

People Escaping from Buildings

Widespread disruption in the Tokyo metropolitan, due to shortage of electric power.

Refugees in Tokyo on March 11, 2011s
(Over 21,000 people were forced to stay in stations)

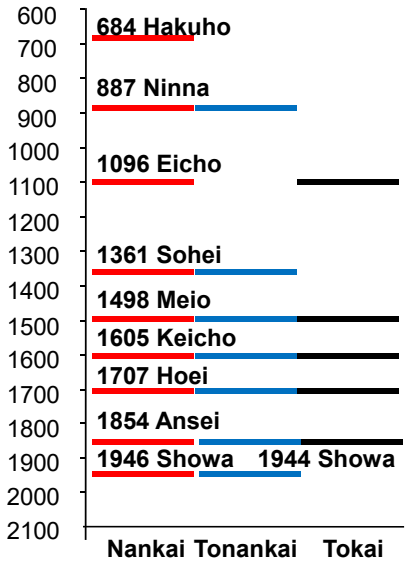
Traffic Jam

Long line for waiting train
(due to rotating blackout)

Sleeping in Station

Food store with no food

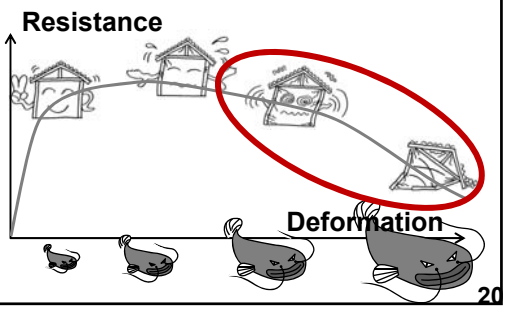
Historical Records of Large Earthquakes



Huge Ocean-Ridge Quake - More to Expect in Near Future

Lessons from 2011 Tohoku

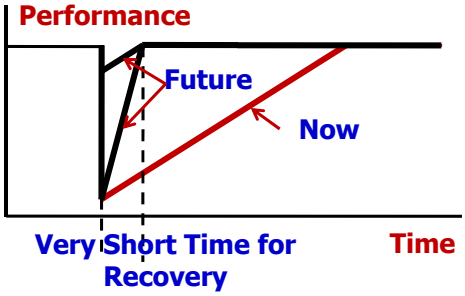
- **Nature is more formidable than what we want it to be.**
- **What is assumed (expected, supposed, conceived) in design, for example, design earthquake force, is determined by human (not by nature) in consideration of cost performance.**
- **No matter how less frequent it may be, a catastrophic disaster shall occur; in such a case, we cannot expect "no damage" any longer in our life and society.**



20

Resilience

- **After 2011 Tohoku, the term "Resiliency" is sensed more realistic. Here, I define "resilient" as ability to recover to its normal condition as quickly as possible. We need to develop technologies to promote prompt recovery.**



Lessons to Earthquake Engineering Community

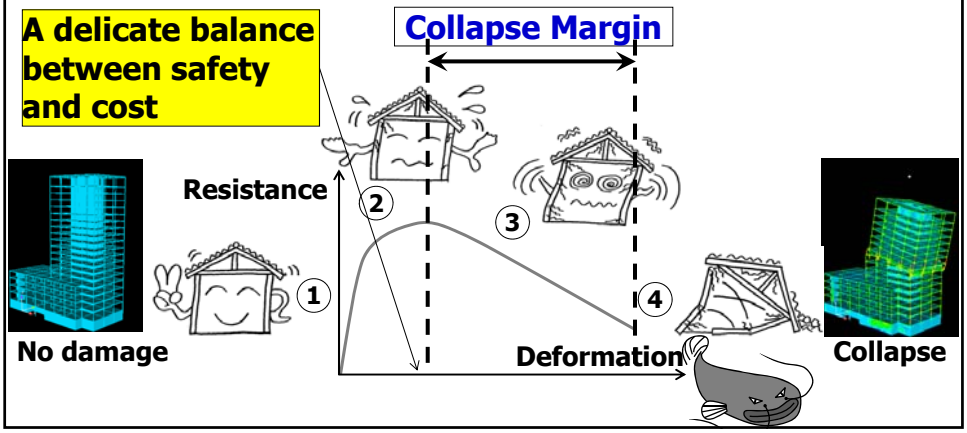
(1) Response to earthquakes beyond what is considered in structural design
(2) Continuing business and prompt recovery

