Brief review of building damage by the 2011 Tohoku Japan earthquake and following coping activities

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BRI : Building Research Institute
NILIM : National Institute for Land & Infrastructure Management

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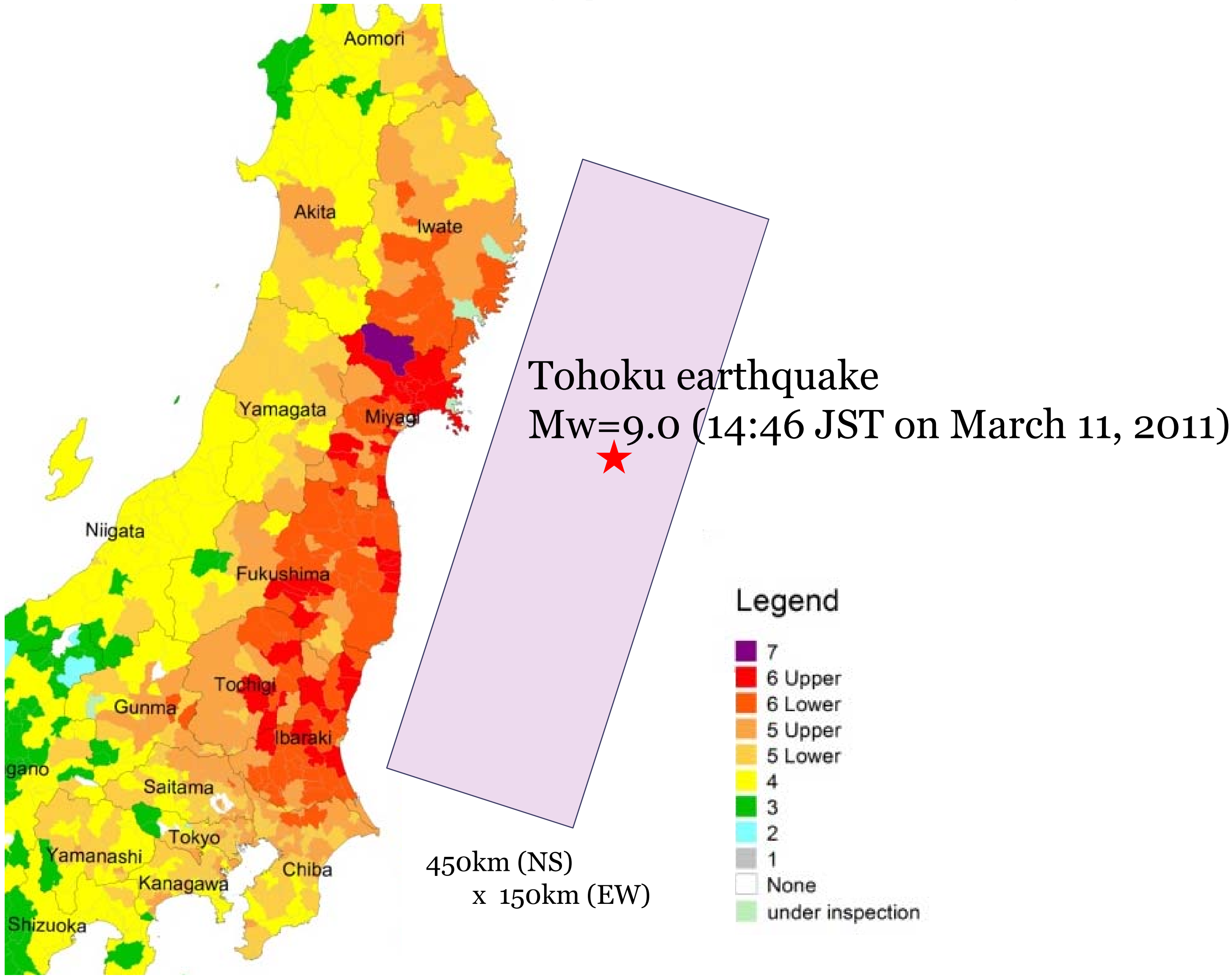
1. Introduction

