The Current State of Seismic Resistant Buildings in Japan

June 15th, 2014

Building Research Institute, Japan

Matsutaro SEKI

SEKI, 5CNIS&1CNISS, June, 2014, Bucharest
Disaster Risk in the World

Disaster Risk in Japan is highest in the World: Tokyo, Osaka
Recent Big Earthquakes higher than M.8 in the World (2010)

- 1960 Chile Earthquake Mw9.5
- 1964 Alaska earthquake Mw9.2
- 2004 Sumatra Oki Earthquake Mw9.0
- 2005 Nias Island Earthquake Mw8.6
- 2007 Bengle Earthquake Mw8.5
- 2008 Wenchuan Earthquake Mw7.9
- 2010 Chile Central Earthquake Mw8.8
- 2011 Tohoku Earthquake Mw9.0

ERI, Univ. of Tokyo

SEKI, 5CNIS&1CNISS, June, 2014, Bucharest
Casualties by Earthquakes in the World
(1990-2008.8)

Countries with more than 10000 dead
(without Tsunami Damage)

Source: 岡田義光編「自然災害の事典」ほか

Nakano (IIS, U-Tokyo)

SEKI, 5CNIS&1CNISS, June, 2014, Bucharest
Recent Big Earthquakes in Japan

(1900-2011: higher than M.7)

2011.3.11 Tohoku Earth. (M9.0)

1995 Hyogoken Nanbu Earth. (M7.3)

1923 Kanto Earth. (M7.9)

1944 Tonankai Earth. (M7.9)

1946 Nankai Earth. (M8.0)

SEKI, 5CNIS&1CNISS, June, 2014, Bucharest
Earthquake Prediction and Early Warning System

DONET (Dense Oceanfloor Network System for Earthquakes and Tsunamis)
By JAMSTEC (Japan Agency for Marine Earth Science and Technology), Jan. 2013

http://www.jamstec.go.jp/j/about/press_release/20101213_2/

SEKI, 5CNIS&1CNISS, June, 2014, Bucharest
Earthquake Prediction and Early Warning System

Earthquake Observation in Japan

Seismic intensity
(Japan Meteorological Agency + Others)
Total: 4,200 points

Strong ground motion
(National Research Institute for Earth Science and Disaster Prevention = NIED: K-Net & KIK-Net)
Total: 1,700 points
  K-Net: 1000 points (20 km distance)
  KIK-Net: 700 points

SEKI, 5CNIS & 1CNISS, June, 2014, Bucharest
Earthquake Prediction and Early Warning System

Instrumental seismic intensity records

Japan Meteorological Agency + Others

Total: 4200 points

Immediately disclosing records for public by TV, Radio, etc.

http://www.jmbsc.or.jp/index.htm

SEKI, 5CNIS&1CNISS, June, 2014, Bucharest
Earthquake Prediction and Early Warning System

Japan Meteorological Agency - started in Feb. 2004

Records are gathered at JMA and Transferred immediately to related organizations

http://ja.wikipedia.org/wiki

SEKI, 5CNIS&1CNISS, June, 2014, Bucharest
Earthquake Prediction and Early Warning System

An Application: Controlling emergency stop for trains while running

http://www.mlit.go.jp/sogoseisaku/bousai/sokuhou/siryou3_1.pdf#search='地震速報警報システム'

SEKI, 5CNIS&1CNISS, June, 2014, Bucharest
Earthquake Resistant Design for New Buildings

Required Horizontal Strength in New Seismic code (First Step)

1977: Draft of New Seismic Code

Characteristics

- Required strength is calculated by linear response spectrum.
- Required horizontal strength can be reduced based on the ductility of structure

SEKI, 5CNIS&1CNISS, June, 2014, Bucharest
Earthquake Resistant Design for New Buildings

Development of Performance Design has started. (Second Step)

1. 1981 seismic code is available: Small modification
2. Limit Strength Calculation (Performance design)
3. Nonlinear time history response analysis: High rise building more than 60 m, seismic isolation building
4. Others: Energy method

SEKI, 5CNIS&1CNISS, June, 2014, Bucharest
Earthquake Resistant Design for New Buildings

What is Limit Strength Calculation (Performance design)?

1) Structural designer defines “Damage Limit” and “Safety Limit”

2) Soil amplification should be considered from seismic bedrock to soil surface

3) Response quantity will be calculated using effective stiffness and effective damping.

