Safeguarding Quality of Life: Research Needs for Condition Assessment and Collapse Quantification of Building and Infrastructural Systems

January 18, 2013

Masayoshi Nakashima
Disaster Prevention Research Institute (DPRI)
Kyoto University

Today's Topics

- **Some Lessons of the 2011 Tohoku Earthquake**
- **Past Research using Large-Scale Testing Facilities**
- **A New Project on Condition Assessment and Collapse Quantification**

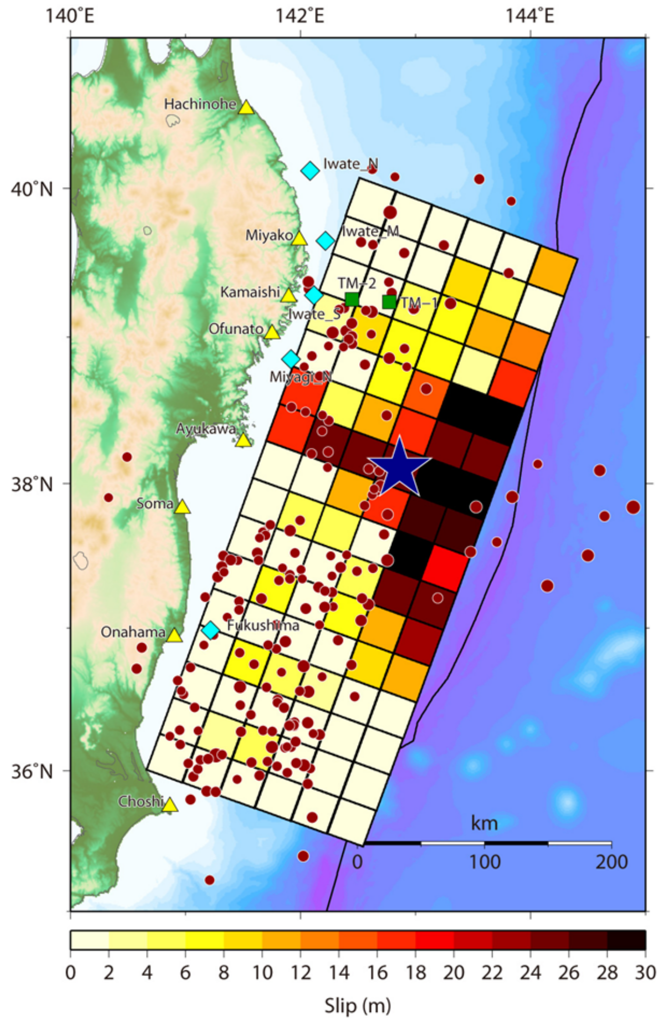
Notable Issues Observed in 2011 Tohoku Disaster (from Reconnaissance by Architectural Institute of Japan)

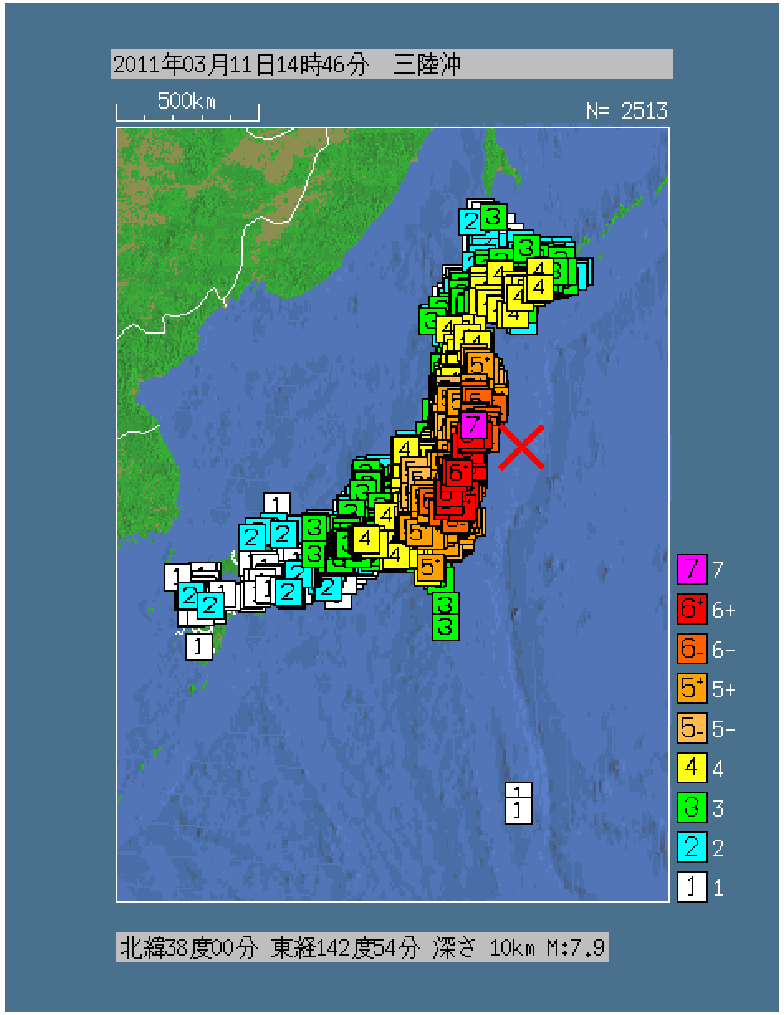
1. Extremely large rupture, over 400 km, occurred, which was not anticipated by seismologists.
2. A huge tsunami caused complete devastation of many towns and villages and large loss of life. Damage and deaths from tsunamis were much greater than those from the earthquake shaking.
3. Significant subsidence (about 1 to 2 meters) of coast lines was notable, which had aggravated the tsunami damage.
4. Urban damage, such as the one observed in Sendai, was particularly characterized by the loss of lifelines.
5. Performance of hundreds of high-rises and base-isolated buildings in the Tokyo metropolitan area appears to be good. Many days are needed to collect associated data.
6. Widespread disruption in the Tokyo metropolitan area was notable due primarily to the shortage of electric power.
7. Post-earthquake responses of the central and local governments were tested. Several hundred thousand people were forced to move to evacuation centers.
8. Technical and social response to nuclear accidents is a major issue for the country.
9. Large fires were caused by the earthquake, including at oil tank farms.
10. Severe liquefaction in areas of reclaimed land was notable.

