COMPARISON OF SEISMIC EVALUATION METHODS OF JAPAN AND CHINA FOR RC BUILDINGS

（日中両国における鉄筋コンクリート造建物の耐震診断法の比較研究）

by

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Then a special thank goes to Mr. Shigenobu KATO, who is a senior in laboratory and also a superior at work, for his kindness that helped me to find the profession I would like to pursue in the future.

I also appreciate the kind friendship from all the members in Maeda Laboratory, especially Dr. Kazuto MATSUKAWA, Mr. Hamood ALWASHALI and my tutor Miss. Kanako TAKAHASHI. They have given me many helpful advices about my research and life in Japan.

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Life is not all roses, but with your friendship, love and affection, I have been able to overcome a lot and will keep moving forward with no regret in the future.

Dandan ZHAO

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Table of Content

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References

Summary

Chapter 1. Introduction

1.1 Background

Both Japan and China are located near to the Pacific Ring of Fire, which is an area where a large number of earthquakes and volcanic eruptions occur in the basin of the Pacific Ocean. About 90% of the world's earthquakes and 81% of the world's largest earthquakes occur along this Ring of Fire.

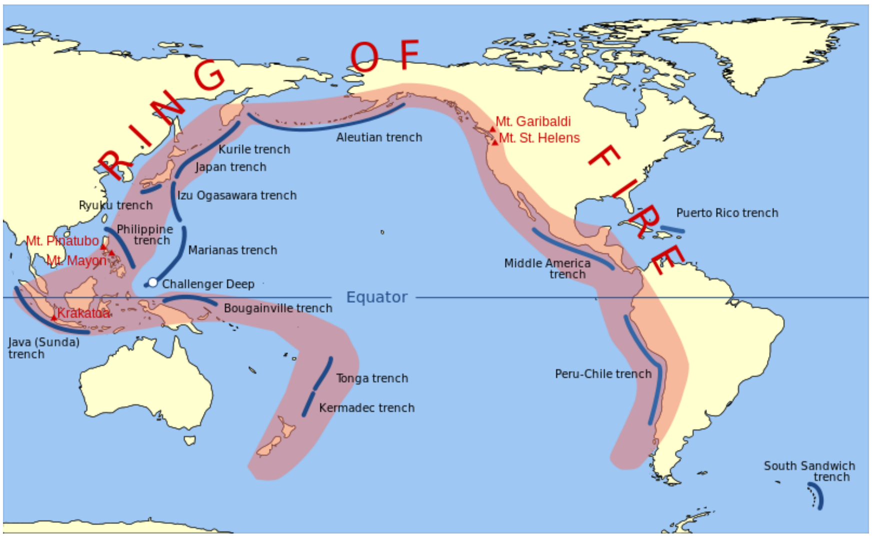


Figure 1-1 Map of the Pacific Ring of Fire

As we can see from the figure below: the frequency of earthquake occurs in Japan and west of China could be identified as "very high", while other parts of China also suffer from earthquakes sometimes.

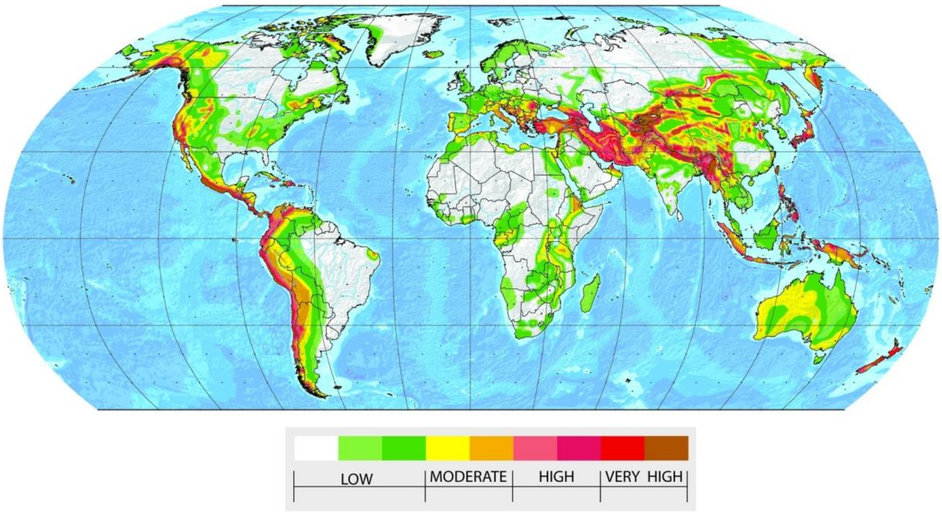


Figure 1-2 Frequency of earthquake occurs in the world

Figure 1-3 Building damaged during 512 and 311 earthquakes

For instance, a magnitude 8.0 (Richter magnitude scale) earthquake occurred in Sichuan province, China on Monday, May 12th 2008. And on Friday, March 11th 2011, the Great East Japan Earthquake occurred in Tohoku, Japan.

According to the report from *Ministry of Civil Affairs (MCA) of the People’s Republic of China*, by the noon of July 2nd 2008, 69,197 people lost their lives and 18,222 people were missing during the earthquake. The number of people injured was up to 374,176 by then.

As to the Great East Japan Earthquake, *National Police Agency of Japan* confirmed 15,883 deaths, 6150 injured and 2643 missing on September 12th 2012.

Table 1-1 Basic information and humanitarian crisis

	2008 Sichuan Earthquake	**2011 Great East Japan Earthquake**
Date	May 12th, 2008	March 11th, 2011
Magnitude	8.0	9.0
Depth	19km	30km
Death	69,197	15,833
Injured	374,176	6150
Missing	18,000	2643
***Source**	*Ministry of Civil Affairs (MCA) of the PRC*	*National Police Agency of Japan*

As the most effective protection for human lives, buildings were also damaged severely during the earthquakes mentioned above, which was the first reason that caused those lost of lives. As shown in the following table, during Sichuan Earthquake, about 216,000 buildings collapsed, 4,150,000 buildings partially damaged, and in Tohoku of Japan, the number is 129,225 and 691,766, while another 254,204 buildings "half collapsed".

Behind these numbers, one of the brutal facts is that over 6800 school buildings collapsed. It caused about 19,065 deaths of students, and is over 20% of the total death number of this earthquake.

Table 1-2 Building damage

	2008 Sichuan Earthquake	**2011 Great East Japan Earthquake**
Damaged	4,150,000	691,766
Half Collapsed		254,204
Collapsed	216,000	129,225
***Source**	*Ministry of Civil Affairs (MCA) of the PRC*	*National Police Agency of Japan*

1.2 Problem Statement

People is getting to know much more about building structure and earthquakes, improving technology to make buildings stronger against such kind of disasters. However, safety of existing old buildings, those are not well designed before their construction, is also related to a large percent of human lives. Therefore, a large number of existing buildings should be investigated based on a feasible method of seismic evaluation.

Birth of seismic engineering in Japan is 1891, and in 1924 Japan published the first version of building seismic design standard. After that, researches about seismic evaluation and retrofit were started from 1968, and the first standard of seismic evaluation came out in 1977.

Not until the next year 1978, China published a technical recommendation for seismic retrofit based on the applying experience in Beijing and Tianjin. An official and formal standard of seismic evaluation was not completed until 2009, which is nearly 30 years after 1977.

Development of seismic engineering in Japan and China is listed as the following table.

Table 1-3 Development of seismic engineering

	Japan	**China**
1890s	Birth of seismic engineering	--
1900s	--	
1910s	--	
1920s	Standard for seismic design	
1930s	--	
1940s	--	
1950s	Construction law	
1960s	--	Trial use of seismic evaluation (Beijing and Tianjin)
1970s	First revise of construction law Standard for seismic evaluation	Technical manual for seismic retrofit
1980s	Second revise of construction law	--
1990s	Revise of seismic evaluation standard	Construction law
2000s	--	Standard of seismic evaluation

2010s

Seismic evaluation standard is different from country to country; therefore, seismic evaluation result of same building is different according to different methods. There is both advantage and disadvantage of each standard, and there is also something similar among different standards.

1.3 Objectives and Purpose

It is necessary that, based on the similarities and differences between two kind of seismic evaluation methods of Japan and China, make a proposal to improve one or both of these two methods. If possible, advantages of both methods could be taken to make a combined, better seismic evaluation method.

1.4 Outline of the Thesis

This research is divided into 6 chapters:

Chapter 1: Introduction

This chapter presents general background, defines the research problems, objectives, purpose and significance of this research.

Chapter 2: Investigation of seismic evaluation method of Japan

This chapter gives a brief introduction to development and general ideas of seismic evaluation method of Japan – "*Standard for Seismic Evaluation and Guidelines for Seismic Retrofit of Existing RC Buildings (Standard and Guideline)*", which is published in 1977 by *the Japan Building Disaster Prevention Association (JBDPA)*. And second level screening procedure, which is mainly used to existing RC buildings, is investigated and discussed.