JMA Seismic Intensity & Hypocentral Region

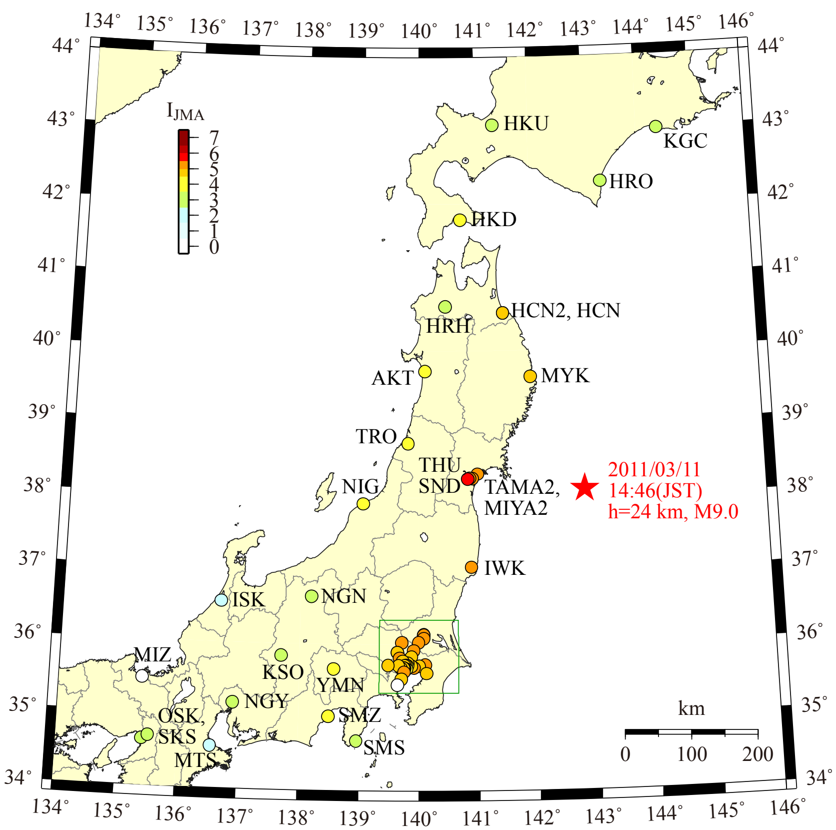


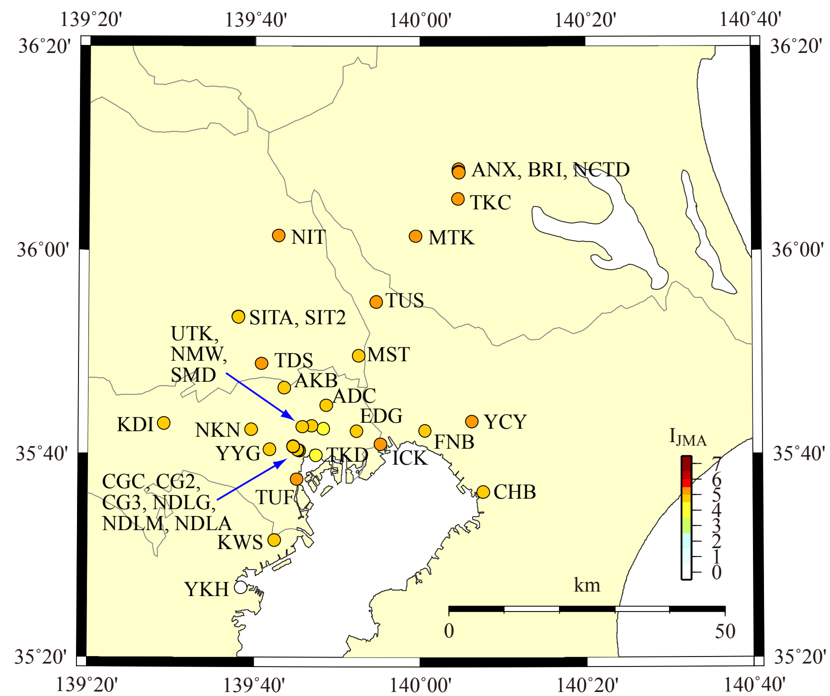
Building and Residential Land Damage by Earthquake Motion and Tsunami

- *BRI and NILIM sent 43 teams for field survey and the following reports are available as of December 2, 2012*
  - http://www.kenken.go.jp/japanese/contents/publications/data/132/index.html
  - http://www.kenken.go.jp/japanese/contents/publications/data/135/index.html
  - http://www.kenken.go.jp/japanese/contents/topics/20110311/0311report.html
  - http://www.kenken.go.jp/japanese/contents/publications/data/138/index.html
  - http://www.kenken.go.jp/english/contents/topics/20110311/0311summaryreport.html

2. Recorded Ground and Building Motions

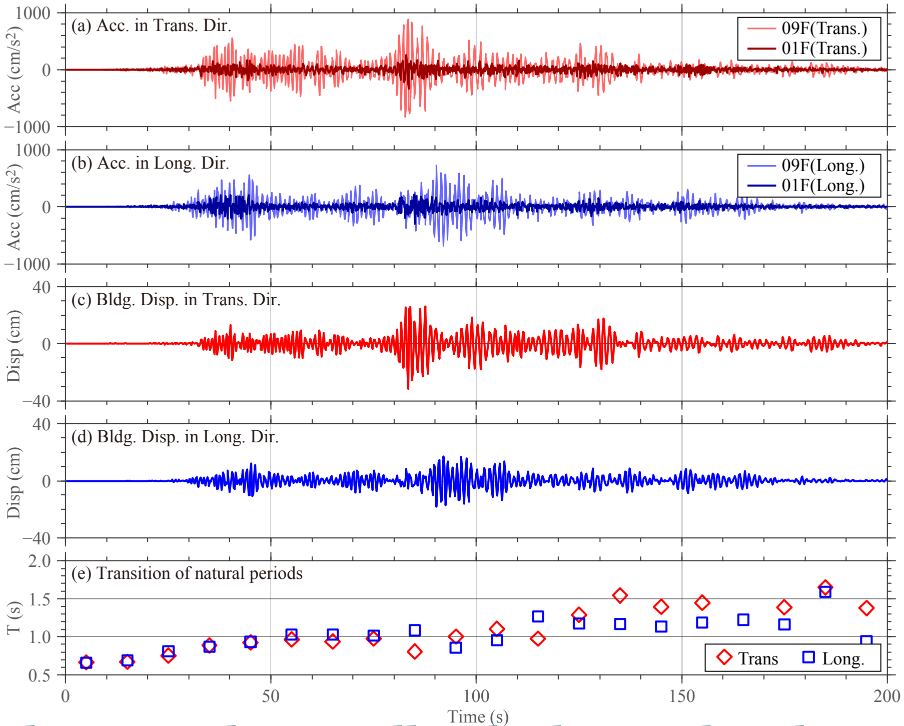
BRI Strong Motion Network





In 1957, BRI started strong motion network.

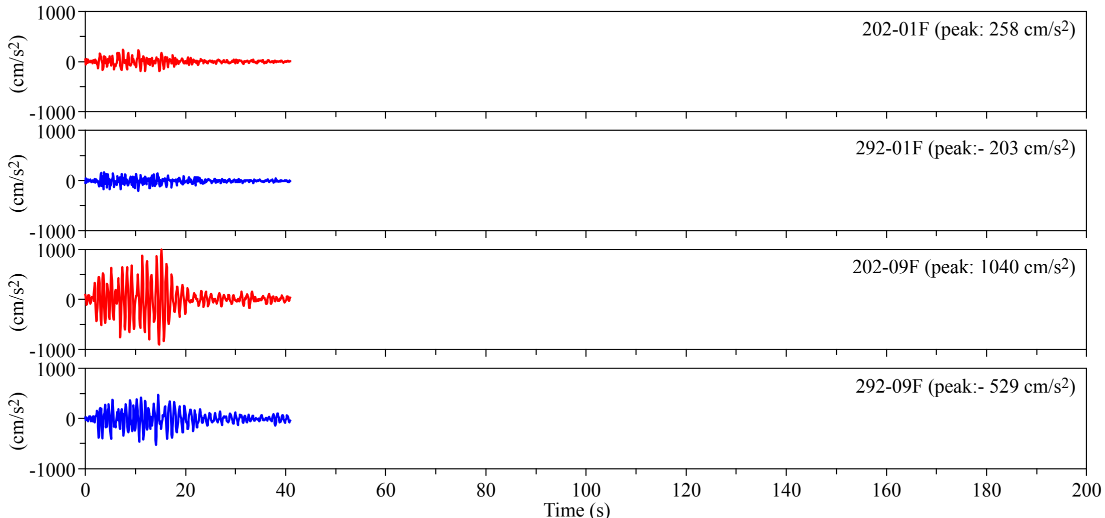
Damaged Building in Sendai city



Flexural failure of multi-story shear walls which can absorb large earthquake energy was observed. Though the building could secure human lives by preventing its collapse as demand of seismic codes, buckling and/or rupture of steel bars and steel plates in the columns and compressive crashing of concrete were observed. Finally, the building was demolished.

Damaged Building in Sendai city (cont.)