Notable Issues Observed in 2011 Tohoku Disaster Summary

- **Huge rupture that caused M9 quake**
- **Tsunami that lost the lives of 20,000**
- **Subsidence of land by 1 to 2 meters**
- **Damage in Sendai characterized by lifeline loss**
- **Performance of high-rises subject to long-period motion**
- **Inconvenience in metropolitan due primarily to blackout**
- **Disaster responses in vast regions**
- **Nuclear disaster**
- **Fire that followed tsunami**
- **Liquefaction in reclaimed land**

Extremely large rupture, over 400 km, which was not anticipated by seismologists





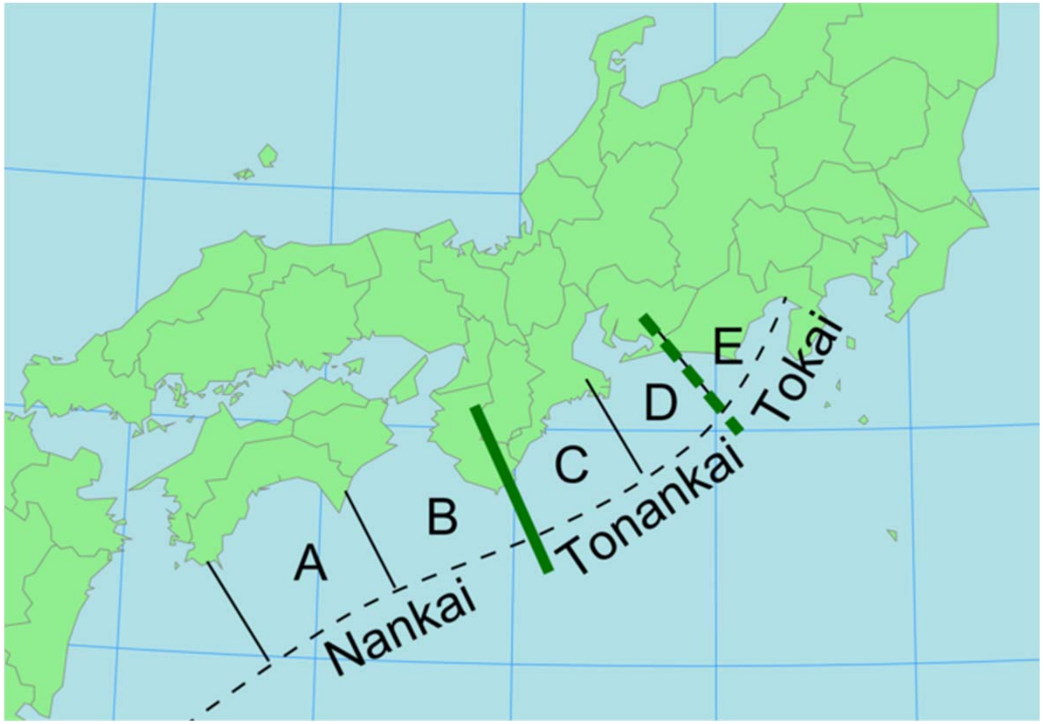
Fault Rupture　　**Shindo Distributions**

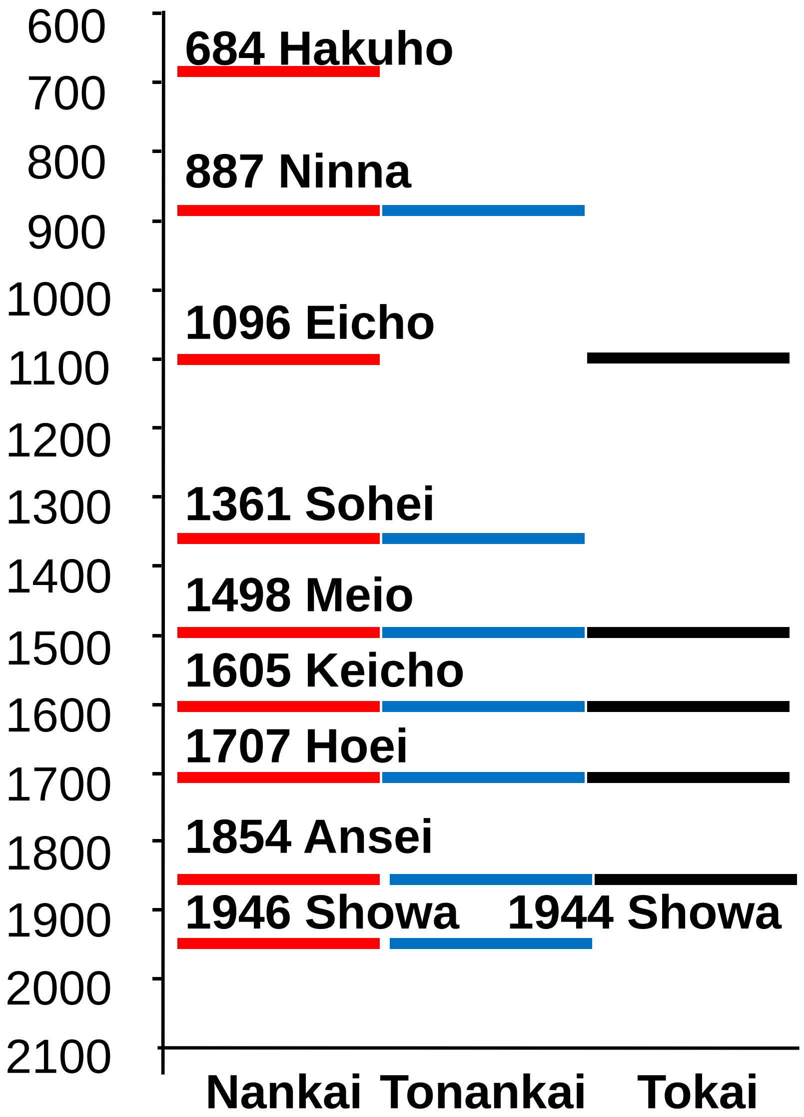
Extremely large rupture, over 400 km, which was not anticipated by seismologists

Recent Damaging Earthquakes in Japan

Year	Name	Magnitude	Death (missing)	Injury	Collapse	Severe