Chapter 3: Investigation of seismic evaluation method of China

This chapter gives the investigate results of development, general ideas, introduction and calculation of two levels of screening procedure of China, based on *"Standard for Seismic Appraiser of Building (GB50023-2009)"* published by *Ministry of Housing and Urban-Rural Development* and *General Administration of Quality Supervision, Inspection and Quarantine of the People's Republic of China*.

Chapter 4: Seismic evaluation results of existing RC buildings

Four existing RC buildings in Japan and China are selected as sample buildings in this chapter, and second level screening procedures of seismic evaluation of Japan and China are applied to the above four buildings. Information of sample buildings and seismic evaluate results are discussed in this chapter.

Chapter 5: Comparison and improvement of seismic evaluation methods

This chapter discusses the similarities and differences between seismic evaluation methods of two countries in building characteristics, basic concept of seismic evaluation and results of application to existing RC buildings.

Chapter 6: Conclusions and Future Extensions

This chapter highlights the main results of this research, gives recommendations for further studies.

Chapter 2. Investigation of Seismic Evaluation Method of Japan

2.1 General

Construction law of Japan was published in 1950 and revised twice in 1971 and 1981. New buildings built after 1981 enjoy stronger earthquake resistance thanks to this strengthened standard, while those built based on old standards are left behind and remain in danger.

Therefore, the first version of the "*Standard for Seismic Evaluation and Guidelines for Seismic Retrofit of Existing RC Buildings (Standard and Guideline)*" is published in 1977 by *the Japan Building Disaster Prevention Association (JBDPA)*, followed by twice revisions in 1990 and 2001.

Evaluation standard mentioned and used in this research is the recent published version of *Standard and Guideline* in 2001.

2.2 Standard for Seismic Evaluation of Existing RC Buildings in Japan

2.2.1 Introduction - seismic evaluation method for RC buildings

Seismic performance of structure is expressed by I_S value in Japan. I_S should be calculated by the following equation at each storey and in each principal horizontal direction of a building, while the irregularity index S_D and the time index T should be used commonly for all stories and directions.

$$\mathrm{I_S = E_0 \times S_D \times T}$$

The multiplication of strength index C and deformation capacity F makes a basic seismic index of structure E_0, which is to evaluate the basic seismic performance of the building by assuming other sub indices as unity, should be calculated for each storey and each direction.

And there is a seismic demand index I_{S0} calculated by the following equation combined with basic seismic demand index of structure E_S, zone index Z, ground index *G* and usage index *U*.

$$I_{S0} = E_S \times Z \times G \times U$$

If I_S value is not smaller than I_{S0} and the following equation:

$$C_{TU} \times S_D \geq 0.3$$

is satisfied, the building could be assessed to be “safe”. Otherwise, the building should be assessed to be “uncertain” in seismic safety.

There are 3 levels of seismic screening in Japan as follows:

> *First level screening procedure*
>
> This procedure is the simplest procedure mainly used for wall structures. Average material strengths and cross-sectional dimensions should be calculated to estimate strengths of only vertical members (structural columns and walls).
>
> *Second level screening procedure*
>
> This procedure is mainly used for column-collapse buildings. Since most of existing RC buildings designed based on old seismic standard, which should be investigated, could be applied second level screening, it is the most widely used among three levels of screening for existing RC buildings.
>
> General idea of second level screening is that, taking the influence of steel bars into consideration, figure out strength and deformation capacity of each column and wall in the building.
>
> *Third level screening procedure*
>
> This procedure is used for beam-collapse structures so that strength of beams is also evaluated.

2.2.2 First level screening and third level screening procedures

Structural vertical members are divided into three groups and ductility index *F* of each group is identified as follows in first level screening procedure:

Table 2-1 Definition and ductility index *F* in first level screening

Vertical member	**Definition**	**Ductility *F***
Column	$H_0/D>2$	1.0
Short column	$H_0/D\leq2$	0.8
Seismic wall	--	1.0

Strength index C is also calculated simply according to average shear stress τ of each type of members, shown in the following table, multiplied by its section area a.

Table 2-2 Definition and average shear stress τ in first level screening

Vertical member	**Definition**	**Average shear stress τ**
Long column	$H_0/D>6$	0.7 N/mm^2
Column	$2<H_0/D\leq6$	1.0 N/mm^2
Short column	$H_0/D\leq2$	1.5 N/mm^2
Wall without column		1.0 N/mm^2
Wall with one boundary column		2.0 N/mm^2
Wall with two boundary columns		3.0 N/mm^2

For structures with short columns, basic seismic index of structure E_0 should be calculated by the following equation:

$$E_0 = \frac{n+1}{n+i}(C_{sc} + \alpha_2 C_w + \alpha_3 C_c) \times F_{sc}$$

and for structures without short columns:

$$E_0 = \frac{n+1}{n+i}(C_w + \alpha_1 C_c) \times F_w$$

Relationship between effective strength factor α and *C-F* line is shown as follows:

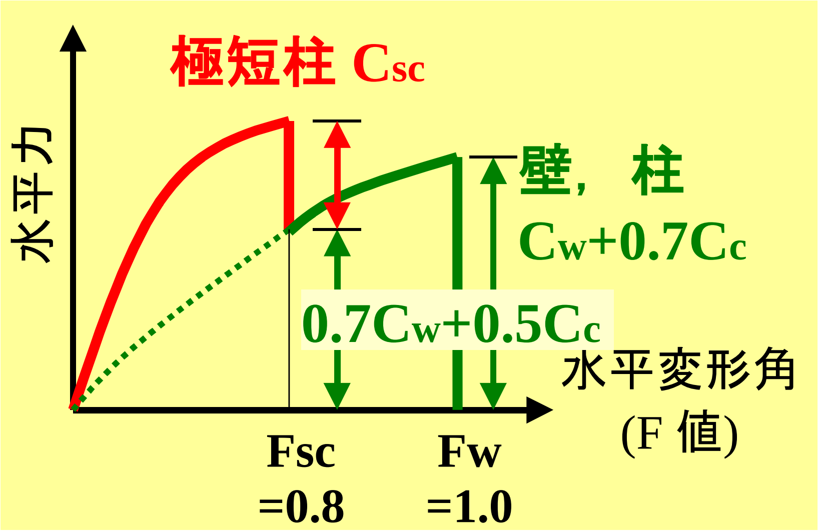


Figure 2-1 Relationship between α and *C-F* line

As to S_D and T index needed to get I_S value, there are check list including horizontal balance, elevation balance, eccentricity, stiffness for S_D index, and deflection, cracking in walls and columns, fire experience, occupation, age of building, finishing condition for T index. Either of these two indices is plus and smaller than 1.0.

After getting the value of seismic capacity I_S, seismic demand index of structure I_{S0} is supposed to be 0.8 for the first level screening.

Since column-collapse structure is more dangerous than beam-collapse structure, it is better to assume that columns will fail earlier than beams during earthquakes. Therefore, three level screening is a complicated procedure with less significance that it is not widely used and also not an object in this research.

2.2.3 Second level screening procedure

Second level screening is the most widely used procedure of seismic evaluation thanks to its column-collapse object and well balance between accuracy of result and difficulty of calculation.

In second level screening procedure, vertical members of structure are divided accurately into 5 types, and ductility index *F* of members of the same type could also be different from each other, shown in the following table.

Table 2-3 Definition and ductility index *F* in second level screening

Vertical member	**Definition**	**Ductility *F***
Short column	$H_0/D \leq 2$	0.8
Shear column	$H_0/D>2$ & shear failure	1.0
Flexural column	$H_0/D>2$ & flexural yielding	1.27~3.2
Shear wall	Shear failure	1.0
Flexural wall	Flexural yielding	1.0~2.0

If we get results of all vertical members in a building, we would be able to consider members with similar results as one group, and all members could be divided into several groups. Usually, in second level screening procedure, the number of groups is three or four.

Based on this kind of classification of vertical members, equations to get basic seismic index of structure E_0 in procedure of second level screening is also different from the way in first level screening.