- 1978



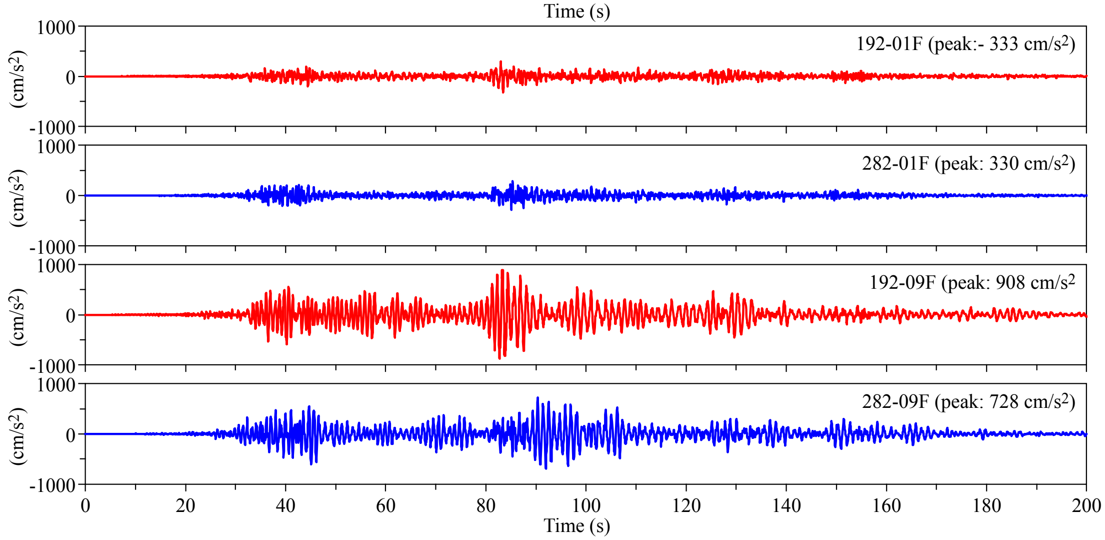
1F(NS) 258 cm/s^2

1F(EW) 203 cm/s^2

9F(NS) 1040 cm/s^2

9F(EW) 529 cm/s^2

- 2011



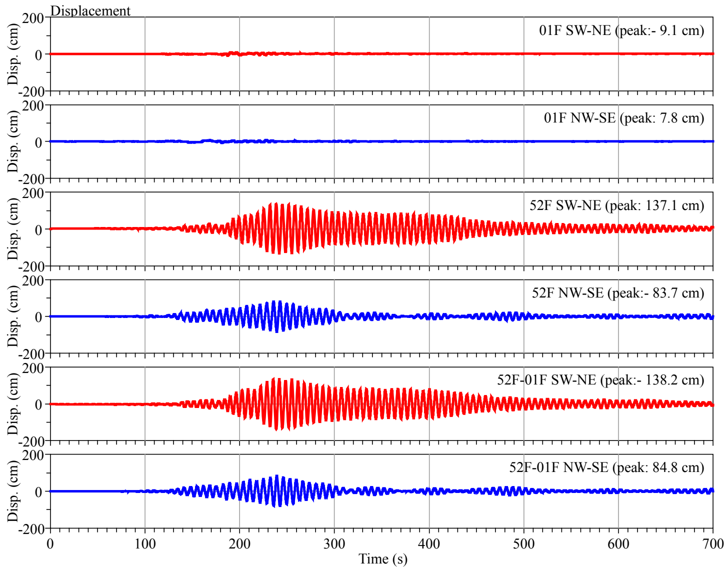
1F(NS) 333 cm/s^2

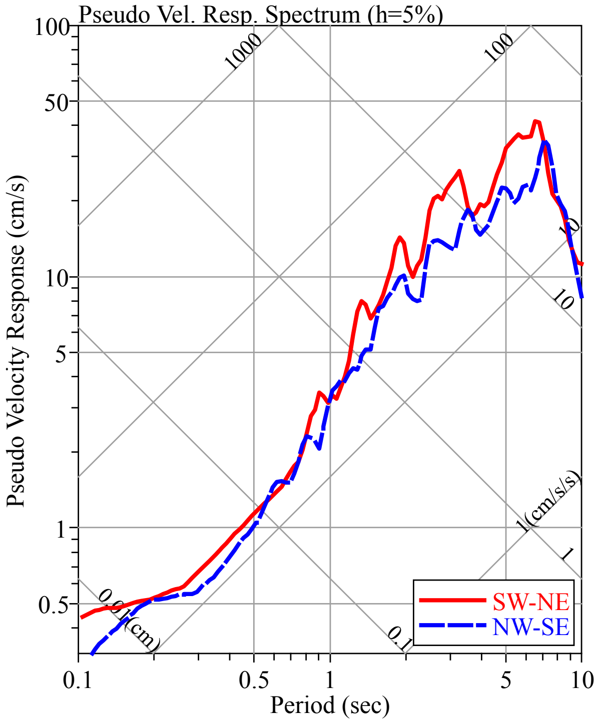
1F(EW) 330 cm/s^2

9F(NS) 908 cm/s^2

9F(EW) 728 cm/s^2

52+3 story building in Osaka city

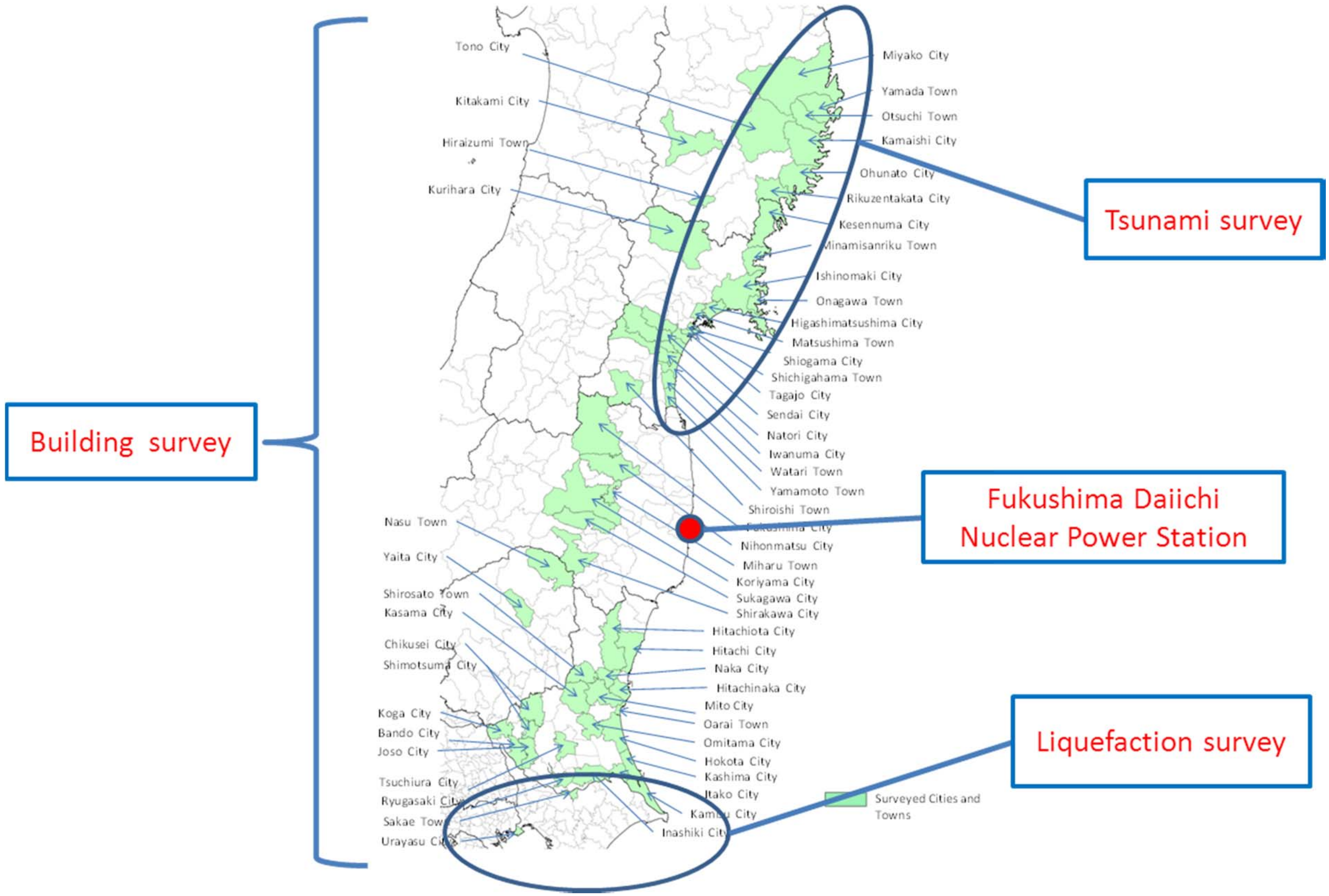




- *The large responses lasted at least 10 minutes in the building in Osaka, 770km from the epicenter. A 137cm maximum displacement occurred on the top floor.*
- *Many non-structural interior members such as ceilings, walls, fire doors, sprinklers, etc. were damaged, and even confinements of passengers in elevators occurred.*

3. Building and Residential Land Damage

Field surveyed area by BRI and NILIM teams