1995	Hyogo-Ken Nanbu	7.3	6,437	43,792	105,000	144,000
1997	Kagoshima-Ken Hokuseibu	6.4		74	4	31
2000	Tottori-Ken Seibu	7.3		182	435	3,101
2001	Geiyo	6.7	2	288	70	774
2003	Miyagi-Ken Oki	7.1		174	2	21
2003	Miyagi-Ken Hokubu	6.4		677	1,276	3,809
2003	Tokachi-Oki	8.0	1	849	116	368
2004	Niigata-Ken Chuetsu	6.8	68	4,805	3,175	13,810
2005	Fukuoka-Ken Seihou-Oki	7.0	1	1,204	144	353
2005	Miyagi-Ken Oki	7.2		100	1	984
2007	Noto-Hantou	6.9	1	356	686	1,740
2007	Niigata-Ken Chuetsu-Oki	6.8	15	2,346	1,331	5,709
2008	Iwate Miyagi Nairiku	7.2	17	426	30	146
2008	Iwate Engan Hokubu	6.8	1	211	1	379
2009	Suruga-Wan	6.5	1	319		6
2011	Tohoku-Chiho Taiheiyou-Oki	9.0	15,202 (9,761)	5,338	97,932	51,466

Extremely large rupture, over 400 km, which was not anticipated by seismologists





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

Urban damage, such as observed in Sendai, is particularly characterized by the loss of lifelines.