Specific Engineering Research Needed

(A) Quantification of collapse margin of high-rise buildings
(B) Monitoring and prompt condition assessment of buildings

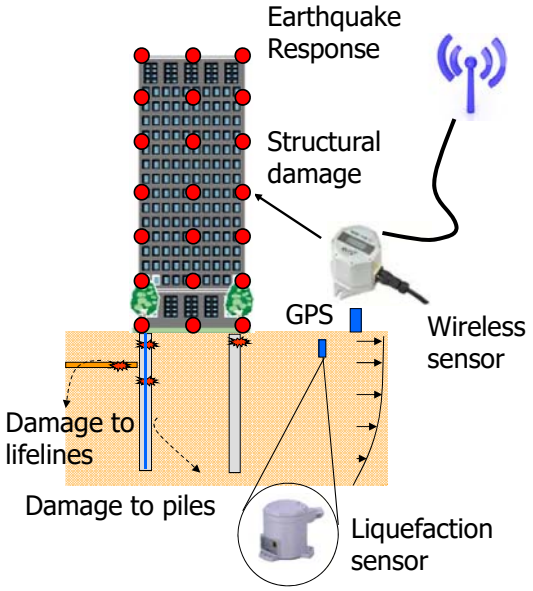
Engineering Research Need After 2011 Tohoku Earthquake –I–

(1) Quantification of Collapse Margin: To make a consensus to the response to earthquakes that go beyond one considered by codes, we shall quantify the performance of each structure up to complete.



Engineering Research Need After 2011 Tohoku Earthquake –II–

(2) Technologies for Enhanced Health Monitoring: To make our society more resilient, we need more advanced sensing and monitoring technologies by which we can detect damage and/or evaluate state of safety immediately.



Reducing Vulnerability for Urban Mega Earthquake Disasters (2012 – 2016) (about 2 million USD per year)

Architectural Institute of Japan

Oversight Committee
綿川光正(北大)、西山功(国総研)、北村春幸(東理大)、盛谷浄修治(東大)、西谷章(早大)、福和伸夫(名大)、中井正一(千葉大)、草川三郎(東工大)、金箱温春(JSCA)、伊藤儀(JSCA)、杉山義孝(建防協)

Headquarters
- DPRI, Kyoto U. (M. Nakashima, PI)
- E-Defense, NIED (K. Kajiwara, Vice-PI)
- Kobori Institute (N. Koshika, Secretary)

Research Team

①-1:S造高層余裕度
責任機関:鹿島(高橋元典、項目代表)
協力機関:清水建設、小堀研、京都大学(吹田啓一郎、部会主査)、防災科技研

①-2:RC造余裕度
責任機関:大林組(勝俣英雄、項目代表)
協力機関:清水建設、京都大学(西山峰広、部会主査)、防災科技研

②-1:モニタリング上部
責任機関:清水建設(斎藤知生、項目代表)
協力機関:鹿島、大林組、名古屋大学(飛田潤、部会主査)、京都大学、防災科技研

②-2:モニタリング地盤
責任機関:大成建設(藤井俊二、項目代表)
協力機関:小堀研、京都大学(田村修次、部会主査)、防災科技研

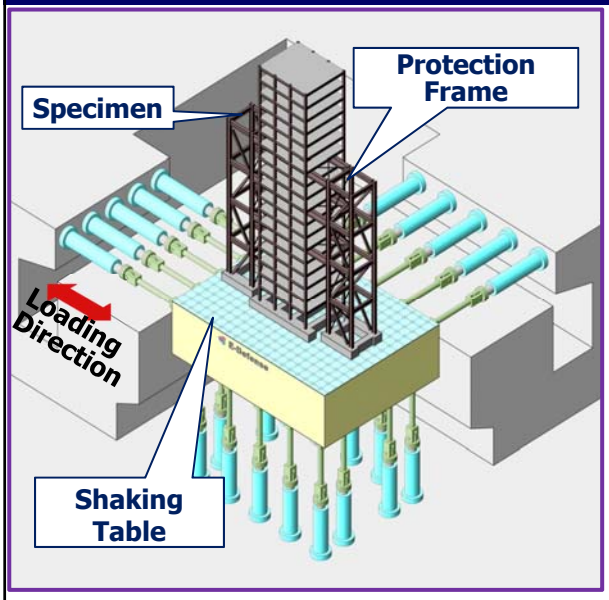
②-3:モニタリング連成システム
責任機関:小堀研(岡野創、項目代表)
協力機関:京都大学、清水建設、大成建設、竹中工務店、横浜国立大学(植木浩一、部会主査)、防災科技研