E_0 indices of these three or four groups (take three as an example) should be calculated separately, expressed by E_1, E_2, E_3, and E_0 index should be calculated in the following ways:

$$E_0 = \frac{n+1}{n+i}\sqrt{{E_1}^2 + {E_2}^2 + {E_3}^2}$$

$$E_0 = \frac{n+1}{n+i}\left(C_1 + \sum_j \alpha_j C_j\right) \times F_1$$

Relationship between C and F index of different types of columns and walls are shown below:

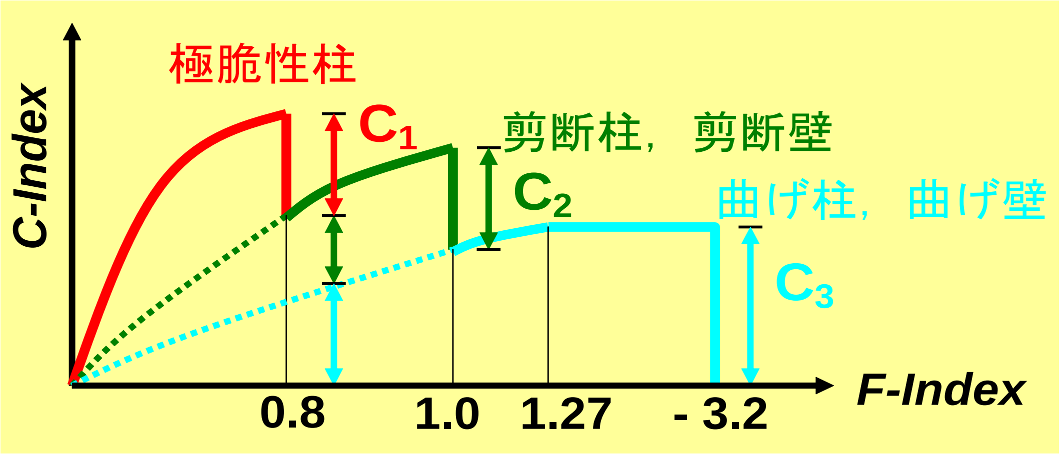


Figure 2-2 Relationship between *α* and *C-F* line

For columns,

$$cM_u = 0.8a_t \times \sigma_y \times D + 0.5N \times D \times \left(1 - \frac{N}{bDFc}\right)$$

$$cQ_{mu} = \frac{2Mu}{h_0}$$

$$\mathrm{cQ_{su}} = \left\{ \frac{0.053\mathrm{p_t}^{0.23}(18 + \mathrm{Fc})}{{}^{\mathrm{M}}\!/_{\mathrm{Q \cdot d}} + 0.12} + 0.85\sqrt{\mathrm{p_w} \times \sigma_{\mathrm{wy}}} + 0.1\sigma_0 \right\} \times \mathrm{b} \times (0.8\mathrm{D})$$

The smaller one of Qmu and Qsu decides the final strength of a column, and if cQsu>cQmu, which means this column has flexural yielding, ductility index *F* is calculated as follows:

$$\mu = 10\left(\frac{\mathrm{cQ_{su}}}{\mathrm{cQ_{mu}}} - 1\right) \quad (1 \leq \mu \leq 5)$$

$$\mathrm{F} = \frac{\sqrt{2\mu - 1}}{0.75(1 + 0.05\mu)}$$

For seismic walls,

$$\mathrm{wMu} = \mathrm{a_t} \times \sigma_{\mathrm{y}} \times \mathrm{Lw} + 0.5 \sum (\mathrm{a_w} \cdot \sigma_{\mathrm{w}})\, \mathrm{Lw} + 0.5\mathrm{N} \times \mathrm{Lw}$$

$$\mathrm{wQmu} = \frac{2\mathrm{Mu}}{\mathrm{h_0}}$$

$$\mathrm{wQsu} = \left\{ \frac{0.053\mathrm{p_{te}}^{0.23}(18 + \mathrm{Fc})}{{}^{\mathrm{M}}\!/_{\mathrm{Q \cdot d}} + 0.12} + 0.85\sqrt{\mathrm{p_{we}} \times \sigma_{\mathrm{wy}}} + 0.1\sigma_0 \right\} \times \mathrm{b_e} \times (0.8\mathrm{D})$$

The same as columns, if wQsu>wQmu, it means that the wall will suffer flexural yielding.

If ratio of wQsu to wQmu is not over 1.2, ductility index *F* of this flexural wall is decided as 1.0.

Otherwise, if the ratio is over 1.3, ductility index *F* is increased to 2.0.

Not as the basic capacity E_0, the irregularity index S_D and the time index *T* could be checked according to check-lists in the *“Standard and Guideline”* simply.

Chapter 3. Investigation of Seismic Evaluation Method of China

3.1 General

History and development of seismic evaluation and retrofit for RC building in China could be divided into three stages.

Premier stage (1966~1985)

Earthquakes happened in Xingtai and Hejian created a great number of collapses of building in 1966 and 1967. Under this kind of circumstances, first seismic investigation to existing buildings was carried out in Beijing and the city nearby, Tianjin. Based on the investigations, a preliminary specification for buildings in these two cities was written in 1968, which after the Haicheng Earthquake in 1975, was published as the first seismic evaluation code in China.

Strengthen methods in this stage was simple and rough, such as add columns or bond beams outside the original structures, but it is economical and a good response to the emergency situation.

Developing stage (1985~1995)

Urbanization of cities in China sifted out the old method that adds extra structures independent to original structures.

During this decade, seismic retrofit methods tend to improve strengths of structure members, such as to expand section area of columns or foundations.

However, seismic retrofit methods in this stage were completely rigid.

Comprehensive stage (1995~now)

Experiences from 1994 Northridge Earthquake in Los Angeles, U.S. and 1995 Great Hanshin Earthquake in Japan, set good examples of new technologies in field of seismic engineering.

Materials such as carbon fiber and hi-strength glue made the former rigid methods to soft and more flexible ones.

Seismic evaluation method of China discussed in this research is the current *"Standard for Seismic Appraiser of Building (GB50023-2009)"* published by *Ministry of Housing and Urban-Rural Development* and *General Administration of Quality Supervision, Inspection and Quarantine of the People's Republic of China*.

3.2 Standard for Seismic Appraiser of Building (GB50023-2009)

3.2.1 Introduction - seismic evaluation method for RC buildings

There are two levels of screening procedure to make seismic evaluation in China.

> *First level screening procedure* composed of material strength, structure type, entire and partial construction. These four factors also make up to the entire and partial indices necessary for second level screening procedure.
>
> *Second level screening* procedure is called checking computation, and capabilities of structure members are calculated in this procedure.

Besides, buildings in China are divided into three types according to their follow-up service life: a building that is supposed to be in function for another 30 years is a type A building, and a type B or type C building is supposed to be used for another 40 or 50 years from now on.

For buildings of type A, first level screening procedure is necessary and second level screening procedure is needed only in case that the building could not pass the first level screening procedure.

However, for buildings of type B or C, which are supposed to be used for a longer time than type A, both first level and second level screening procedure are needed. Failure in either of these two procedures will claim the danger of buildings during earthquakes.

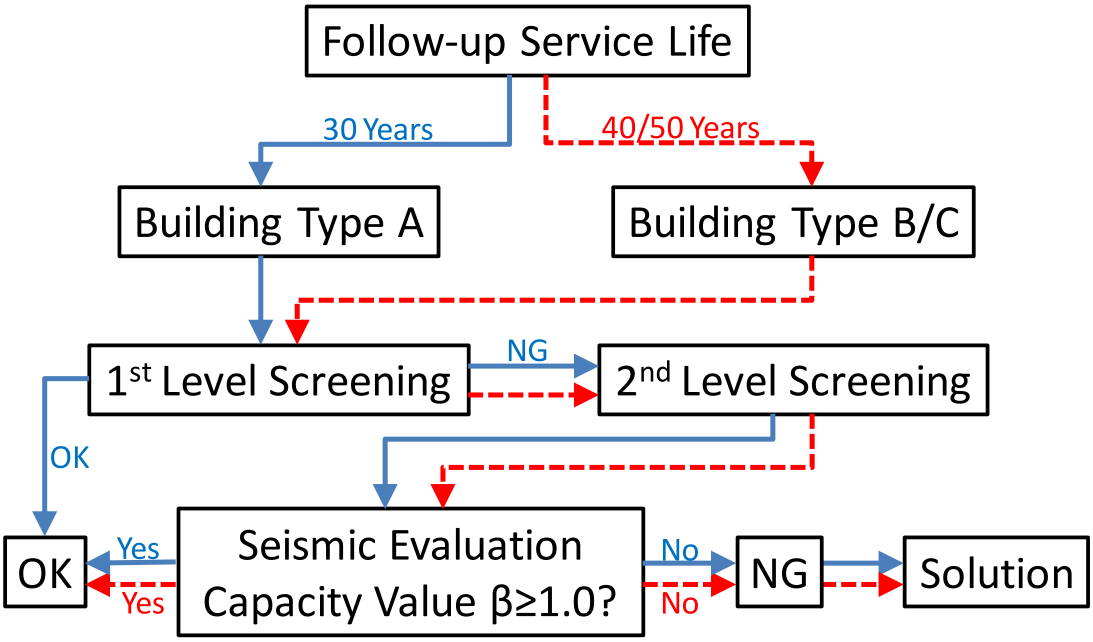


Figure 3-1 Evaluate flow for RC buildings in China

3.2.2 First level screening procedure

First level screening procedure is based on a check list, which includes entire and partial, structural and nonstructural factors in a building.

For instance, regularity of the entire building is taken into consideration as well as size of columns, and material strengths of both columns and gables are influence factors in first level screening procedure.

Items of first level screening procedure are listed in the following table:

According to this check list, seismic evaluation could be made in a quite short time. And it is flexible even there are no particular details of building structure.

First level screening procedure is a qualitative method of seismic evaluation. Result of this evaluation is a simple definition of Yes or No.

Except that important structural items must be satisfied, judgment of nonstructural items could be quite subjective.

Generally, first level screening is a very simple and quick procedure.