Collapse of First Story in Two-Story RC

Downtown Sendai Right After Qauke

Shear Failure of RC Columns

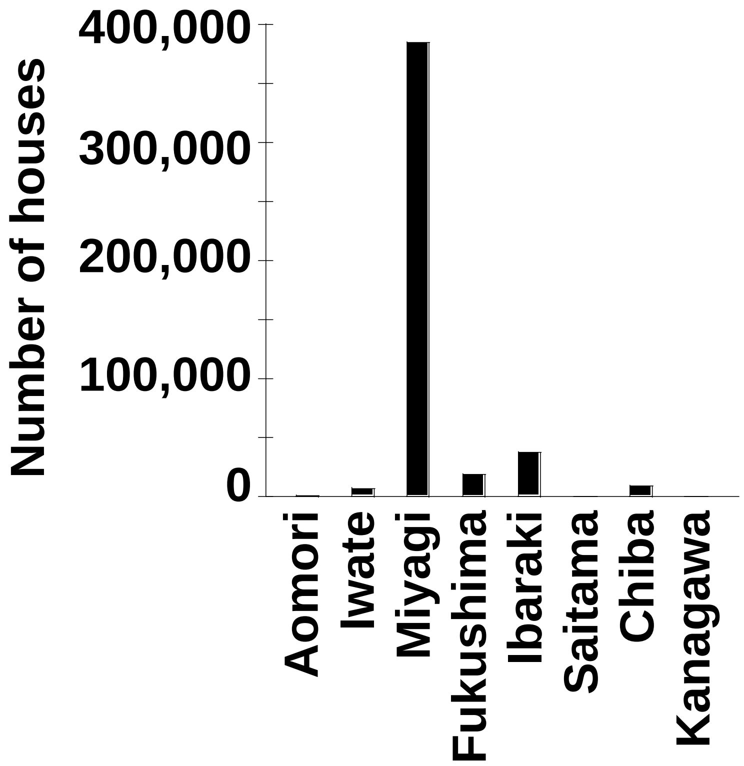
Failure of House by Landslide

Nonstructural Damage

Urban damage, such as observed in Sendai, particularly characterized by the loss of lifelines

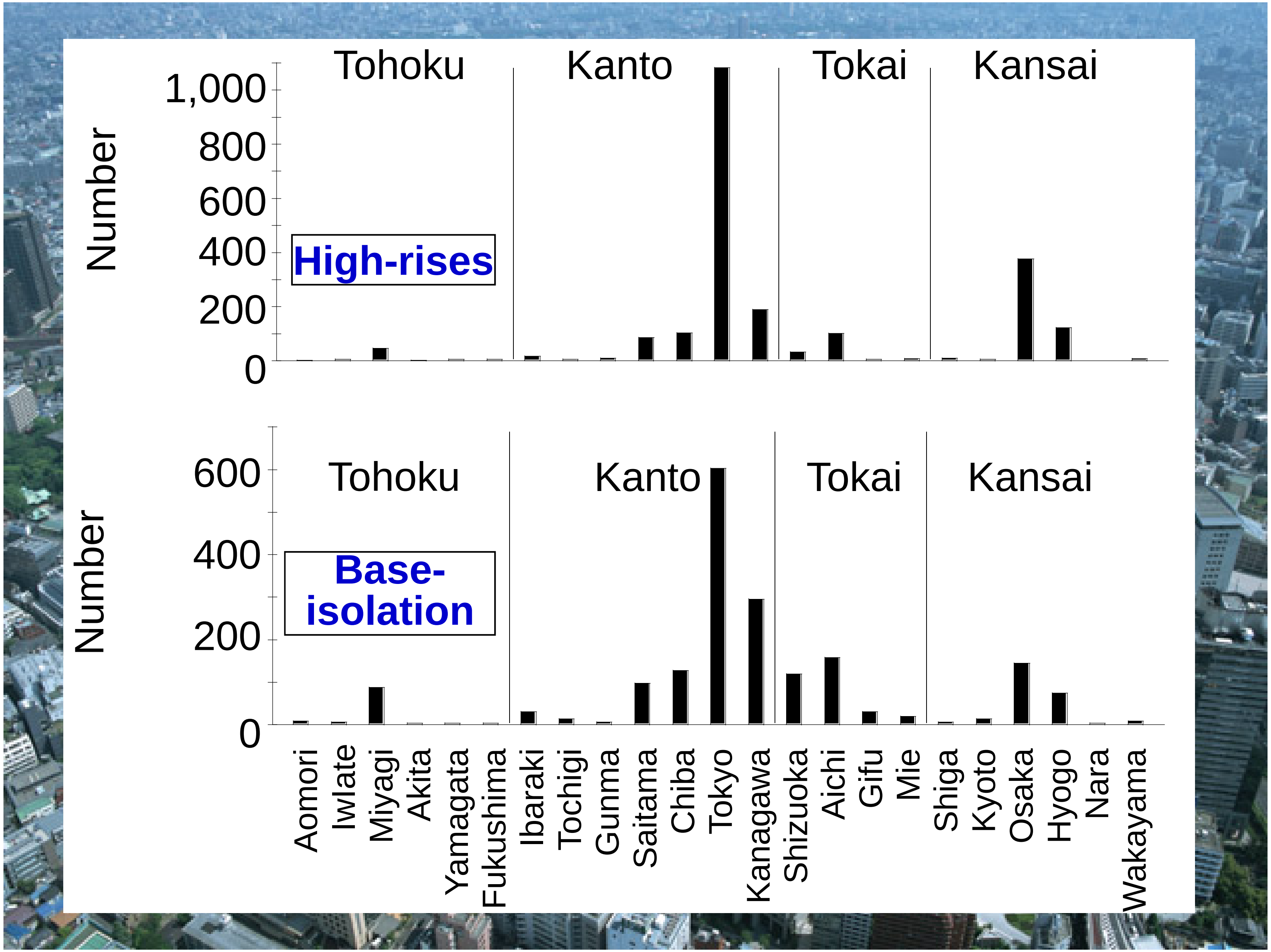
Electricity :Number of blackouts (Number of households covered)

	March 11	April 20
Tohoku Electric	4,400,000 (7,700,000)	145,700
Tokyo Electric	4,050,000 (28,600,000)	0