③:MeSO-net観測
責任機関:竹中工務店(小林喜久二、項目代表)
協力機関:東京大学地震研究所(酒井慎一、部会主査)、京都大学、防災科技研

Consortium of Academia, Government, and Industry

Big Five Design/Construction Firms

Shaking Table Test for Collapse of Steel High-Rise Building (Implemented in December 2013)



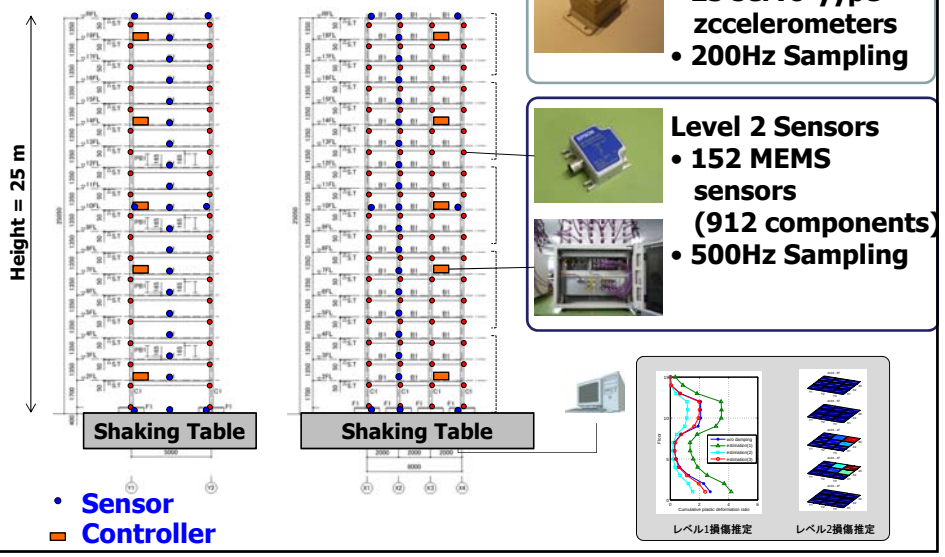
Shaking Table
Use of E-Defense

Specimen
A height of 25 m adopted in light of E-Defense allowable limit (27 m)

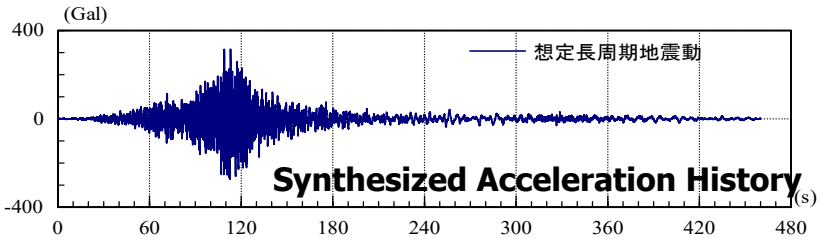
Protection Frame
Developed to protect collapsing specimen as well as to serve as a frame to lift specimen

Input Motion
Synthesized motion considering simultaneous ruptures of three troughs

Monitoring and Condition Assessment (Planned on December 2013)



Synthesized Ground Motion



- **Amplification of Original History**

Average (110cm/s)	baseline
Large (180cm/s)	1.64 times
Very Large I (220cm/s)	2 times
Very Large II (250cm/s)	2.27 times
Very Large III (300cm/s)	2.73 times
Very Large IV (340cm/s)	3.1 times (at the table capacity)