SEKI, 5CNIS&1CNISS, June, 2014, Bucharest
Earthquake Resistant Design for New Buildings
Limit Strength Calculation

Required Performance Curve
Seismic capacity curve

Strength, Earthquake Force

Disp., Period

Safety Limit

SEKI, 5CNIS&1CNISS, June, 2014, Bucharest
Earthquake Resistant Design for New Buildings

Cover areas of “Functional Resilience” in the lateral force-deflection relationship

Fukuyama (BRI)

SEKI, 5CNIS&1CNISS, June, 2014, Bucharest
Earthquake Resistant Design for New Buildings

Concept of Business Continuity Plan

Fukuyama (BRI)

SEKI, 5CNIS&1CNISS, June, 2014, Bucharest
Seismic Evaluation and Strengthening

Lessons from Hyogoken Nanbu Earthquake, 1995

Construction year and damage degree

Before 1980

After 1981

SEKI, 5CNIS&1CNISS, June, 2014, Bucharest
Seismic Evaluation and Strengthening

Achievement for Earthquake Resistant Conversion in 2013

Seismic Proof Ratio (%)

2015: Target Year

Disaster Prevention Facilities: 70%
Medical Facilities: 76%
Educational Facilities: 84%

SEKI, 5CNIS&1CNISS, June, 2014, Bucharest
# Seismic Evaluation and Strengthening

## Comparison of Seismic Evaluation Method

<table>
<thead>
<tr>
<th></th>
<th>Response Analysis</th>
<th>Seismic Design</th>
<th>Seismic Evaluation</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Magnitude of Input</strong></td>
<td>○</td>
<td>○</td>
<td>◎</td>
</tr>
<tr>
<td>Ground motion</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Ultimate Strength</strong></td>
<td>○</td>
<td>◎</td>
<td>○</td>
</tr>
<tr>
<td><strong>Ultimate Deflection</strong></td>
<td>◎</td>
<td>○</td>
<td>○</td>
</tr>
</tbody>
</table>

- ◎: Target
- ○: Conditions

---

*SEKI, 5CNIS&1CNISS, June, 2014, Bucharest*
Seismic Evaluation and Strengthening

Seismic Evaluation Method

Seismic capacity of reinforced concrete building is expressed by “Strength Index” and “Ductility Index”

\[ Is = Eo \times S_D \times T \]

- \( Eo \) : Basic Capacity Index
  \[ = C \times \text{(Strength Index)} \times F \times \text{(Ductility Index)} \]
- \( S_D \) : Shape Index
- \( T \) : Age Index

SEKI, 5CNIS&1CNISS, June, 2014, Bucharest
Seismic Evaluation and Strengthening

Basic Capacity Index (E₀ Index)

\[ E₀ \text{ Index} = C \text{ Index} \times F \text{ Index} \]
Seismic Evaluation and Strengthening

Method of Seismic Strengthening

JBDPA Guideline, 2001

SEKI, 5CNIS&1CNISS, June, 2014, Bucharest
Seismic Evaluation and Strengthening
Seismic Index of Damaged Buildings

After: Umemura, Okada, Murakami
1978: Miyagiken Oki Earth.
1978: Izu Oshima kinkai Earth.
1987: Chibaken Toho Oki Earth.

Is = 0.6

2nd Screening method

SEKI, 5CNIS&1CNIS, June, 2014, Bucharest
Seismic Evaluation and Strengthening
Various Strengthening Method

Strength Increase
- Shear Wall
- Outer Frame

Ductility Increase
- Carbon Fiber
- RC Column

Input Earthquake Force Decrease
- Seismic Control
- Seismic Isolation

SEKI, 5CNIS&1CNISS, June, 2014, Bucharest
Seismic Evaluation and Strengthening

Increase of Strength

RC Shear Wall  Steel Plate Shear Wall

SEKI, 5CNIS&1CNISS, June, 2014, Bucharest
Seismic Evaluation and Strengthening

Increase of Ductility

Carbon Fiber Sheet

SEKI, 5CNIS&1CNISS, June, 2014, Bucharest
Seismic Evaluation and Strengthening
Increase of Ductility

Steel Plate

SEKI, 5CNIS&1CNISS, June, 2014, Bucharest
Seismic Evaluation and Strengthening
Increase of Strength

Outer Steel Brace

SEKI, 5CNIS&1CNISS, June, 2014, Bucharest
Seismic Evaluation and Strengthening
Increase of Strength