Check list

Code Number	**Item**	**Request**
6.2.1-1	Moment resist frame	Two directions
6.2.1-2	Span	More than one span
6.2.1-3	Regularity	$b \leqq a$; $b \leqq 30\%W$
		$b \leqq 25\%W$
		$G \geqq G_{upstair}$; When $G_1 \leqq G_2 \leqq G_3$, $G_1 \geqq 50\%G_3$
		No masonry member connected; Anti-lateral-force members and weight should be symmetrical and uniform.

<table>
<tr>
<td>6.2.1-4</td>
<td>Floor & roof</td>
<td>Length-width ratio of floors and roofs between earthquake-resistant walls without big opening should not be bigger than
<table>
<tr><td></td><td>Intensity 8</td><td>Intensity 9</td></tr>
<tr><td>Field-made floor</td><td>3.0</td><td>2.0</td></tr>
<tr><td>Prefabricated floor</td><td>2.5</td><td>1.0</td></tr>
</table>
</td>
</tr>
<tr>
<td>6.2.1-5</td>
<td>Masonry
anti-lateral-force wall</td>
<td>When intensity is 8 degree, masonry anti-lateral-force wall: thickness t≧240mm, strength of mortar M≧M2.5, the average distance between two walls must not be bigger than
<table>
<tr><td>Storey</td><td>3</td><td>4</td><td>5</td><td>6</td></tr>
<tr><td>Distance</td><td>17m</td><td>14m</td><td>12m</td><td>11m</td></tr>
</table>
</td>
</tr>
<tr>
<td>6.2.2</td>
<td>Strength of concrete</td>
<td>When intensity is 6 or 7 degree, C13; when intensity is 8 or 9 degree, C18.</td>
</tr>
<tr>
<td>6.2.3-1</td>
<td>Frame member when</td>
<td>The anchor length L should be:</td>
</tr>
</table>

<table>
<tr><td></td><td rowspan="2">intensity is 6 or 7 degree, soil type is I or II.</td><td>$L \geqq 25d_b$ (HPB235); $L \geqq 30d_b$ (HPB335);
When the strength of concrete is C13, L should increase by $5d_b$.</td></tr>
<tr><td>6.2.3-2</td><td>When intensity is 6 degree, type of fortify is II, longitudinal steels of middle columns and side columns should not be less than 0.5%, corner columns 0.7%. Space $S \leqq 8d$ and 150mm, minimum of $d \geqq 6mm$.</td></tr>
<tr><td>6.2.4-1</td><td rowspan="2">Frame member when intensity is 7 degree, soil type is III or IV, or intensity is 8 or 9.</td><td>Space between hoops in the area shown below must be: $S \leqq 200mm$ (8 degree), $S \leqq 150mm$ (9 degree).</td></tr>
<tr><td>6.2.4-2</td><td>When type of fortify is III, hoops in the area shown below must be:
$d \geqq 6mm$, $S \leqq 200mm$ (intensity is 7 degree with soil type III or IV, or 8 degree);
$d \geqq 8mm$, $S \leqq 150mm$ (intensity is 9 degree).
When type of fortify is II, hoops in this area must be:
<table><tr><td></td><td>7 degree with soil type I or II</td><td>7 degree with soil type III or IV, 8 degree with soil type</td><td>8 degree with soil type III or IV, 9 degree</td></tr></table></td></tr>
</table>

<table>
<tr><td></td><td></td><td>
<table>
<tr><td></td><td></td><td>I or II</td><td></td></tr>
<tr><td>Space (mm)</td><td>Max(8d, 150)</td><td>Max(8d, 100)</td><td>Max(6d, 100)</td></tr>
<tr><td>Minimum of d (mm)</td><td>8</td><td>8</td><td>10</td></tr>
</table>
</td></tr>
<tr><td>6.2.4-3</td><td>Reinforce of short columns($H_0/D \leqq 4$)</td><td>d≧8mm
S≦150mm (8 degree); S≦100mm (9 degree)</td></tr>
<tr><td rowspan="2">6.2.4-4</td><td rowspan="2">Ratio of vertical reinforce</td><td>Corner columns ≧0.8% (8 degree), 1.0% (9 degree)</td></tr>
<tr><td>Other columns ≧0.6% (8 degree),0.8% (9 degree)</td></tr>
<tr><td>6.2.4-5</td><td>Section size of frame columns</td><td>b≧300mm, 400mm (8 degree with soil type III or IV, or 9 degree);
ratio of axial force≦0.8</td></tr>
<tr><td>6.2.5-1</td><td>When intensity is 8 or 9</td><td>Sides of earthquake-resistant wall and frames around should make up a whole or reinforced frame.</td></tr>
</table>

<table>
<tr><td>6.2.5-2</td><td rowspan="2">degree, reinforce and structure of frame and earthquake-resistant wall should</td><td>Thickness of walls should not be less than 140mm, and $1/30H_0$; ratio of reinforce must not be less than 0.15%.</td></tr>
<tr><td>6.2.5-3</td><td>Connection of walls and floors must be able to pass seismic forces.</td></tr>
<tr><td>6.2.6</td><td>When there is a load-bearing gable,</td><td>There must be RC wall columns connecting the gable with frame.
If not, reinforce is needed when intensity is 8 or 9 degree.</td></tr>
<tr><td>6.2.7-1</td><td>Connection between masonry and internal walls with main structure.</td><td>When the anti-lateral-force of internal walls is considered, the thickness and mortar strength must be
<table>
<tr><td></td><td>6-8 degree</td><td>9 degree</td></tr>
<tr><td>Thickness (mm)</td><td>≧180</td><td>≧240</td></tr>
<tr><td>Mortar strength</td><td>≧M2.5</td><td>≧M5</td></tr>
</table>
Internal walls must be in the plan of frame (be in-fill walls).</td></tr>
</table>

6.2.7-2		There must be 2Φ6 connected walls and columns about every 600mm high; the length should not be less than 1/5L_w, and 700mm when intensity is 8 or 9 degree; when the wall is higher than 5m, there should be a beam in the wall connected to columns; When the wall is longer than 6m (hollow block wall is longer than 5m), and intensity is 8 or 9 degree, the wall must be connected to the floor upstairs.
6.2.7-3		Internal walls must be connected to walls or columns around; when the length is over 6m, and intensity is 8 or 9 degree, internal walls must be connected to the floor upstairs.

3.2.3 Second level screening procedure

Since many buildings of type A built under old standards could not satisfied every items in check list of first level screening procedure, and buildings of type B and C are also widely existing in China, under these circumstances, second level screening procedure is needed to be applied to the object buildings.

In second level screening procedure of China, seismic performance of structure is expressed by β index, which is composed of modification index, basic capacity of the building and seismic demand, and the equation is shown below:

$$\beta = \psi_1 \times \psi_2 \times \xi_y$$

ψ is modification index including entire and partial influences, and they are decided from the first level screening procedure. Besides, deformation capacity of building is also expressed in this part.

Yield strength index ξ_y shows the ratio basic capacity of structure, expressed by V_y, to seismic demand V_e as shown below:

$$\xi_y = \frac{V_y}{V_e}$$

If basic capacity of structure is larger than seismic demand, which equals to the following equation:

$$\beta = \psi_1 \times \psi_2 \times \frac{V_y}{V_e} \geq 1$$

the building could be identified as “safe” against an earthquake.

Otherwise, the building is not satisfied to the seismic demand in China.

A brief calculation flow is shown below:

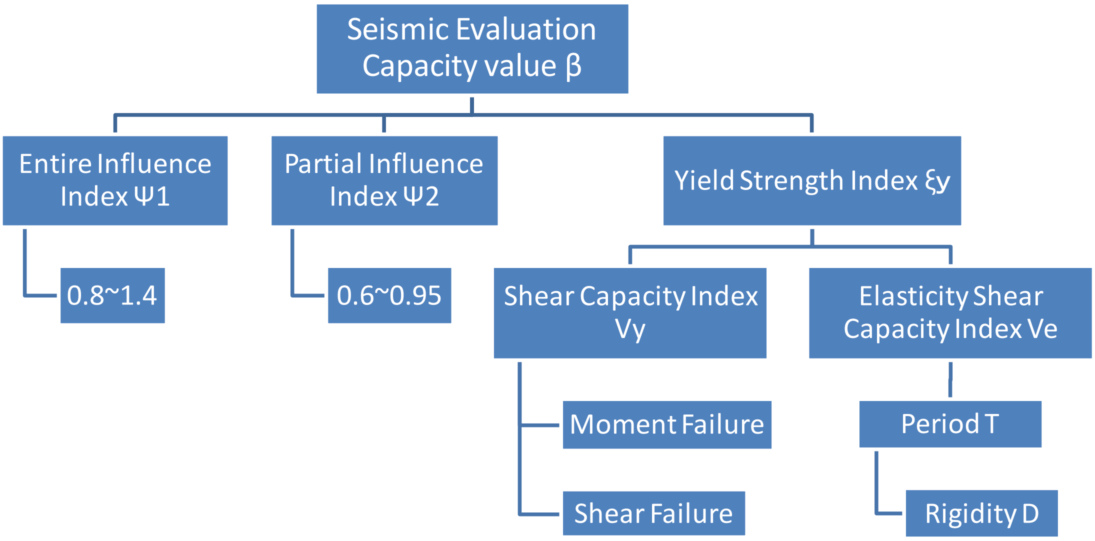


Figure 3-2 Seismic evaluation flow of second level screening procedure in China

In order to get basic capacity of structure, damage mode of each members, flexural yielding or shear failure, should be decided first.