- **Contracted to $1/\sqrt{3}$ with respect to time domain**

Failure Overview

Collapse of lower stories, leaning to protection frame

Fracture of beam end

Local buckling at column base

Damage to Buildings and Cities/Towns in 2016 Kumamoto

Problems Surfaced out from Past Large Earthquakes

1995 Kobe (Hanshin-Awaji)

Collapse, Seismic Retrofit
→ **Strong Motion（K-Net）**
→ **Shaking Table (E-Defense)**

2000 Tottori-Ken Seibu
2001 Geiyo
2003 Tokachi-Oki
2004 Niigata Chuetsu
2007 Noto Hanto

2007 Niigata Chuetsu-Oki
2008 Iwate-Miyagi

Business Continuity（BCP）
→ **Long-Period Ground Motion**

2011 Tohoku

Huge Tsunami
→ **Resilience**
→ **Seabed Motion（S-Net）**
→ **SIP**

2016 Kumamoto

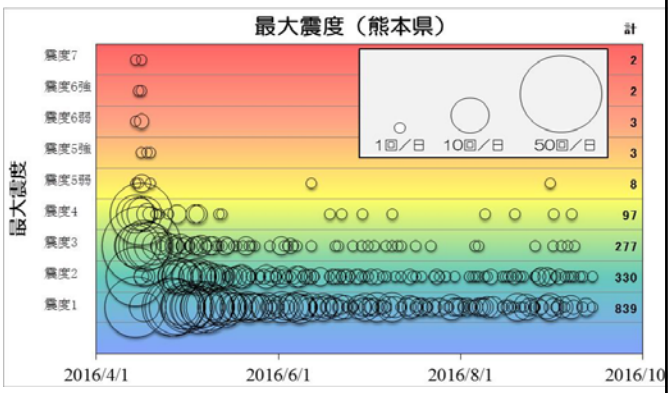
Repeated Shakings
→ **Judgment of Safety**

Damage to Houses in Mashiki Town

Repeated Strong Motions in Kumamoto

Characterized:

* Twice of shaking in Shindo 7
* Second shaking greater than first one
* JMA changes: "Main Shock → After Shock" to "Pre Shock" → "Main Shock"

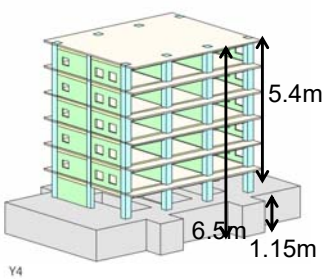


* Ten shakings (greater than Shindo 5) within four months
* A large number of after shocks (greater than previous max at 2004 Chuetsu

Shaking Table Test Applied to Mid-Rise RC Wall-Frame Under Repeated loadings

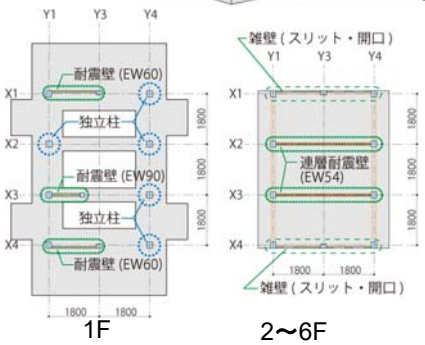
Object：Mid-rise Apartment

Designed following Current Code
Typical Plan used in Urban Areas
1st Story for Shops and 2nd Story Above for Housing
Fewer Walls in 1st Story

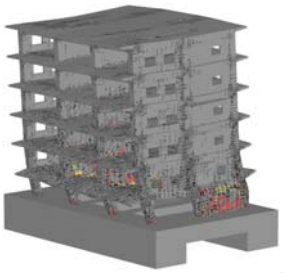


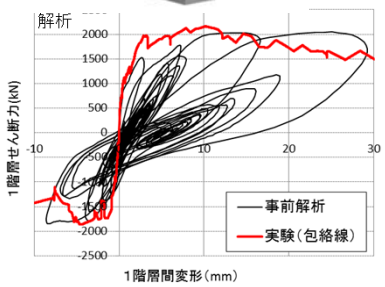
Specimen:

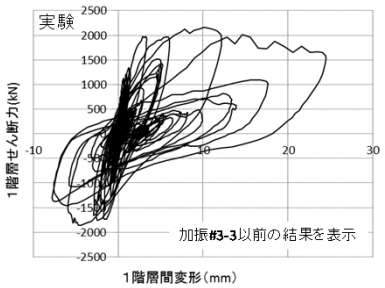
Scale: 30%（1/3.33）
Weight: about 320ton
Number of Stories: 6
Height：about 6.5m
Plan: 3 x 2
Materials:
Concrete: Fc30
Rebars: SD295, SD345