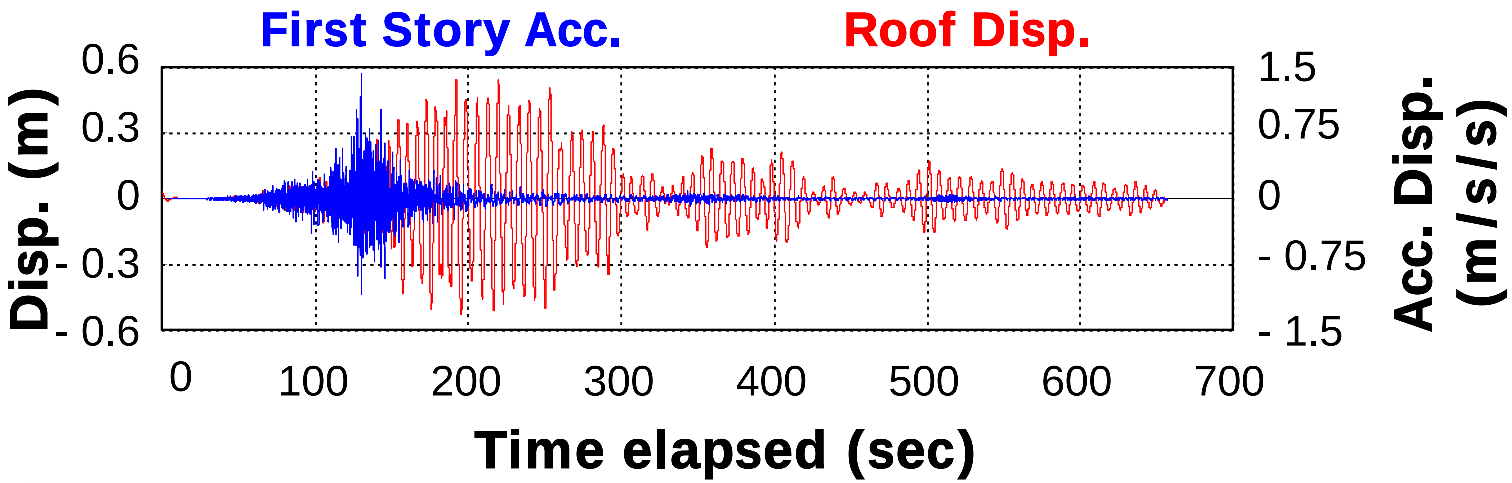


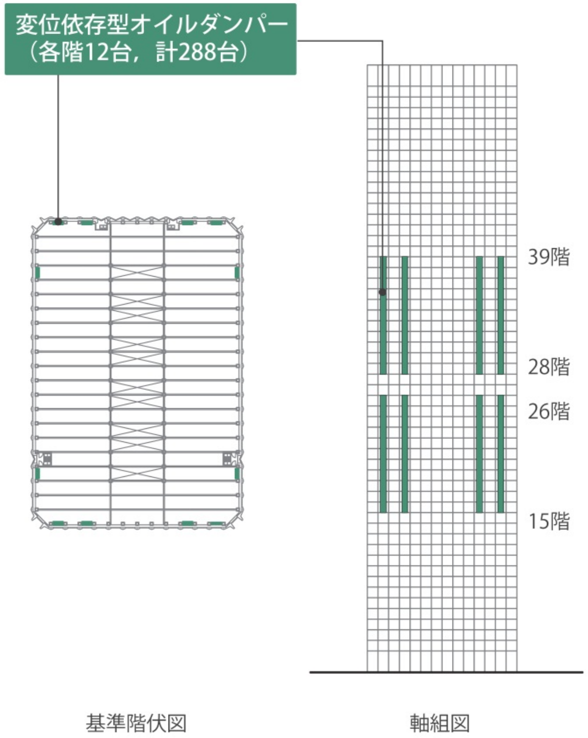
Shortage of Gas Supply

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



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





Effect of Retrofit:

Disp. → about 20％ reduction
Acc. → about 30％ reduction
Decay after quake → about 50％ reduction

The figures and photos appearing in this slide are presented here by the courtesy of Taisei Co.

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

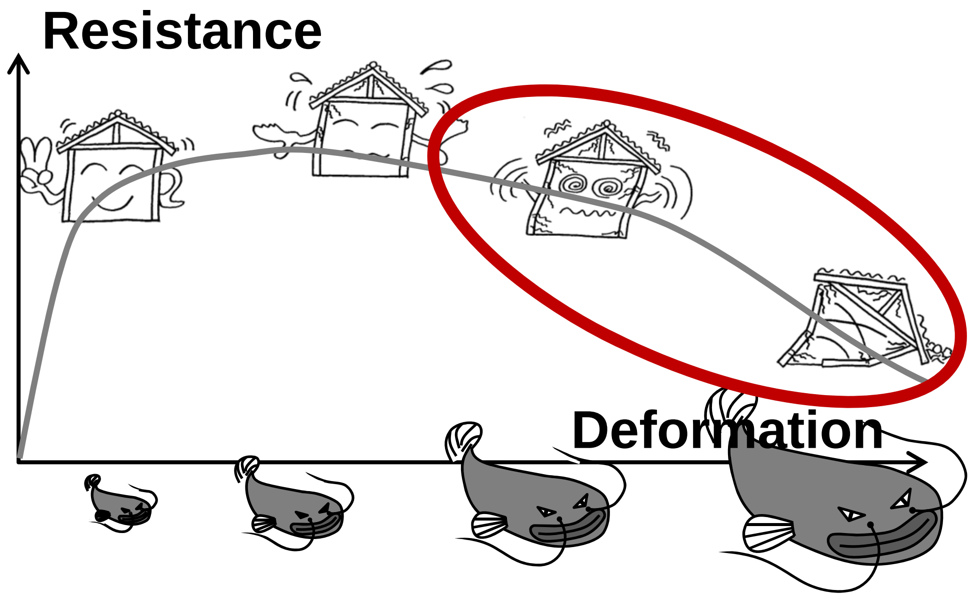
Performance of hundreds of high-rises and base-isolated buildings in the Tokyo metropolitan area