Earthquake Motion Damage





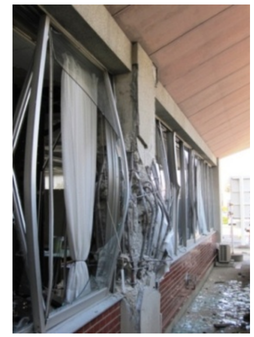




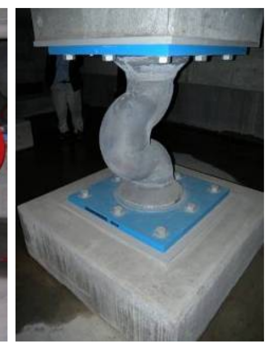

Courtesy to the Japan MLIT

Earthquake Motion Damage (cont.)









Tsunami Damage



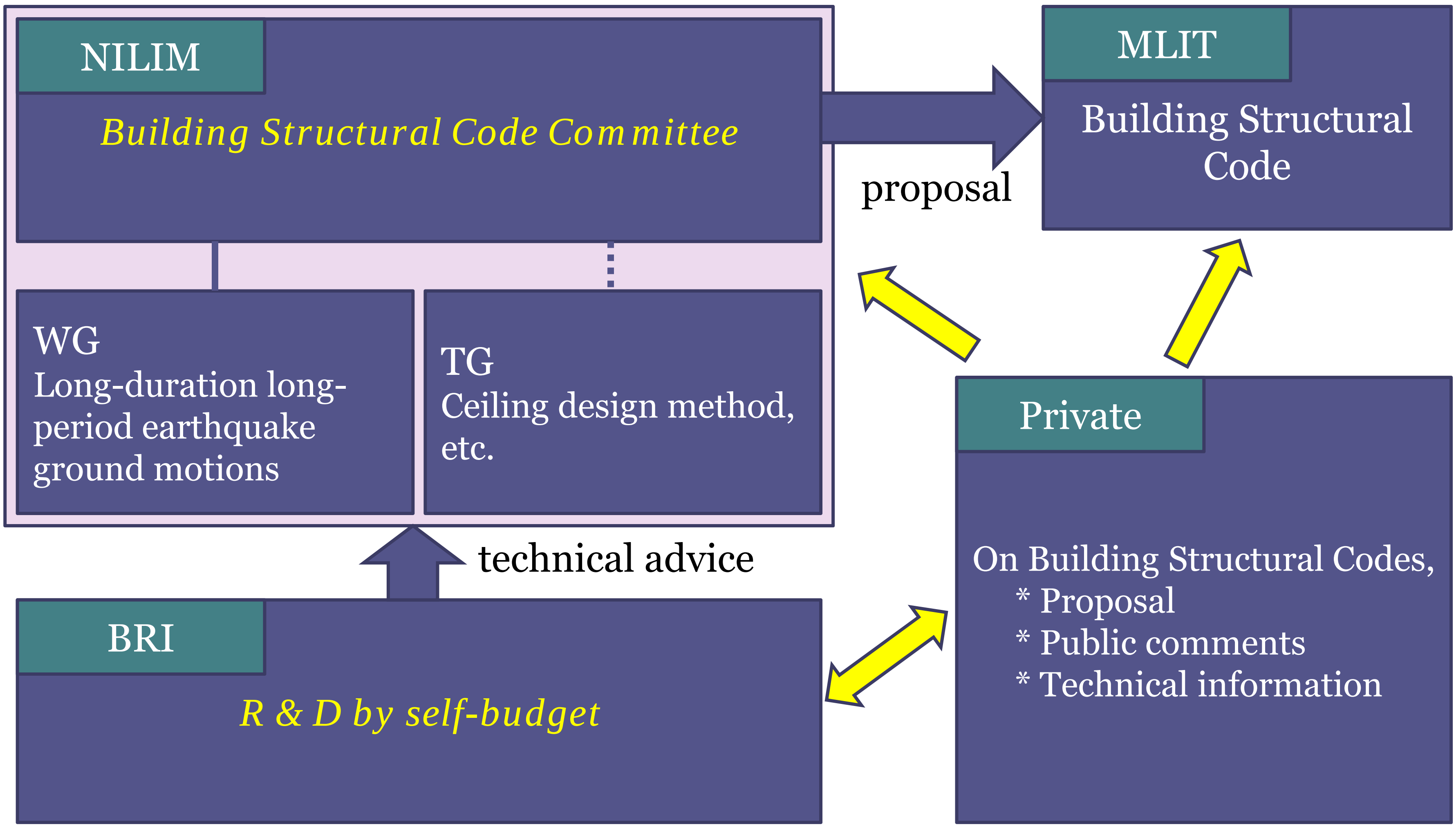







4. Coping Activities on Selected Issues

System to Revise Building Structural Codes



1. *Digital data by BRI strong motion network*
2. *Long-duration and long-period ground motion, structural performance under multiple cycles of loadings*
3. *Higher level of PBD, functional after earthquake*
4. *Fall down of ceilings in spatial structures and escalators in shopping centers*
5. *Fractured lead damper in seismically isolated buildings*
6. *Inclination due to liquefaction in residential houses*
7. *Evaluation of tsunami force*
8. *etc.*