Test Results and Pre-Analysis







Test versus Pre-Analysis　　Test

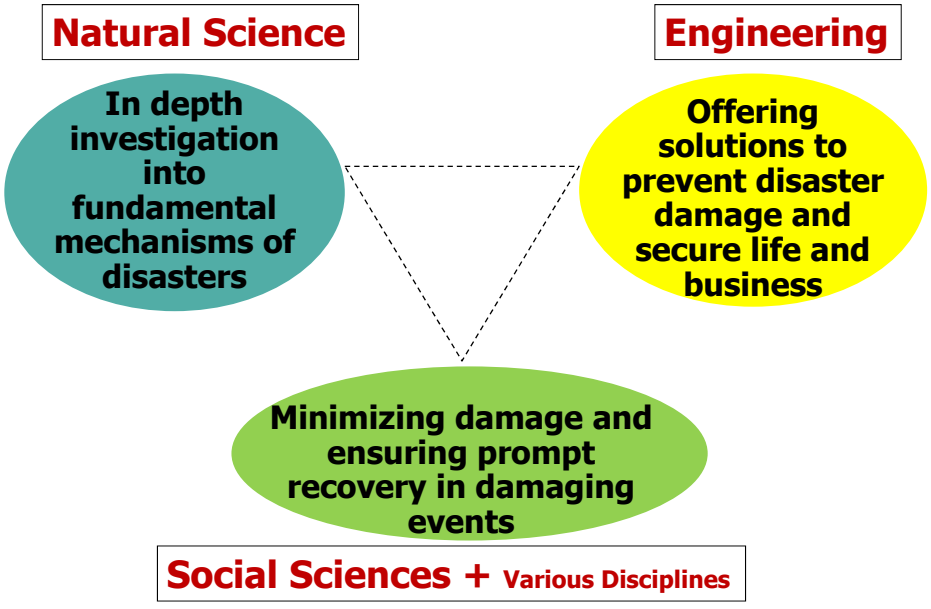
Comparison in Failure mode and First-Story Shear vs First-Story Drift Angle Relationships

Summary of Past Major Quakes, Lessons, and Efforts

1995 Kobe (Hanshin-Awaji)	Collapse, Seismic Retrofit → Strong Motion（K-Net） → Shaking Table (E-Defense)	Advanced estimation of strong motion Prevention of Collapse Seismic Retrofit
2007 Niigata Chuetsu-Oki	Business Continuity（BCP） → Long-Period Ground Motion	Attention and Action to BCP Advanced estimation of Tsunami
2011 Tohoku	Huge Tsunami → Resilience → Seabed Motion（S-Net） → SIP	Quantification of collapse margin Motivation to monitoring
2016 Kumamoto	Repeated Shakings → Judgment of Safety	Recovery/resilience of cities and communities

Where is Japan moving ahead for more positive disaster mitigation?

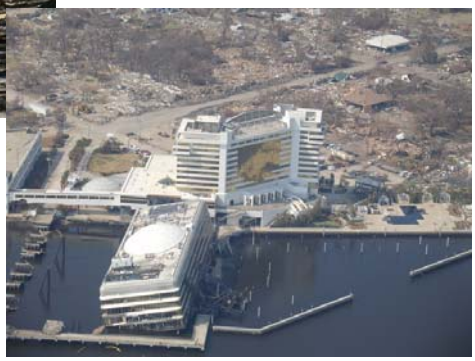
Three Disciplines Essential for Earthquake Disaster Prevention/Mitigation



Collaboration Indispensable to Pursue Resilience - Interdependency of many, many factors of our Society

Flood

Hurricane



My house is fine, but the rest destroyed --- How I can live from this time on???