Lessons Learned:

- Under Shindo-5+ (MM: IX) motion, high-rises and base-isolated buildings performed satisfactorily. No report was given on serious damage.
- Nonstructural damage was reported in not a few cases including falling of ceiling panels; such damage is reconfirmed to bring a serious problem of "business continuity".
- Disruption of transportation, communication failures, and large-scale liquefaction greatly affected the business activities and daily lives of people in the city.

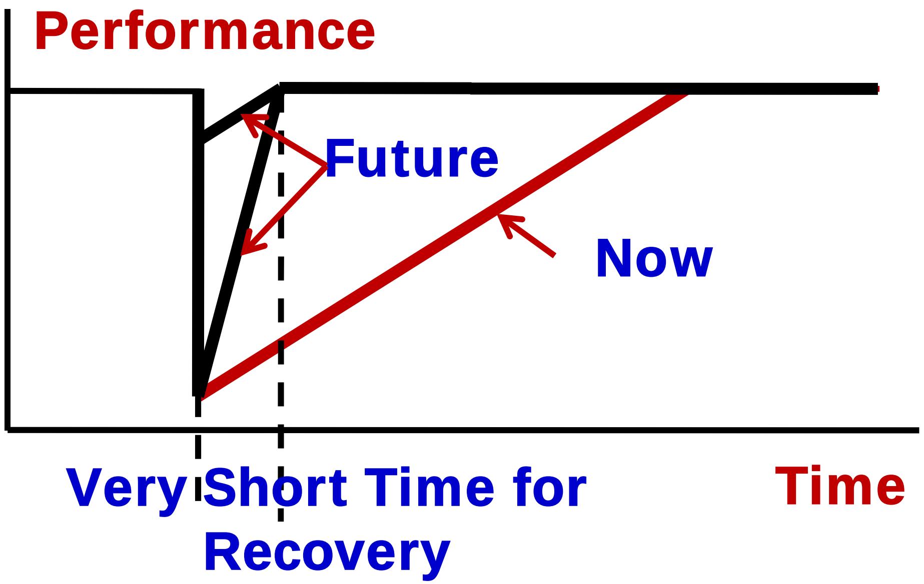
My View on Lessons from 2011 Tohoku

- **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.**



My View on Resilience

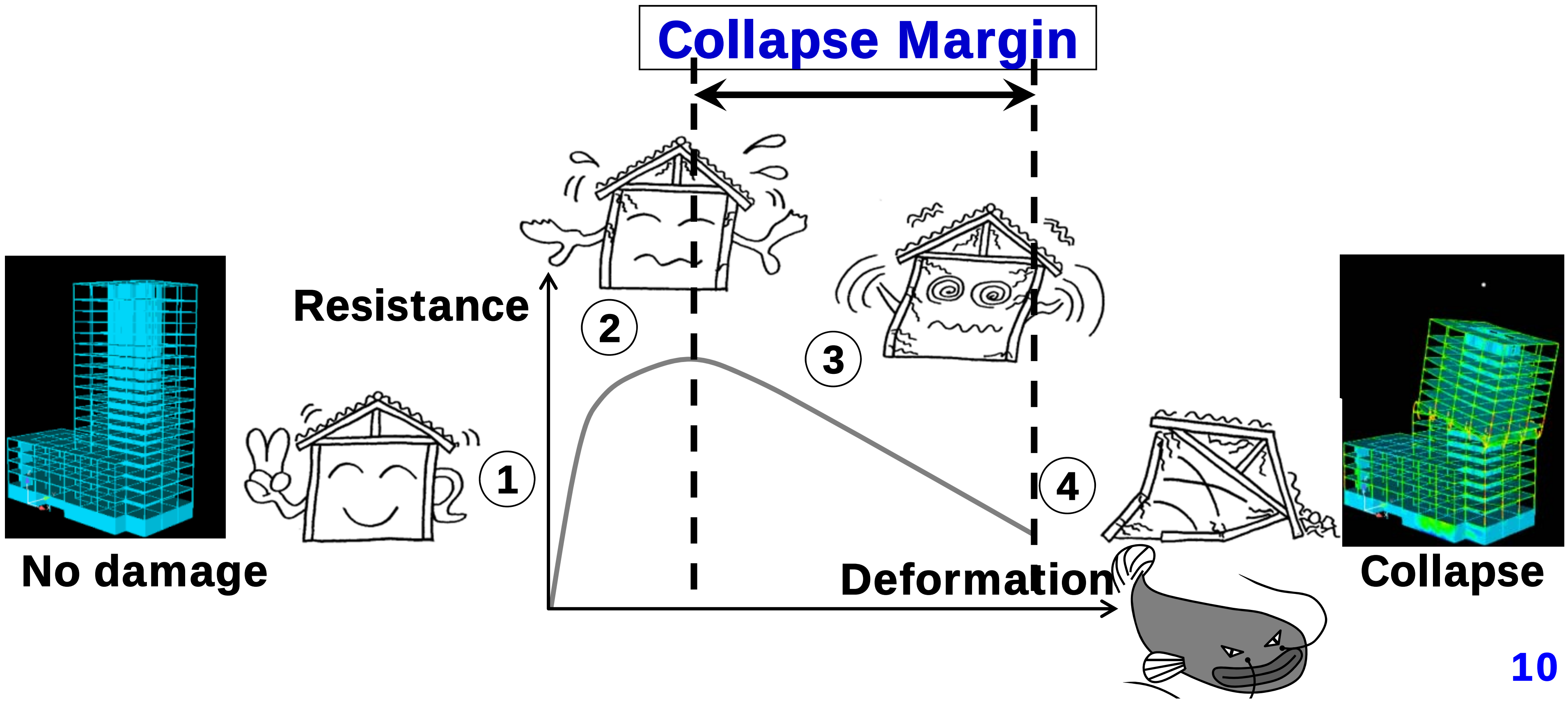
- After 2011 Tohoku, the term "**Resiliency**" is sensed more realistic. Here, I define "resilient" as ability to recover to its normal condition as quickly as possible. We need to develop technologies to promote prompt recovery.