Long-duration and long-period ground motion prediction method based on observation at about 1600 stations

ORIGINAL EVALUATION MODEL

MLIT PROPOSAL FOR DESIGN MOTION
CALL FOR PUBLIC COMMENTS, 2010

2011.3.11 Tohoku EQ.

Revision of the model

Long-duration and long-period motion properties
- Spectral amplitudes from large earthquakes
- Duration of motions with each frequency band

(additional factors)

- **earthquake magnitude**
- **distance**
- **site specific coefficients**

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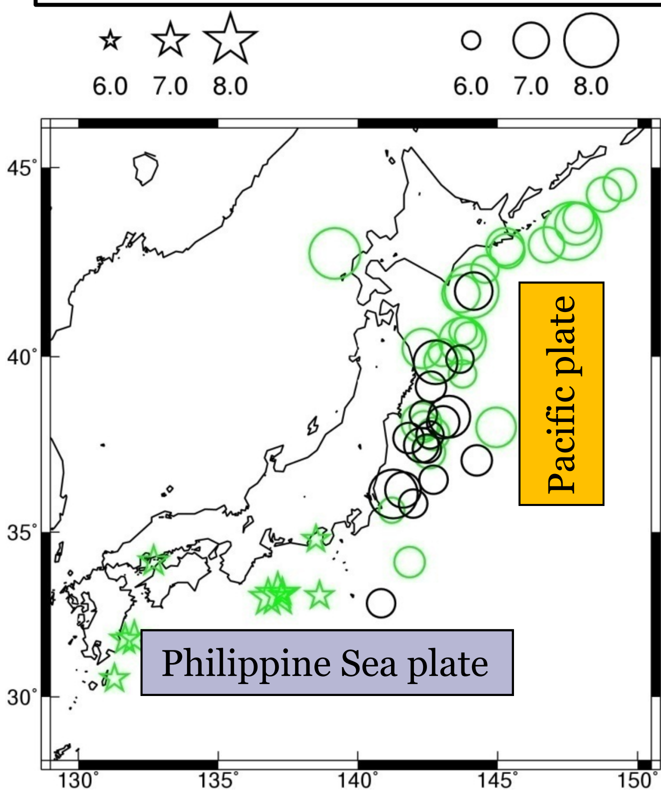
- **Epicenters**
- **Paths**

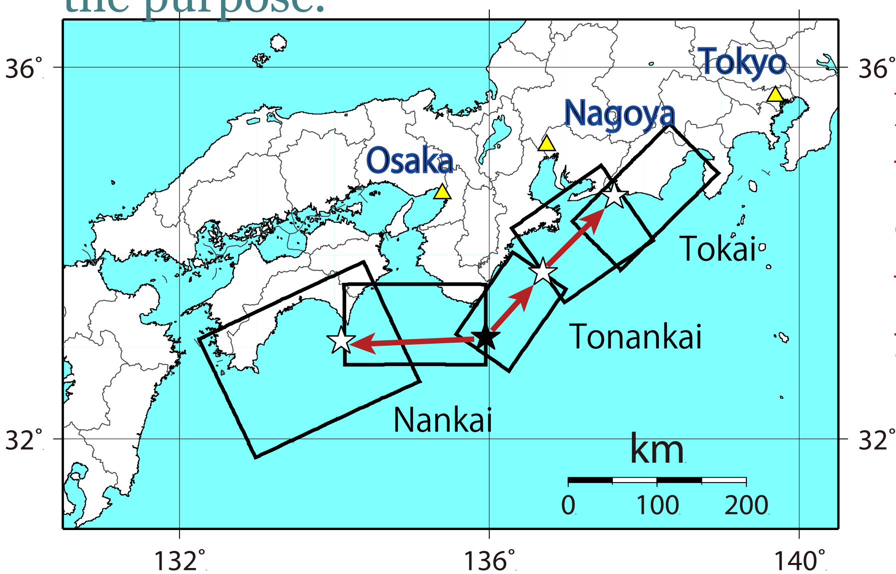
Revised evaluation method



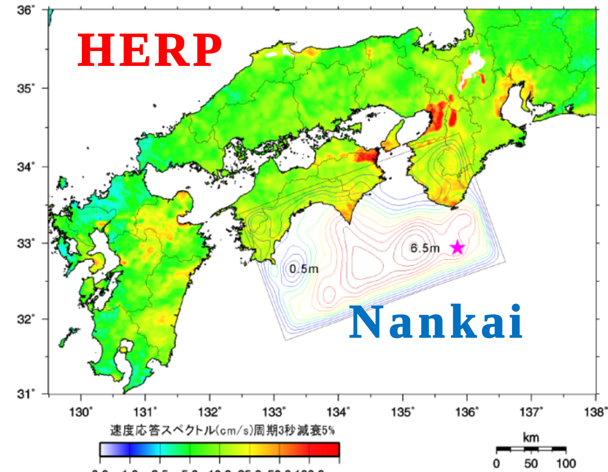
Earthquakes used in the analyses

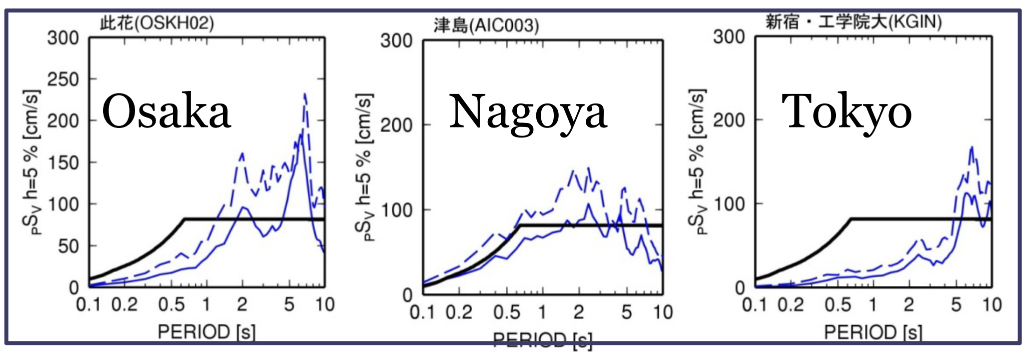
Long-duration and long-period ground motion prediction method based on observation at about 1600 stations (cont.)