For instance, assume a column to suffer flexural yielding during an earthquake, moment M_{cy1} and force V_{cy1} are calculated by the following equations:

$$M_{cy1} = f_{yk}A_s(h_0 - a'_s) + 0.5Nh\left(1 - \frac{N}{f_{cmk}bh}\right)$$

$$V_{cy1} = \frac{2M_{cy1}}{H_n}$$

Then check force V_{cy2} assuming the column to suffer shear failure, using the following equation:

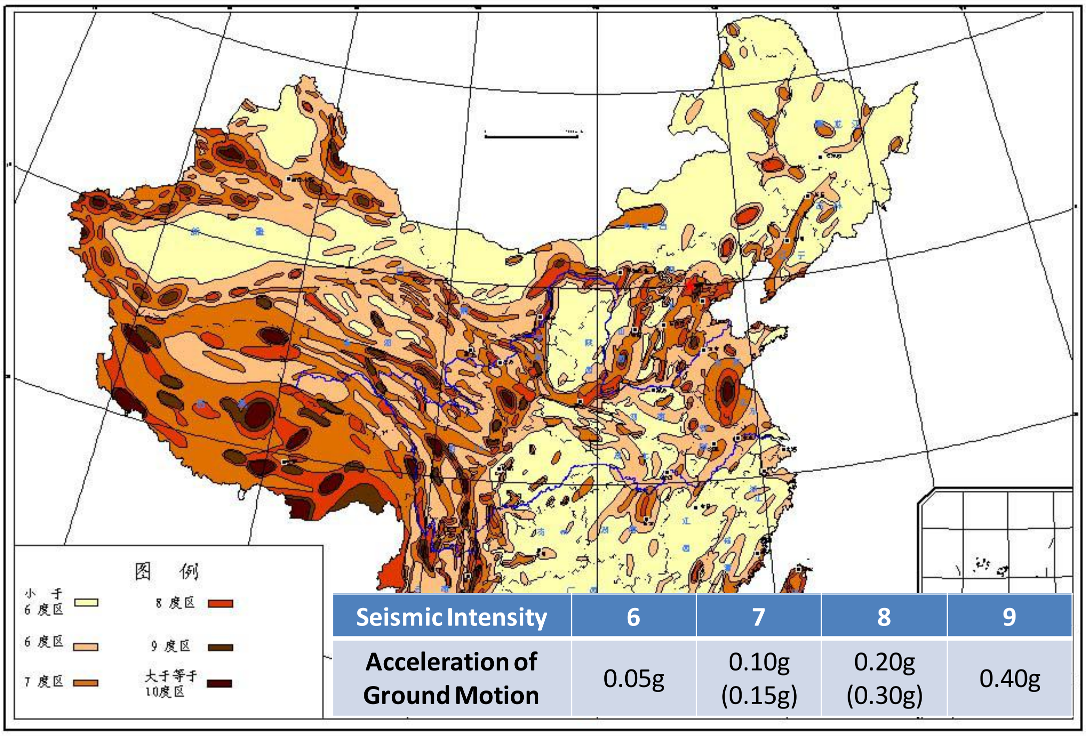
$$V_{cy2} = \frac{0.16}{\lambda + 1.5} f_{ck}bh_0 + f_{yvk}\frac{A_{sv}}{s}h_0 + 0.056N$$

Expected damage mode of the column is determined by the smaller one of V_{cy1} and V_{cy2}, and the smaller value is taken as the basic capacity of structure index V_y to make the following calculations.

V_y indices of seismic walls and filler walls could also be calculated by similar equations.

As to seismic demand V_e, it is calculated by the acceleration of ground motion, which is decided by the expected seismic intensity in Chinese *Liedu* scale.

Since total area of China is 9,600,000 km^2 and the territory lays between latitudes 18°N~54° N, longitudes 73°E~135° E, which is a quite wide area, geological structures differ from place to place in China. Therefore, the entire area is divided into six sections with different acceleration of ground motion based on the expected seismic intensity, shown in the following map:



Seismic Intensity	6	7	8	9
Acceleration of Ground Motion	0.05g	0.10g (0.15g)	0.20g (0.30g)	0.40g

Figure 3-3 Seismic fortification intensity of China

After decided the seismic area and acceleration of ground motion of the building, there are five steps to get the seismic demand index V_e as follows:

① Use the D level method, proposed by Japan architect *Kiyoshi MUTO* and widely used, calculate stiffness D of each frame of the building.

② According to the following equation, figure out the natural vibration period *T* of the building:

$$T = 2\varphi_T \sqrt{\frac{\sum G_i u_i^2}{\sum G_i u_i}}$$

Where, G_i refers to the gravity loading acting on the partial;

u_i is the horizontal displacement under the loading, calculated by the stiffness *D* gotten in the first step by the following equation:

$$u_i = u_{i-1} + \sum_i^n \frac{G_i}{D_i}$$

φ_T is the damping index.

③ Use natural vibration period *T* to get the influence coefficient *α*

Vibration period *T*	Influence coefficient *α*
$0 \le T < 0.1s$	$\alpha = [0.45 + (10\eta_2 - 4.5)T]\alpha_{max}$
$0.1s \le T < T_g$	$\alpha = \eta_2\alpha_{max}$
$T_g \le T < 5T_g$	$\alpha = \left(\frac{T_g}{T}\right)^\gamma \eta_2\alpha_{max}$
$5T_g \le T \le 6s$	$\alpha = [\eta_2 0.2^\gamma - \eta_1(T - 5T_g)]\alpha_{max}$

Indices needed in this step could be check out from the building code.

④ Get the seismic demand V_i of each floor by the following steps:

$$F_i = \beta F_{Ek} = \frac{G_i H_i}{\sum_{j=1}^n G_j H_j} F_{Ek} = \alpha G_{eq} = \alpha 0.85 \sum G$$

$$V_i = \sum_{j=1}^{n} F_j$$

⑤ Use stiffness *D* gotten in the first step again to share the seismic demand V_i of entire floor to each frame.

Based on the steps above, seismic capacity value *β* would be figured out to see if it is over 1.0.

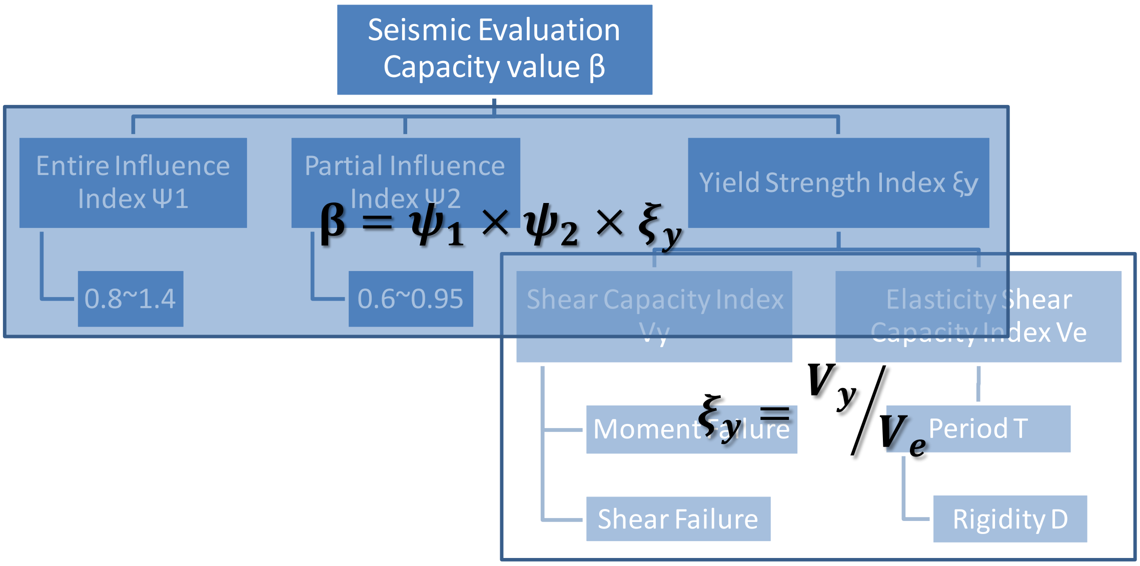


Figure 3-4 Summary of equations

Chapter 4. Seismic Evaluation Results of Existing RC Buildings

4.1 Outline of Selected Sample Buildings

Four buildings in Japan and China are chosen as sample buildings in this research.

Sample A and B are existing school buildings in China, building M is material lecture building in Tohoku University Japan, and building T is a premier school building in Miyagi-ken Japan.