Toward Resilience

Natural Science

In depth investigation into fundamental mechanisms of disasters

Engineering

Offering solutions to prevent disaster damage and secure life and business

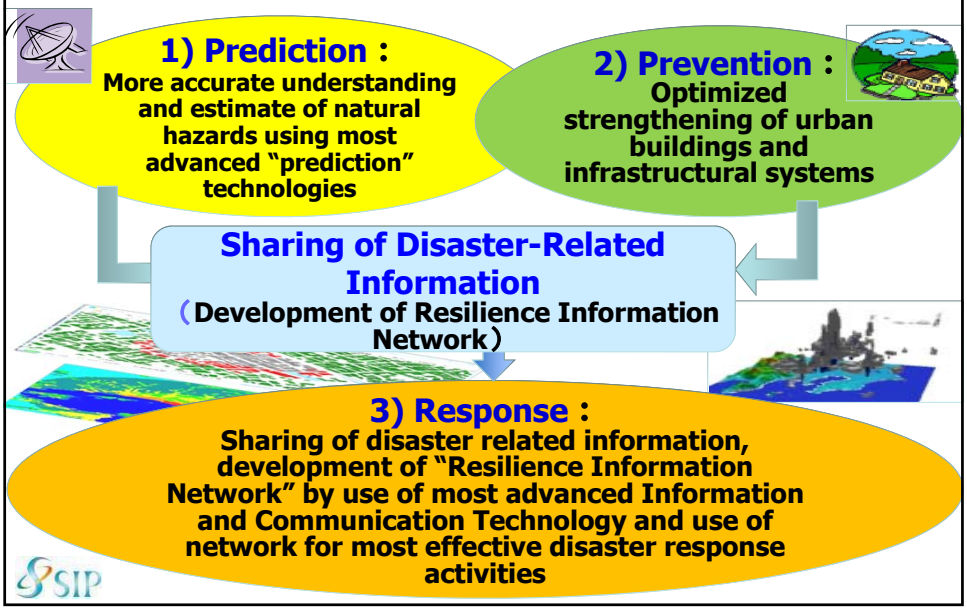
Attempt essential in which Efforts by Others (not only by us) are to be appreciated more.

Minimizing damage and ensuring prompt recovery in damaging events

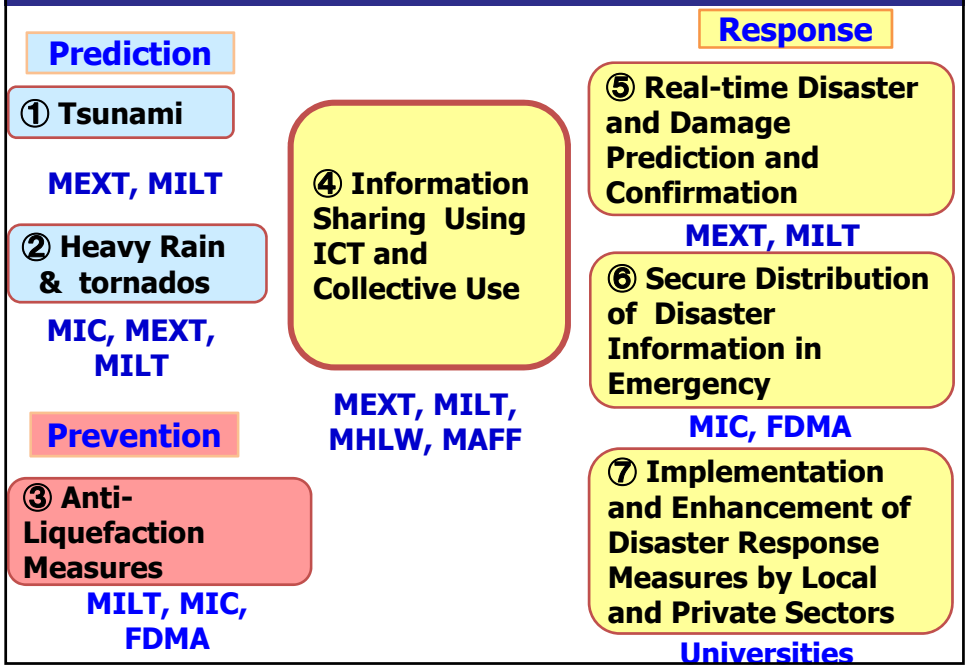
Social Sciences

SIP: Strategic Innovation Program 2014 – 2018
Organized by Cabinet Office of Japan
(Annual Budget: 300 million plus US dollars)