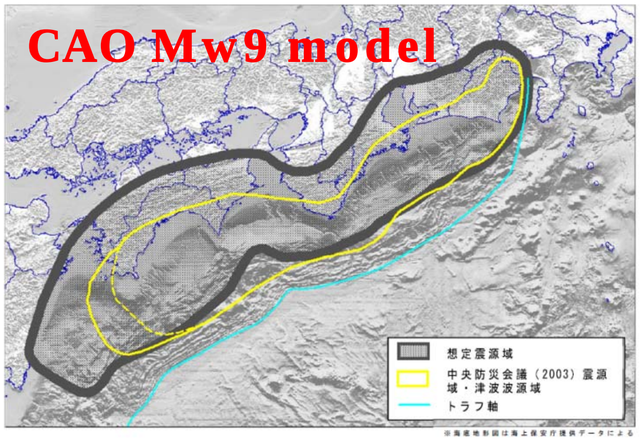
Long-duration and long-period motions were evaluated for major urban areas with two-, three- connected earthquakes, by HERP, CAO, AIJ, etc. MLIT is going to propose a design long-duration and long-period motions and is funding project for the purpose.



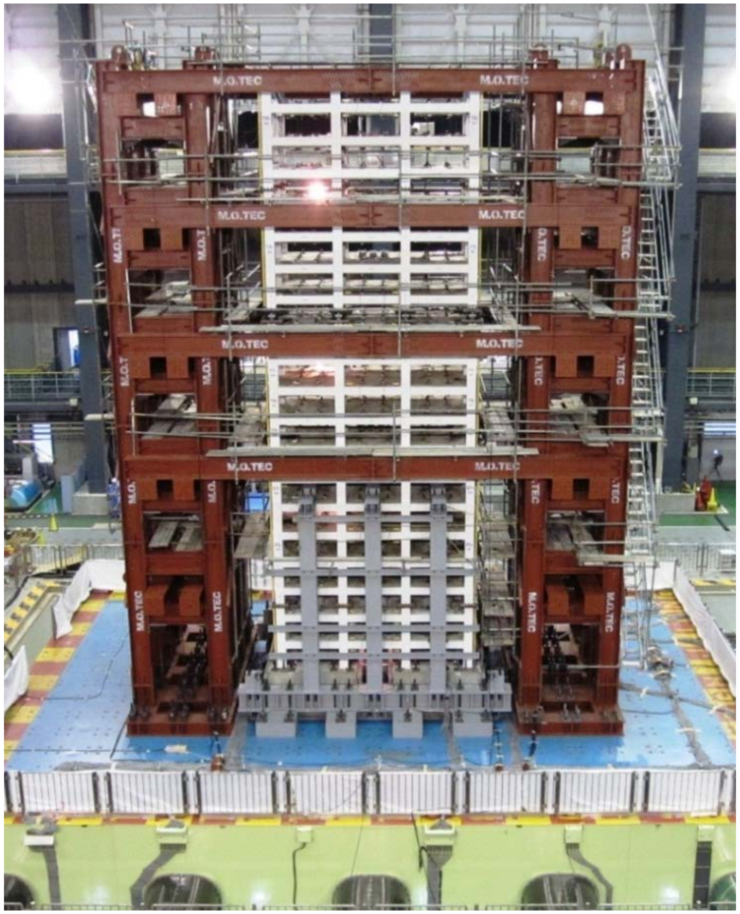
Nankai-trough three-connected earthquake model with revised model for major areas

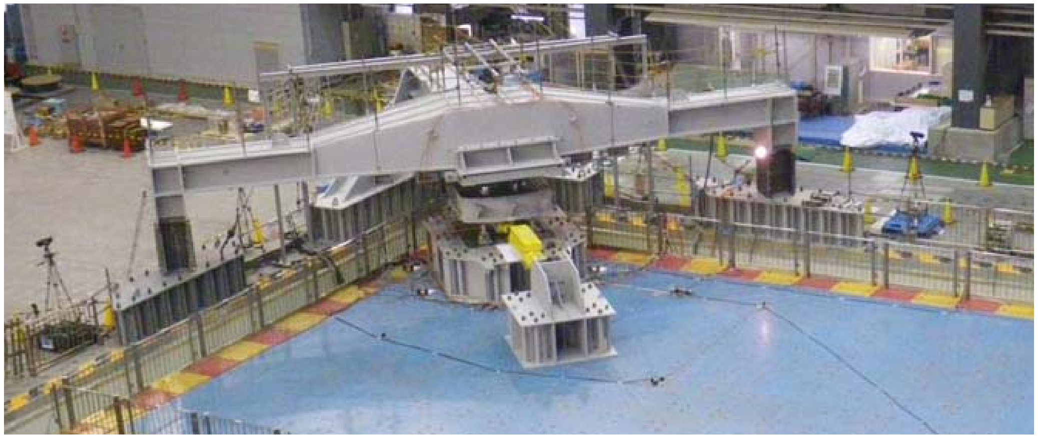






Structural performance against long-duration and long-period ground motions (full-scale)

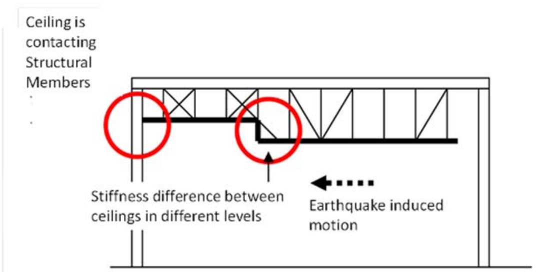




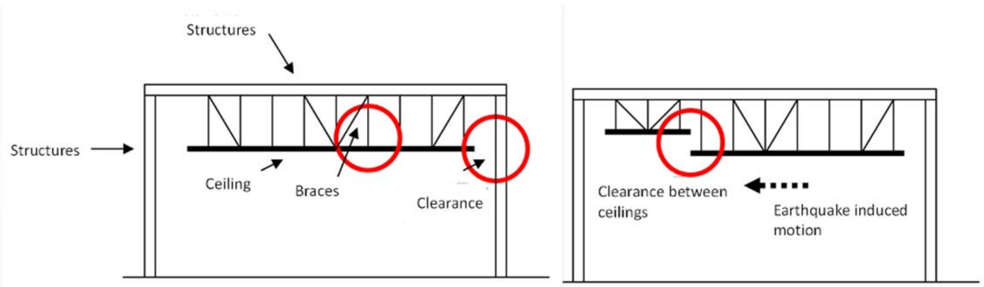
These large-size experiments are carried out under the research cooperation between the BRI and the institutions headed by Obayashi, Kajima and Taisei Co.