According to the investigations mentioned above, there are several factors that would have influence to the results of seismic evaluation, such as acceleration of ground motion of the located area, entire structure system, materials used, volume of the building and typical columns in the building etc.

The following table gives a summary of these factors that are expected to contribute to the seismic evaluation results before they are actually calculated.

Table 4-1 Summary of expected effective factors of sample buildings

	Location (Acc.*)	**Structure (Material)**	**Storey / Height**	**Area [m]**	**Column [mm]**
Sample A	China (0.30g)	RC (SR235, Fc=10.6)	4F / 15.3m	39.6×15	500×500
Sample B		RC (SR335, Fc=24.5)	5F / 19.4m	18×11.4	400×400
Building M	Japan	RC (SD395,	2F / 7.8m	55.2×9	625×650

	(0.30g)	Fc=21)			
Building T		RC (SD295, Fc=18)	3F / 10.8m	85×23	500×600
Acc.: Design basic acceleration of ground motion*					

4.2 Building Information and seismic evaluation results of sample buildings in China

4.2.1 Building information of sample building A and B

Both the two sample buildings selected from China are RC school buildings existing in northern area of China. They are built in the 1970s and in order to make comparison of second level screening procedures between two methods, they are identified as type B buildings.

These two buildings have regular arrangement of plans and sections, show typical plan of sample building A as an example below, which reflect the normal building styles in that period of history in China.

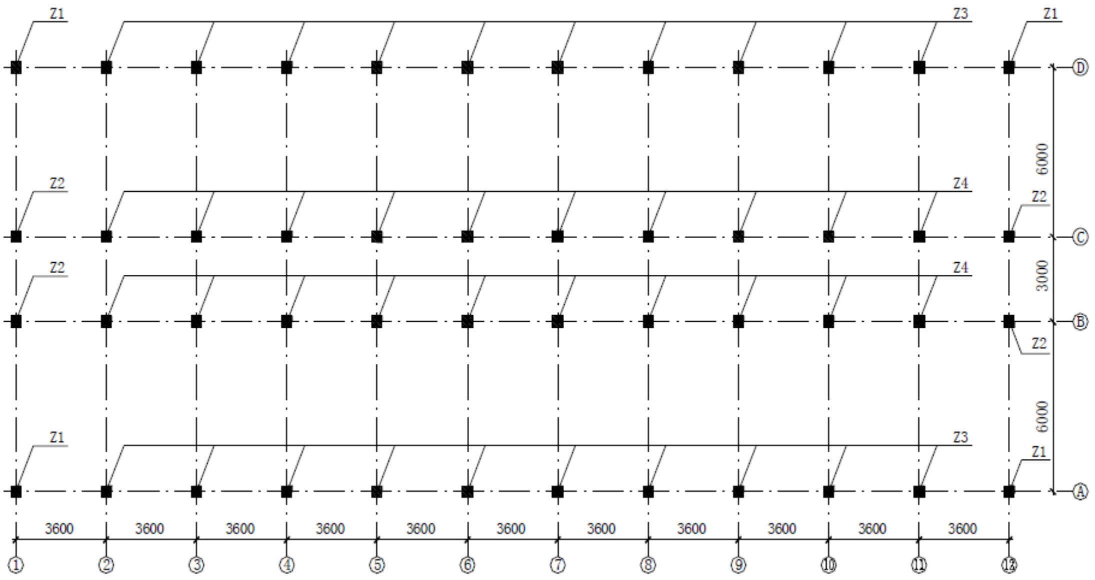


Figure 4-1 Typical arrangement of columns of sample building A

Detailed information, plan and section drawings and characteristics of columns and beams are enclosed as appendix A behind.

4.2.2 Seismic evaluation results of sample building A

Thanks to the regularity of plan arrangement, columns are divided into Z1, Z2, Z3, Z4, four types and in each direction, only two of the four and twelve frames are needed to be calculated.

And in a vertical direction, excepting that the height of first floor is larger than that above, structure system and materials used remain similar from floor to floor in essence.

Therefore, we could expect a result that changes smoothly from first floor to upstairs.

Final results of I_s value and β value of sample building A are shown in the following graphs.

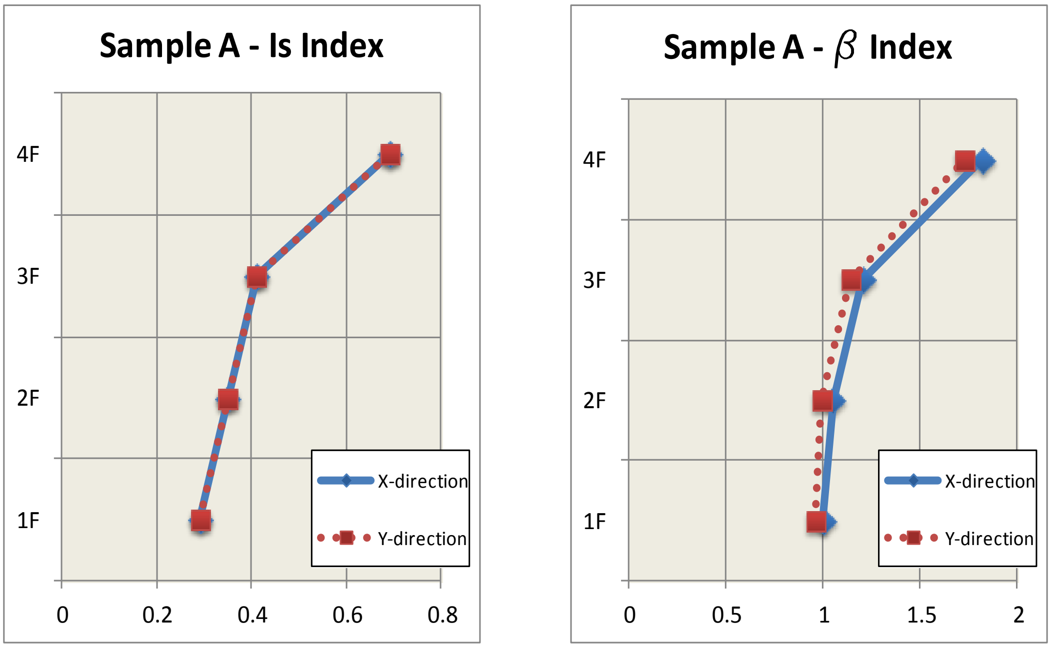


Figure 4-2 Seismic evaluation results of I_s value and β value of sample building A

Results of sample building A confirm the prediction that seismic evaluation index gets larger value smoothly as the floor goes up.

In another word, there are similar tendencies in the results of two different methods of seismic evaluation.

However, absolute values of two seismic capacity indices are totally different not considering that judgment conditions of two methods are also different.

4.2.3 Seismic evaluation results of sample building B

Seismic capacity indices of sample building B are shown in the following graphs.

And same kind of appearance and tendency as results of sample building A is also found in that of sample building B.

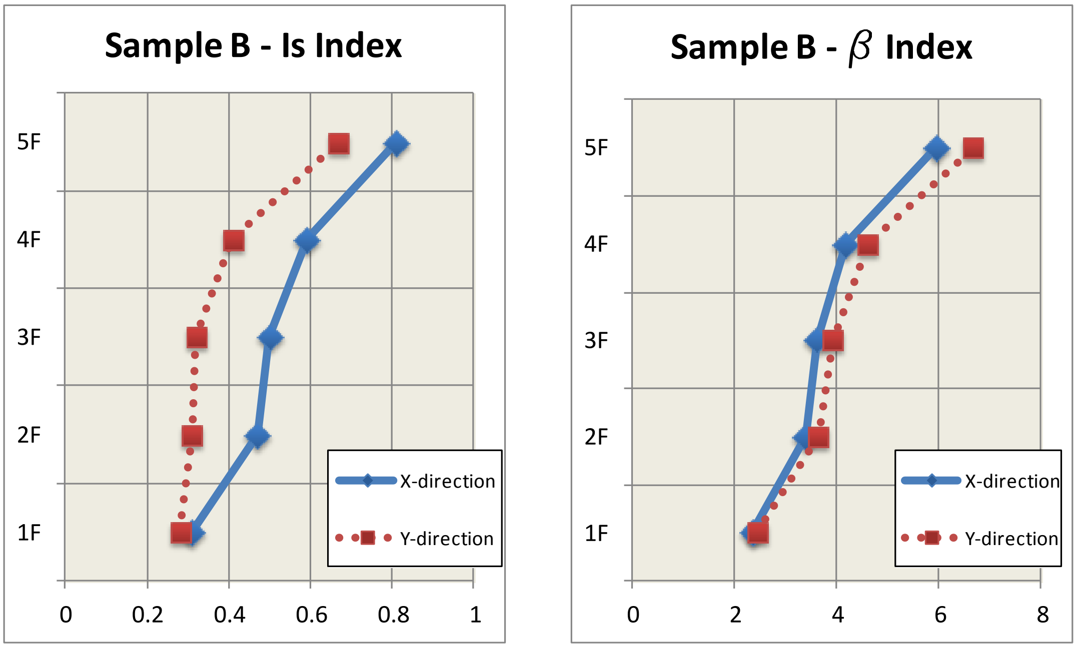


Figure 4-3 Seismic evaluation results of I_s value and β value of sample building B

4.3 Building Information and Actual Damage of Sample Buildings in Japan

4.3.1 Building information of sample building M and T

Two sample buildings selected from Japan are located in Sendai, Tohoku, where the 2011 Great East Japan Earthquake occurred.