SIP: Enhancement of Societal Resiliency against Natural Disasters

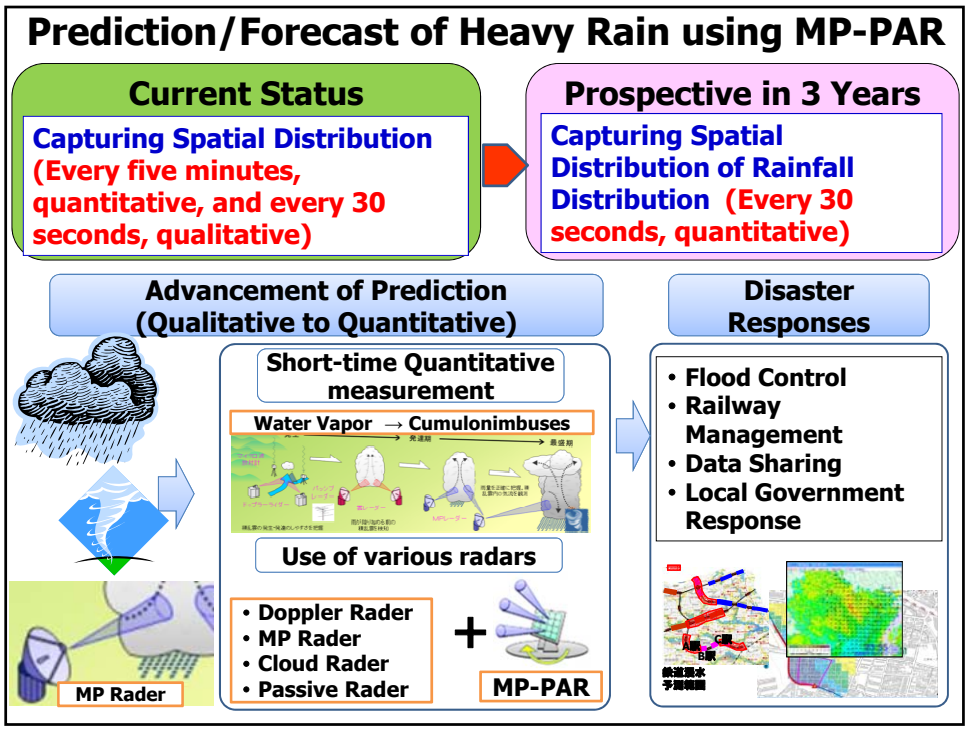


SIP: Resilience – Collaboration among Ministries



SIP: Resilience – Collaboration among Ministries

総務省
(MIC: Ministry of Internal Affairs and Communications)
文部科学省
(MEXT: Ministry of Education, Culture, Sports, Science/Technology)
厚生労働省
(MHLW: Ministry of Health, Labour and Welfare)
農林水産省
(MAFF: Ministry of Agriculture, Forestry and Fisheries)
国土交通省
(MLIT: Ministry of Land, Infrastructure, Transport and Tourism)
消防庁
(FDAM: Fire Defense Agency)



Where is Masayoshi Nakashima going?

Big Five Contractors in Japan





Obayashi (1.61*)	Kajima (1.52)	Shimiz (1.50)	Taisei (1.53)	Takenaka (1.02)