Fall down of ceilings in spatial structures

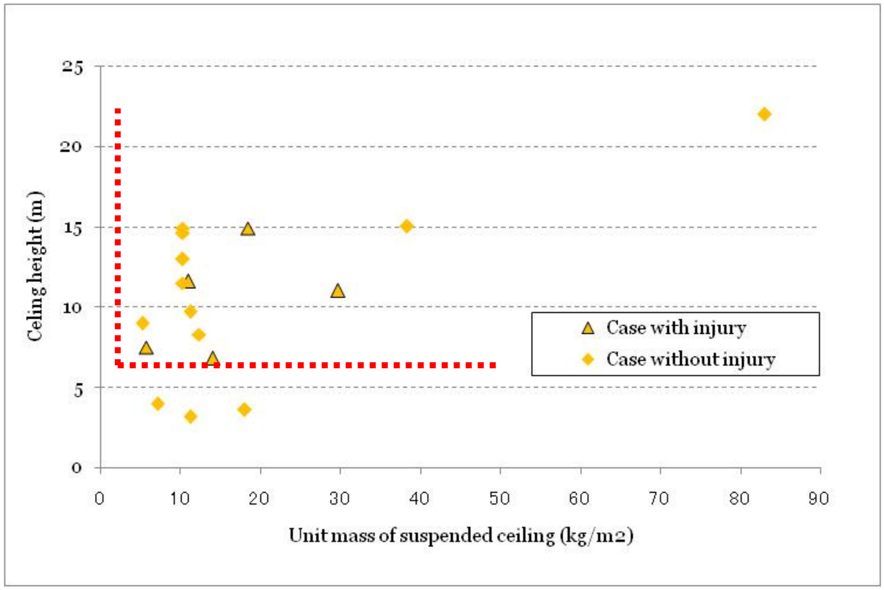
- *After Geiyo earthquake (2001), a technical advice was issued to recommend putting diagonal braces on ceiling rods, and keep clearance around suspended ceiling. (see left figure)*
- *Construction companies reported nearly 2,000 cases of fall down of ceilings during Tohoku earthquake. Examples with/without injury are compared. (see right figure)*



Frequently observed damage by earthquake



Recommended method in an MLIT technical advice



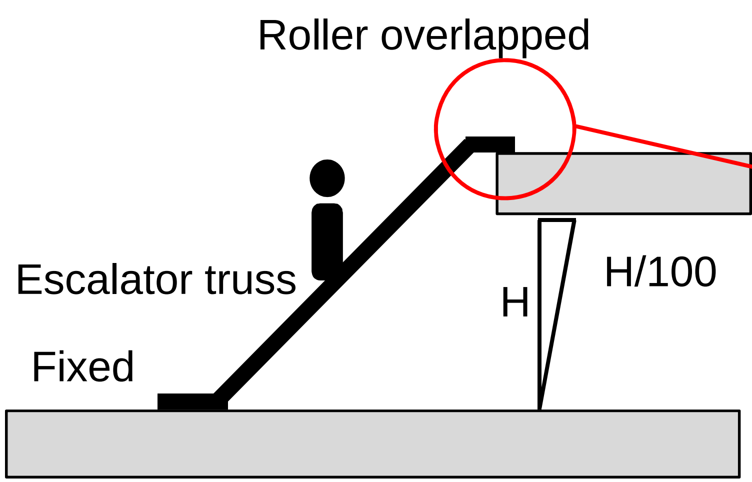
Mass and height of ceiling damaged by earthquake

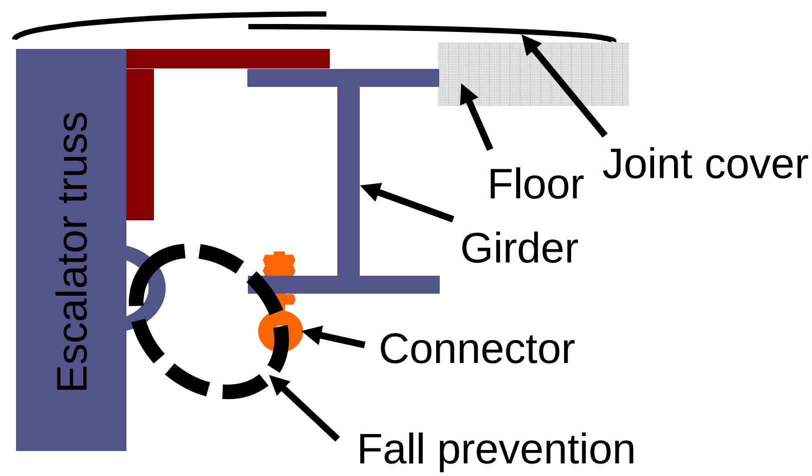
Fall down of ceilings in spatial structures (cont.)

- *(Tentative) Allowable Stress Design for probable earthquake + safety margin*
  - Scope of regulation
    - Ceiling height > 6m
    - Ceiling area > $200m^2$
    - Unit weight of ceiling > $2kg/m^2$
  - Safety margin
    - Vertical strength
    - Clearance around ceiling

Fall down of escalators in shopping centers

- *(Tentative) Requirement from H/100 (current) to H/40*
- *(Tentative) Exceptional relaxation to H/100 in case of fall prevention device*

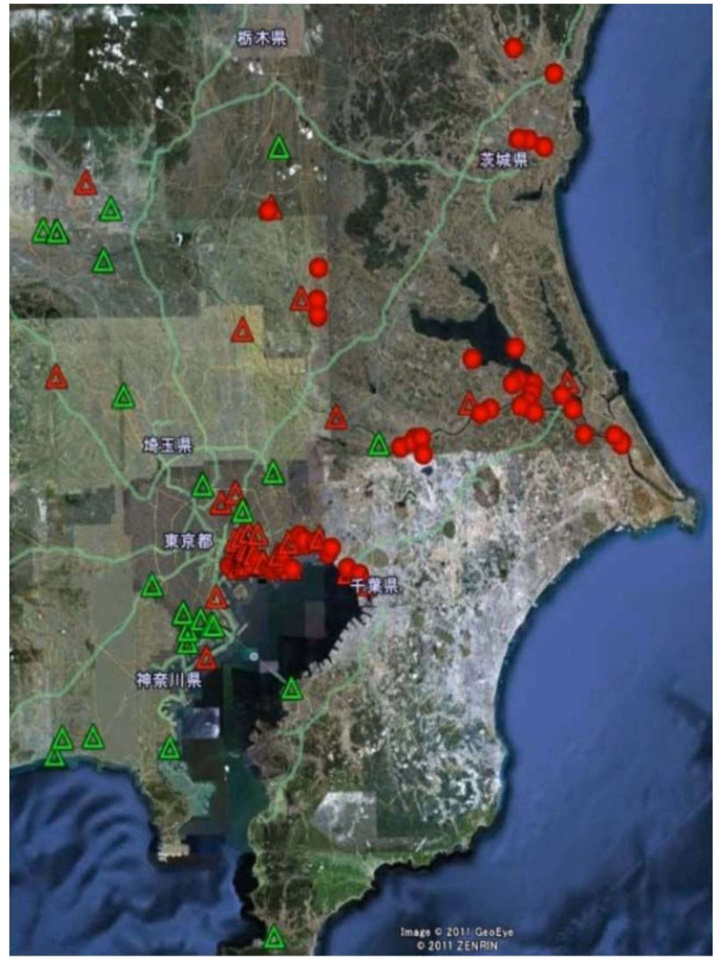




Liquefaction

- *Liquefaction evaluation was made by F_L-method at 112 sites in Kanto area, the results were compared with observations.*
- *Liquefied sites (●) are all predicted ($F_L \leqq 1$) but many non-liquefied sites are cautioned (△).*
- *Improvement of evaluation accuracy is in need.*