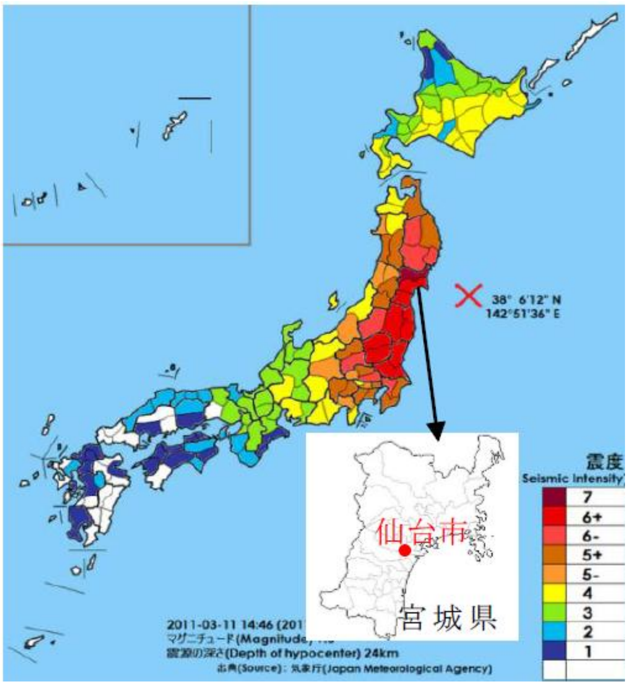


Figure 4-4 Location of Sendai and epicenter of 311 earthquake

Both of these two buildings were damaged during the earthquake.

Thanks to the ground motion stations, the process of earthquake was recorded completely, and the buildings were well investigated after the earthquake.

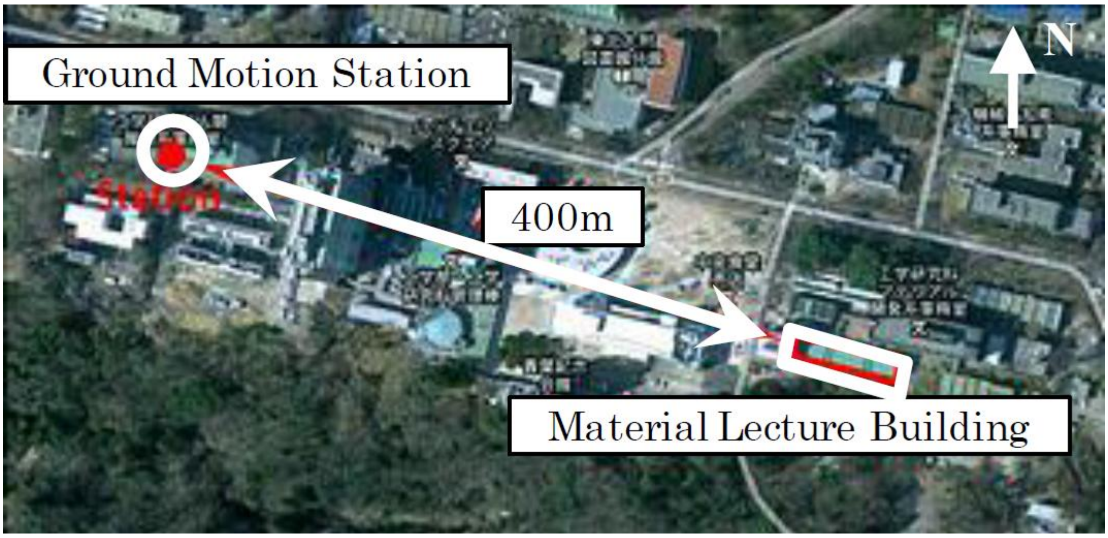


Figure 4-5 Location of sample building M

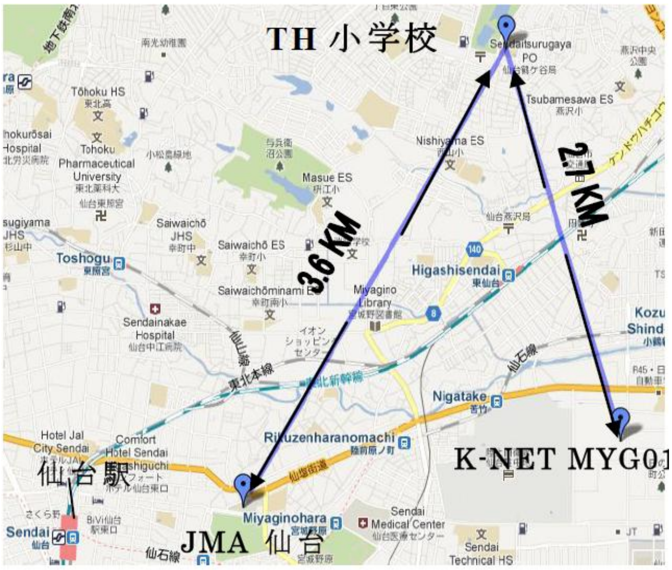


Figure 4-6 Location of sample building T

4.3.2 Damage investigations of sample building M and T

According to the table shown below, from the 2001 edition of *"Guidelines for Post-earthquake Damage Evaluation and Rehabilitation of RC Buildings"* first published by *The Japan Building Disaster Prevention Association* in 1991, there are five levels of damage occurred to the building members.

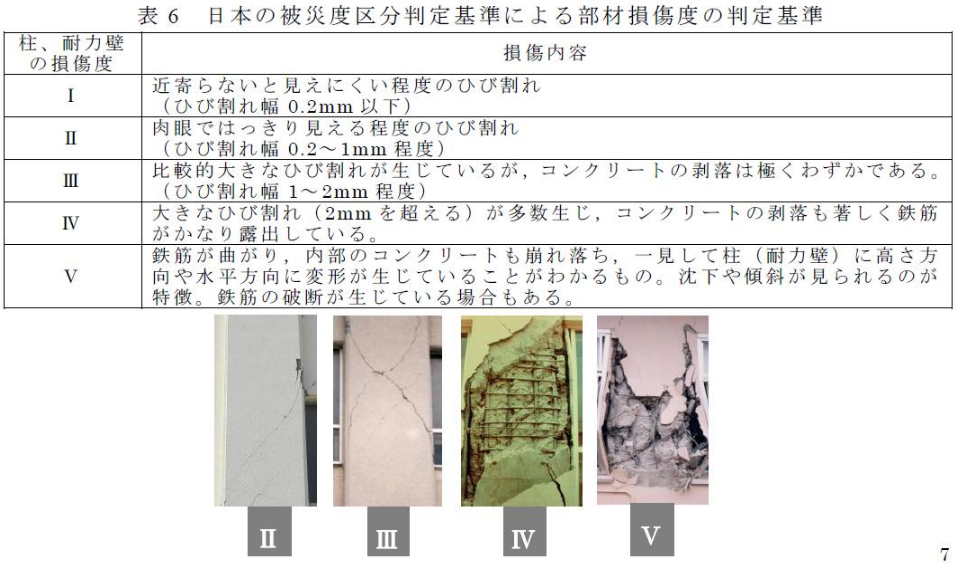


表 6　日本の被災度区分判定基準による部材損傷度の判定基準

柱、耐力壁の損傷度	損傷内容
I	近寄らないと見えにくい程度のひび割れ （ひび割れ幅 0.2mm 以下）
II	肉眼ではっきり見える程度のひび割れ （ひび割れ幅 0.2～1mm 程度）
III	比較的大きなひび割れが生じているが，コンクリートの剥落は極くわずかである。 （ひび割れ幅 1～2mm 程度）
IV	大きなひび割れ（2mm を超える）が多数生じ，コンクリートの剥落も著しく鉄筋がかなり露出している。
V	鉄筋が曲がり，内部のコンクリートも崩れ落ち，一見して柱（耐力壁）に高さ方向や水平方向に変形が生じていることがわかるもの。沈下や傾斜が見られるのが特徴。鉄筋の破断が生じている場合もある。

Figure 4-7 Damage level indicator and examples in Japan

The most severe damage occurred in sample building M was level Ⅲ, and all of the level Ⅲ damage occurred in the columns with partial walls in shapes of shear failure.