Outer Steel Buttress Frame

SEKI, 5CNIS&1CNISS, June, 2014, Bucharest
Seismic Evaluation and Strengthening
Increase of Strength

Outer Steel Brace

SEKI, 5CNIS&1CNISS, June, 2014, Bucharest
Seismic Evaluation and Strengthening
Increase of Strength

Steel Panel

SEKI, 5CNIS&1CNISS, June, 2014, Bucharest
Seismic Evaluation and Strengthening

Seismic Proof Verification Test

Hyogo Earthquake Engineering Research Center: E-Defense, NIED

SEKI, 5CNIS&1CNISS, June, 2014, Bucharest
Seismic Evaluation and Strengthening

Seismic Proof Verification Test

Three Story School Building (E-Defense)

Without Strengthening

Steel Brace Strengthening

SEKI, 5CNIS&1CNISS, June, 2014, Bucharest
Seismic Evaluation and Strengthening

Seismic Proof Verification Test

Reinforced Concrete Column Test (Obayashi Corporation)

Shear Failure Column

Strengthened by Carbon Fiber Sheet

SEKI, 5CNIS&1CNISS, June, 2014, Bucharest
Seismic Isolation and Vibration Control

Principle of Seismic Isolation

- Deflection of Isolator
- Induced Force into Building
- Deflection of Building Structure
- Induced Force into Building
- Seismic Isolation Building
- Non Seismic Isolation Building
- Earth. Force

SEKI, 5CNIS&1CNIS, June, 2014, Bucharest
Principle of Seismic Isolation and Vibration Control

Response Acceleration

Response Displacement

SEKI, 5CNIS&1CNISS, June, 2014, Bucharest
Seismic Isolation and Vibration Control

SEKI, 5CNIS&1CNISS, June, 2014, Bucharest
Number of Seismic Isolated Buildings in Japan - Evolution (Total: 7446, in 2011)

SEKI, 5CNIS&1CNISS, June, 2014, Bucharest
Seismic Isolation and Vibration Control

Location of Seismic Isolators

(a) Without Basement

(b) With Basement

(c) Middle floor Isolation

Upper Structure

Isolator

SEKI, 5CNIS&1CNISS, June, 2014, Bucharest
Seismic Isolation and Vibration Control

A Boutique Building in Tokyo

5th JSSI Award, 2004
MENSHIN, NO. 5, 2004.8

http://www.sawadalab.se.shibaura-it.ac.jp/kenken/kenken2005

SEKI, 5CNIS&1CNISS, June, 2014, Bucharest
Seismic Isolation and Vibration Control

A Boutique Building in Tokyo

SEKI, 5CNIS&1CNISS, June, 2014, Bucharest
Seismic Isolation and Vibration Control

Tokyo Bay Area

High Rise Residential Building (2014. August)

http://kenplatz.nikkeibp.co.jp/article/building/news/20130911/631735/?P=1

SEKI, 5CNIS&1CNISS, June, 2014, Bucharest
Seismic Isolation and Vibration Control

B2F, 44F  H=250m

Isolators: 84
Natural Rubber Bearings: 21
Lead Plug Rubber Bearings: 63

Dampers: 204
Low strength Steel Damper (LY225)
Installed between Boundary Beams

Isolation Story: B2F

http://kenplatz.nikkeibp.co.jp/article/building/news/20130911/631735/?P=1

SEKI, 5CNIS&1CNISS, June, 2014, Bucharest
Seismic Isolation and Vibration Control

Low Strength Steel Damper between Boundary Beams

Boundary Beam

Steel Damper

SEKI, 5CNIS&1CNISS, June, 2014, Bucharest
Middle Floor Isolation

14F, B2F, Isolation Story: between 9F and 10F
Office(1-9F, S), Residence (10-14F, RC)

http://www.nikken.co.jp/ja/archives/20013.html

SEKI, 5CNIS&1CNISS, June, 2014, Bucharest
Seismic Isolation and Vibration Control
Middle Floor Isolation

Isolation Story
(Isolator + Lead Damper)

http://www.nikken.co.jp/ja/archives/20013.html

SEKI, 5CNIS&1CNISS, June, 2014, Bucharest
Seismic Isolation and Vibration Control