- *F_L-method requires following information.*
  - N-value by standard penetration test (SPT)
  - fine fraction content
  - water level
  - maximum design horizontal acceleration at surface
  - earthquake magnitude



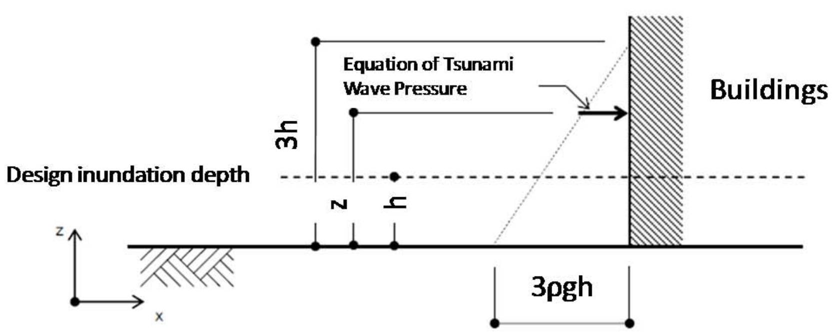
	Liquefied sites	Non-liquefied sites
$F_L \leqq 1$	53 ●	35 △
$F_L > 1$	0 ●	24 △

Liquefaction (cont.)

- *Japan's Building Standard Law does not require structural calculation for detached residence (residential land)*
  - Liquefaction risk is not evaluated
  - Liquefaction measures are not required
- *Show menus and leave selection to owners*
  - Development of affordable liquefaction evaluation method for residential land
    - BRI tries possibility of SWS (Swedish weight sounding test), plus water level and soil judgment
  - Development of practical techniques for residential land
    - Applicability to existing house
    - Prediction of subsidence

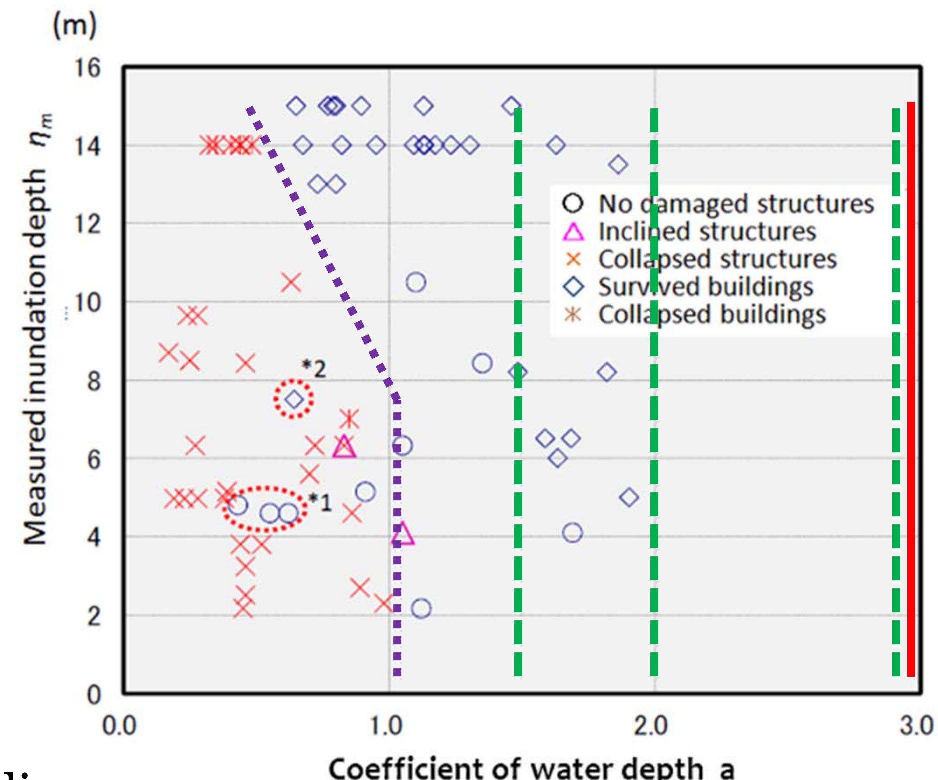
Tsunami wave force

- Tentative guidelines for tsunami evacuation buildings -



Equation of Tsunami Wave Pressure: $q_x = \rho\, g\,(3h - z)$

q_x: design tsunami wave pressure (kN/m^2)
ρ: density of water (t/m^3)
g: gravitational acceleration (m/s^2)
h: design inundation depth (m)
z: height from the ground ($0 \leqq z \leqq 3h$) (m)



Previous guidelines

Partially relaxed current guidelines (tentative guidelines)

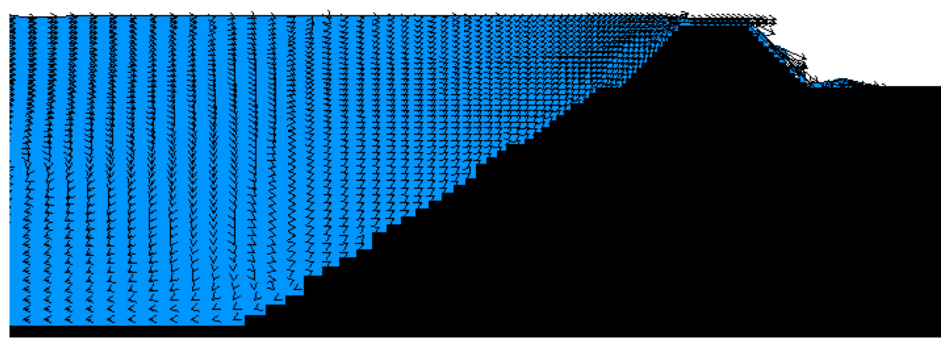
Observed results by Tohoku Japan earthquake

Tsunami wave force (cont.)

- Tentative guidelines for tsunami evacuation buildings -

- *BRI, Kajima Co. and U. of Tokyo have carried out waterway experiments in order to develop (improve) CFD (Computational Fluid Dynamics) technique for evaluation of tsunami pressure on buildings.*
- *Improved CFD technique will be applied to evaluate the effects of openings, water infiltration, etc.*
- *AIJ discusses adding new chapter of tsunami loads on buildings into "(Revised) Recommendations for Loads on Buildings" in 2014.*

Waterway experiment



Numerical simulation of Tsunami over seawall

Thank you for your kind attention.