Engineering Research Need Associated with Resiliency

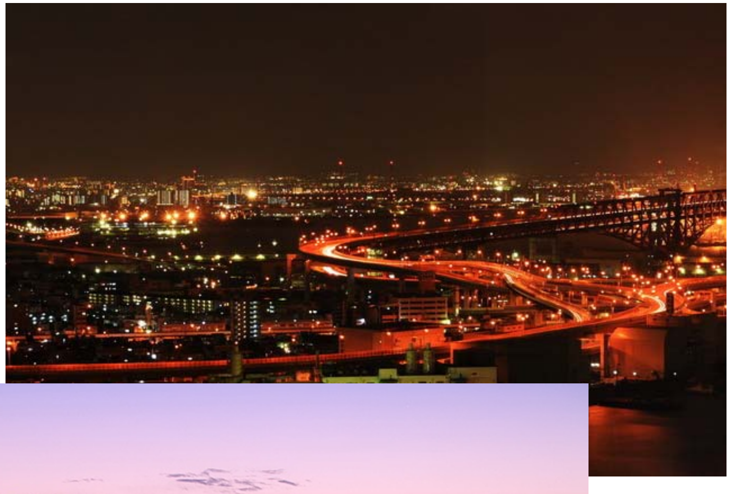
(1) Quantification of Collapse Margin: To make our society more resilient, we shall quantify the performance of each structure up to complete.

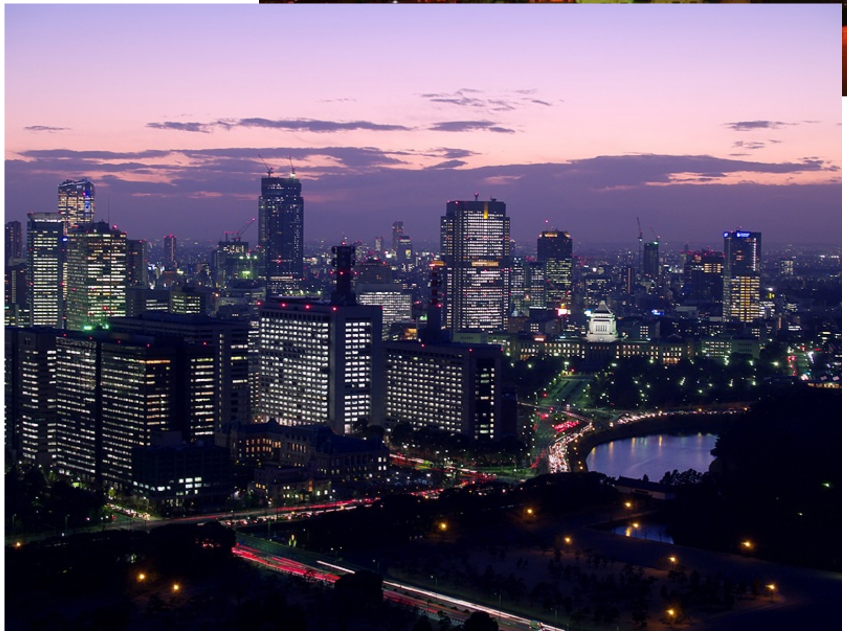
(2) Technologies for Enhanced Health Monitoring:



Rapidly Grown Megacities

Never ceasing urban society, characterized by "high performance", "density", and "globalization.