Thousand City, Kawasaki, Japan

A 7 buildings district (with one thousand residential housing units) seismically isolated, Dec. 2002

http://www.taisei-design.jp/de/feature/menshin/gaiku01.html#

SEKI, 5CNIS&1CNISS, June, 2014, Bucharest
Seismic Isolation and Vibration Control
Strengthened by Seismic Isolation

Osaka Central Public Hall (1918)

5th JSSI Award, 2004
MENSHIN, NO.5, 2004.8

SEKI, 5CNIS & 1CNISS, June, 2014, Bucharest
Seismic Isolation and Vibration Control

Seismic Intensity: Tohoku Earthquake, 11th, March, 2011

Fukushima

Tokyo

SEKI, 5CNIS&1CNISS, June, 2014, Bucharest
Seismic Isolation and Vibration Control
Fukushima 1st Nuclear Power Plants

Seismic Isolation
Important Building
July 2010 (Completed)

http://image.search.yahoo.co.jp/search?rkf=2&ei=UTF-

SEKI, 5CNIS&1CNISS, June, 2014, Bucharest
Seismic Isolation and Vibration Control
Fukushima 1st Nuclear Power Plants

Damage of Main Building

Seismic Isolation Building
Used as Rescue Center

http://arinkurin.colog-nifty.com/blog/2013/06/http.html

SEKI, 5CNIS&1CNISS, June, 2014, Bucharest
Seismic Isolation and Vibration Control

Fukushima 1st Nuclear Power Plants

<table>
<thead>
<tr>
<th></th>
<th>F1</th>
<th>NS</th>
<th>EW</th>
<th>UD</th>
</tr>
</thead>
<tbody>
<tr>
<td>BASE</td>
<td>582</td>
<td>756</td>
<td>446</td>
<td></td>
</tr>
<tr>
<td>1FL</td>
<td>176</td>
<td>213</td>
<td>516</td>
<td></td>
</tr>
<tr>
<td>2FL</td>
<td>155</td>
<td>185</td>
<td>621</td>
<td></td>
</tr>
</tbody>
</table>

Acceleration Records at Seismic Isolation Building

http://image.search.yahoo.co.jp/search?rke=2&ei=UTF-8&p

SEKI, 5CNIS&1CNISS, June, 2014, Bucharest
Seismic Isolation and Vibration Control

Rikkyo Univ. Chapel Building, Tokyo

1918 completed, masonry Building, Rehabilitated by Seismic Isolation

Outside view

Inside view

SEKI, 5CNIS&1CNISS, June, 2014, Bucharest
Seismic Isolation and Vibration Control
Rikkyo Univ. Chapel Building

U-Shaped Lead Damper
Natural Rubber Bearing

SEKI, 5CNIS&1CNISS, June, 2014, Bucharest
Seismic Isolation and Vibration Control
Rikkyo Univ. Chapel Building

Earthquake Records (EW direction)

Main Building (2F)
Chapel Building (1F)
Ground

→ Acceleration (cm/s²)

100 200 300 400 500

Negative side
Positive side

SEKI, 5CNIS&1CNISS, June, 2014, Bucharest
Seismic Isolation and Vibration Control
Isolation effectiveness in Strong Earthquakes

Takayama (Fukuoka Univ.)

SEKI, 5CNIS&1CNISS, June, 2014, Bucharest
Number of Buildings with Vibration Control in Japan - Evolution (JSSI, Total: 2984, in 2011)

SEKI, 5CNIS&1CNISS, June, 2014, Bucharest
Principle of Vibration Control

Reduction of Response by dampers which absorb input energy

Traditional Building

Vibration Control Building

(a) Energy Absorption by Structural Members

(b) Energy Absorption by Dampers

SEKI, 5CNIS&1CNISS, June, 2014, Bucharest
Seismic Isolation and Vibration Control
High Rise office Building (Steel St.)

Low Yielding Strength Steel Damper

Takeuchi (Tokyo Institute of Tech.)

SEKI, 5CNIS&1CNISS, June, 2014, Bucharest
Seismic Isolation and Vibration Control

Medium Rise office Building (Steel. St)

Installation of Oil Damper

Outside View

Takeuchi (Tokyo Institute of Tech.)

SEKI, 5CNIS&1CNISS, June, 2014, Bucharest
Seismic Isolation and Vibration Control

30F office Building (Steel St.)

31F Office Building (steel St.)