OBAYASHI

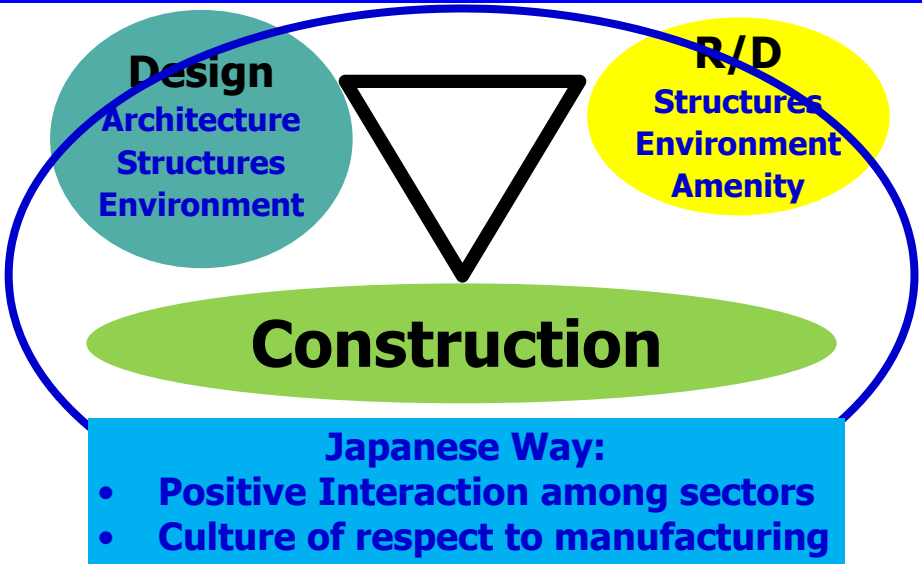
鹿島

SHIMIZU CORPORATION SHIMZ

TAISEI

* Annual Sale in trillion yen (2015)

Design versus Construction



Japanese Way:

- Positive Interaction among sectors
- Culture of respect to manufacturing

Department of Architecture & Building Engineering

Kajima's History on High-End Research

Muto Research Institute (from 1963 to 1989)
Kobori Research Complex (KRC) (from 1986 to date)

Kiyoshi Muto

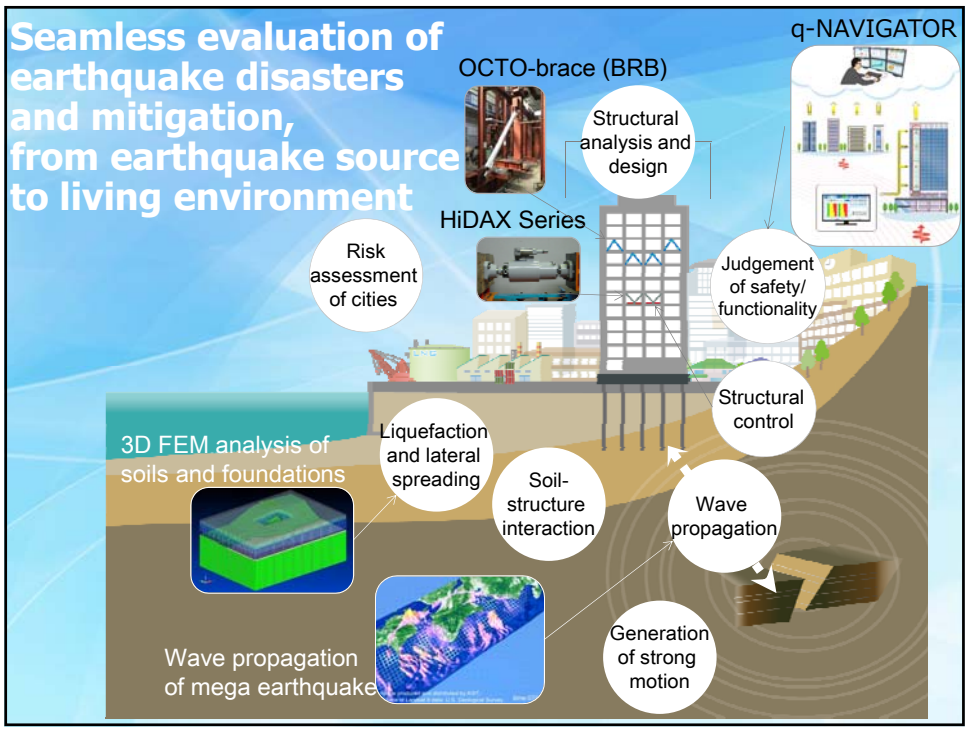
Takuji Kobori

Masayoshi Nakashima

First High-Rise in Japan
Kasumigaseki Building

First Active Control
Kyobashi Seiwa Building

Service through Networking



Closure

To ensure the sustainability of our globe, we must further engineering technologies by effectively collecting and refining relevant human resources from various sectors and regions.

Success in global work depends on whether or not we work with a strong focus on adaptation, meaning an appreciation of one's counterpart's technology and culture in the setting of specific plans and procedures.

With KRC's experiences on the development of relevant technologies as the backbone and further by strengthening our human network and promoting spirit of adaptation, we would like to contribute the sustainable development of our globe.