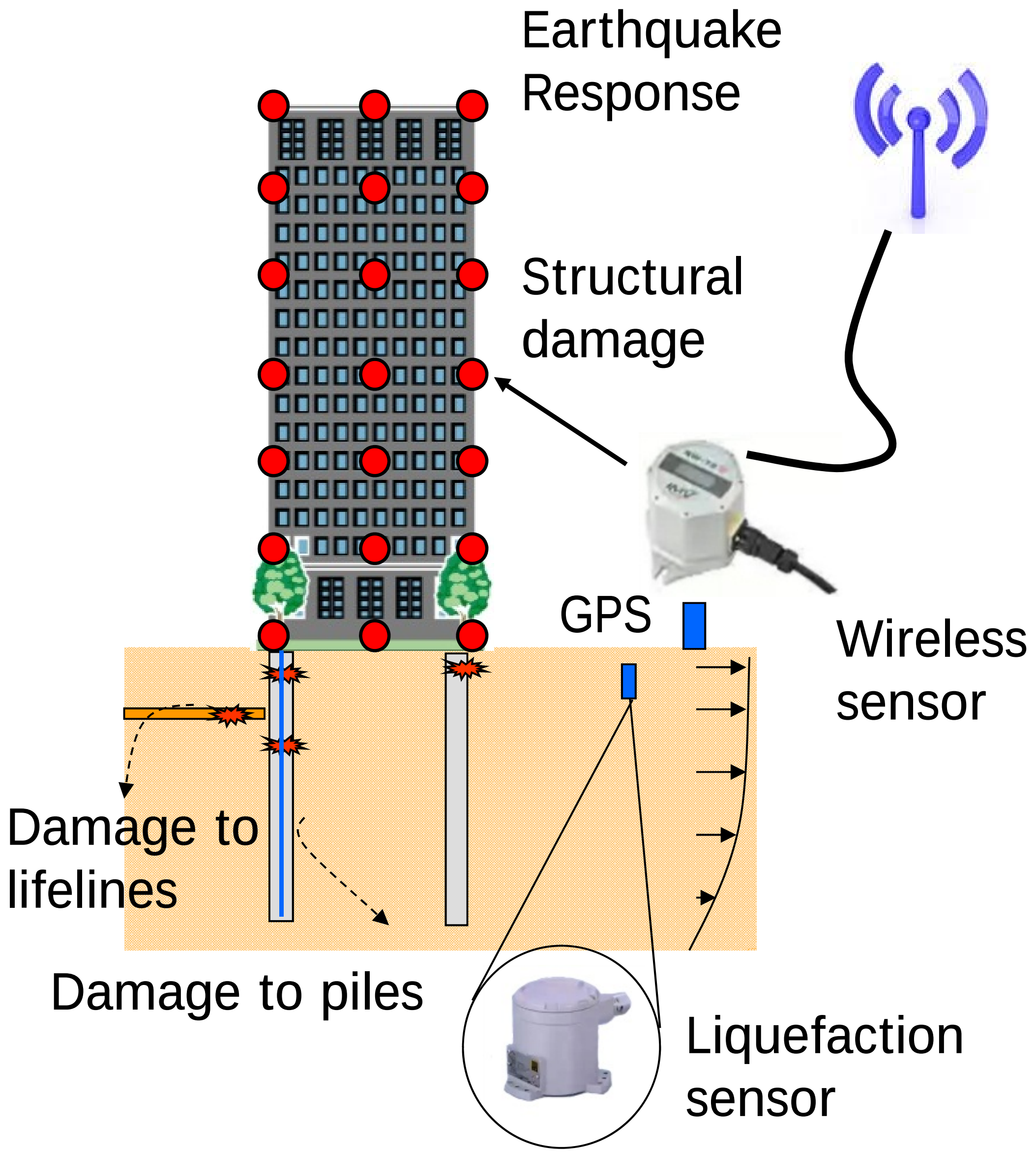




For continuation in life and business, "prompt response" immediately after the quake, i.e., "quick inspection" and "quick decision" is desperately needed.

Engineering Research Need Associated with Resiliency

(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.**



Engineering Research Need Associated with Resiliency

(1) Quantification of Collapse Margin:
(2) Technologies for Enhanced Health Monitoring:

Research and Development

How to verify technologies developed in reply to above needs?

Any technologies and/or developments need be checked for their effectiveness and limitations before actual implementation.

Progress of R&D
based on “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

Changes in Life and Society

Attitude toward "learning from actual damage," seems to make sense, because civil / building engineering traditionally places much emphasis on "experiences" compared to other engineering disciplines

BUT --- Our society has changed significantly for recent decades. We have to deal with urbanized cities like below. "Life safety", of course, but "quality of life" and "security of life" become very important.

Change from “Learning from actual earthquake damage” to “learning from pseudo-actual earthquake damage”

Shall this approach be successful, we would be able to predict our current problems, take action to solve or resolve them, and prepare for the future, all achieved before a real big one would hit us.

A Solution

How are we able to produce pseudo-actual damage? – "very large-scale (or realistic-scale) tests," "tests using actual ground motions," and "tests on entire structure (rather than members and elements)" is a solution.

The tool on the right may be used to this end.