SEKI, 5CNIS&1CNISS, June, 2014, Bucharest
Seismic Isolation and Vibration Control

Friction Damper: Brace type

SEKI, 5CNIS&1CNISS, June, 2014, Bucharest
Seismic Isolation and Vibration Control

Friction Damper: Column type

SEKI, 5CNIS&1CNISS, June, 2014, Bucharest
Seismic Isolation and Vibration Control

High Rise Residential Building (RC St.)

45F, B1F
H=155.5 m
Residential Building
Passive Control System

SEKI, 5CNIS&1CNISS, June, 2014, Bucharest
Seismic Isolation and Vibration Control

Tall Shear Wall Structure (Parking) : 33F
Area: 72,744 m²
45F, B1F
H=155.5 m
Oil dampers: 25KN s/cm; 80 Pieces

Moment Frame Structure (Residence) : 45F

SEKI, 5CNIS&1CNISS, June, 2014, Bucharest
Seismic Isolation and Vibration Control
Dual Frame Vibration Control System

Oil Damper  Parking Building

Rigid Shear Wall  Residential Building

Moment Frame  Oil Damper

Gap between Parking and Residential Building: 650mm

SEKI, 5CNIS&1CNISS, June, 2014, Bucharest
Near Future Programs in Japan

1. Expected Big Earthquake in Near Future
2. Building Design against Tsunami Force
3. Big Earthquakes having Long Period Components
4. Recovering issues from 11th, May, 2011 Earthquake

SEKI, 5CNIS&1CNISS, June, 2014, Bucharest
Near Future Programs in Japan

Nankai Trough Earthquake
(scenario as of 29 August, 2012, Japanese Government)

(1) Probability of occurrence
   - 20% in 10 years, 60% in 30 years

(2) Estimation of damage
   - Intensity: 7, Height of Tsunami: 34m (Max.)
   - Collapsed and burnt building: 954,000-2,382,000
   - Casualties: 80,000 - 323,000
     (240,000 by Tsunami)

SEKI, 5CNIS&1CNISS, June, 2014, Bucharest
Nankai Trough Earthquake
(Scenario as of 29 August, 2012, Japanese Government)

Intensity of Earthquake
(Japan Metrological Agency)

SEKI, 5CNIS&1CNISS, June, 2014, Bucharest
Nankai Trough Earthquake
(Scenario as of 29 August, 2012, Japanese Government)

Height of Tsunami

10-20 m

SEKI, 5CNIS&1CNISS, June, 2014, Bucharest
Near Future Programs in Japan

Building Design against Tsunami Force

http://www.kenchiku-bosai.or.jp/files/2013/11/12_tsunami01.pdf

SEKI, 5CNIS&1CNISS, June, 2014, Bucharest
Near Future Programs in Japan

Big Earthquakes having Long Period Components (3.11, 2011 Earthquake)

Osaka Fusakishima City Office
55F, B2F  H=256m
800km from epicenter
Fundamental Period (T): 7.0 sec

SEKI, 5CNIS&1CNISS, June, 2014, Bucharest
Near Future Programs in Japan

Big Earthquakes having Long Period Components

SEKI, 5CNIS&1CNISS, June, 2014, Bucharest
Near Future Programs in Japan

Big Earthquakes having Long Period Components

Oil Damper

Steel Damper

http://www.pref.osaka.lg.jp/otemaemachi/sas
eibi/cyosyukitorikumi25.html

SEKI, 5CNIS&1CNISS, June, 2014, Bucharest
Near Future Programs in Japan

Big Earthquakes having Long Period Components

52F Displacement by Earthquake Response Analysis
Before Strengthening; 259 cm → After; 207 cm


SEKI, 5CNIS&1CNISS, June, 2014, Bucharest
Near Future Programs in Japan
Three years after 3.11, 2011 Tohoku Earthquake

March, 2011
March, 2013

Nikkei Newspaper 3.11, 2014
SEKI, 5CNIS&1CNISS, June, 2014, Bucharest
Near Future Programs in Japan

Three years after 3.11, 2011 Tohoku Earthquake

Urban Area

March, 2011
March, 2013

Nikkei Newspaper 3.11, 2014

SEKI, 5CNIS&1CNISS, June, 2014, Bucharest
Near Future Programs in Japan

Three years after 3.11, 2011 Tohoku Earthquake

March, 2013

Nikkei Newspaper 3.11, 2014

SEKI, 5CNIS&1CNISS, June, 2014, Bucharest
Thank you for your attention