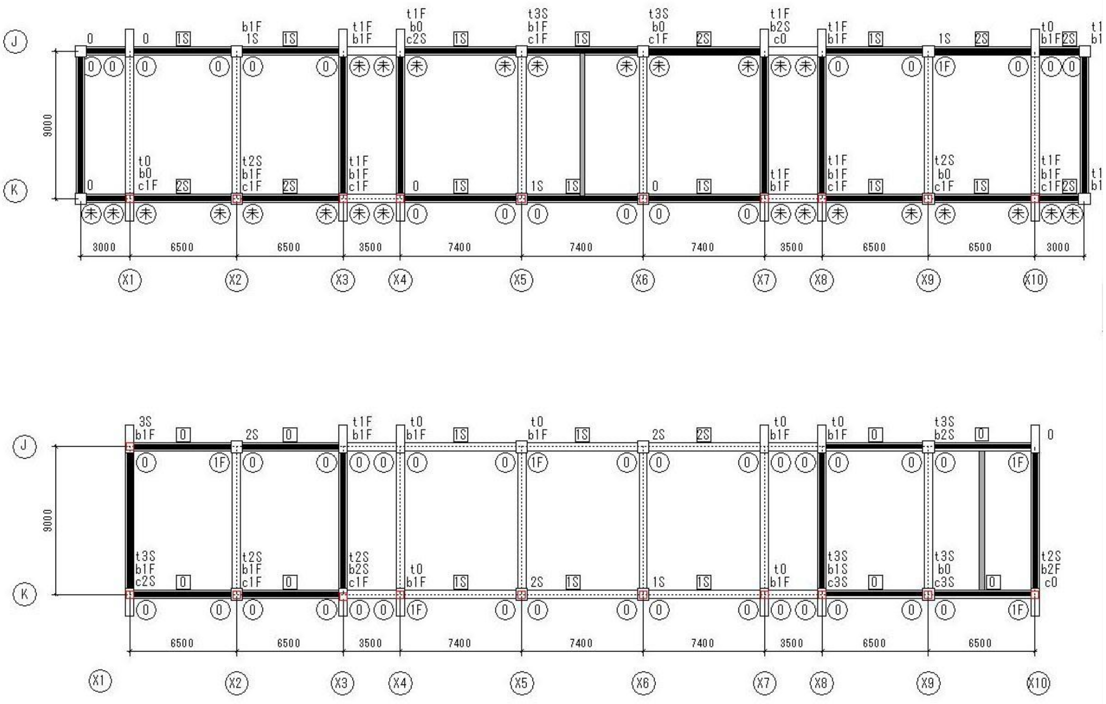


Figure 4-8 Plan and damage levels of sample building M

Vertical position of severe damage occurred and a picture of example are shown in the following figure:

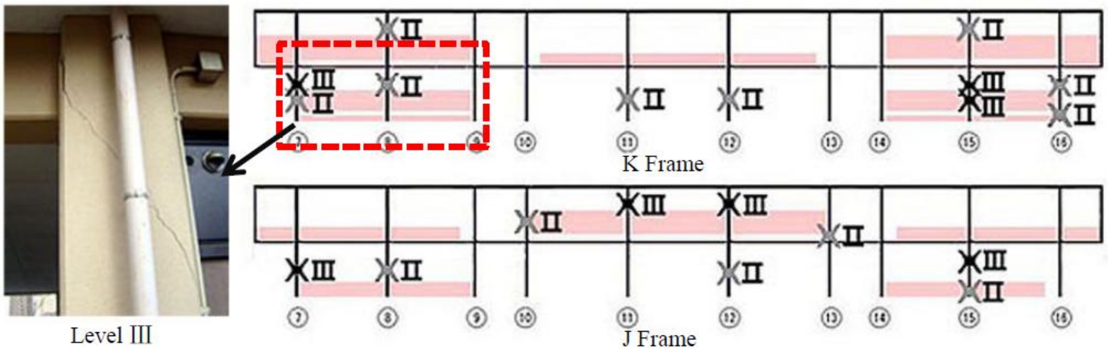


Figure 4-9 Damage position and an example of sample building M

And the following figures show the damage images of sample building T.

Figure 4-10 Examples of damage of sample building T

4.3.3 Seismic evaluation results of sample building M and T

Seismic capacity results of building M and T are shown as the following graphs.

Although, tendencies are not as significant as results of sample building A and B because of the less floor numbers, they are also confirmations to those viewpoints.

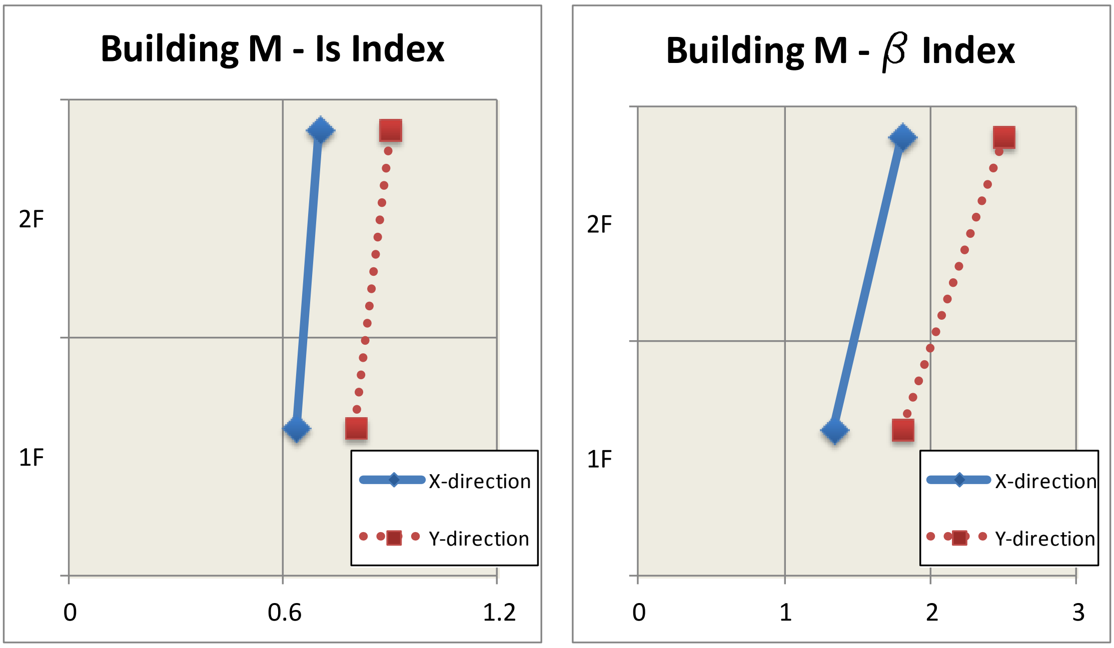


Figure 4-11 Seismic evaluation results of I_s value and β value of sample building M

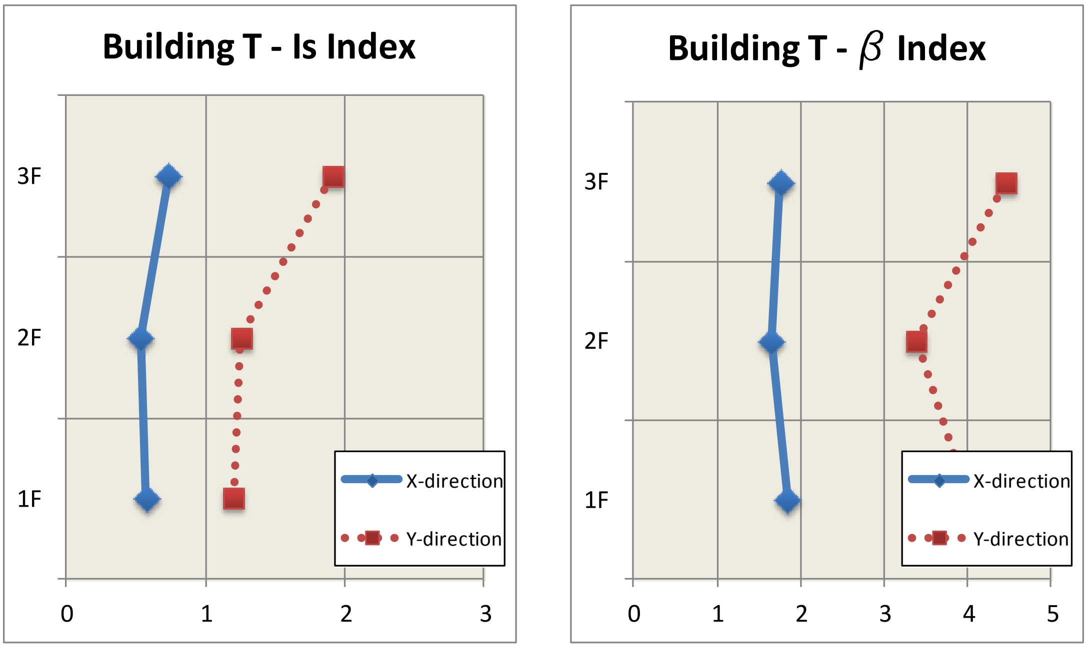


Figure 4-12 Seismic evaluation results of I_s value and β value of sample building T

Chapter 5. Comparison and Improvement of Evaluation Methods

5.1 Characteristics of Buildings in Japan and China

Some basic characteristics of four sample buildings are shown in the following graph:

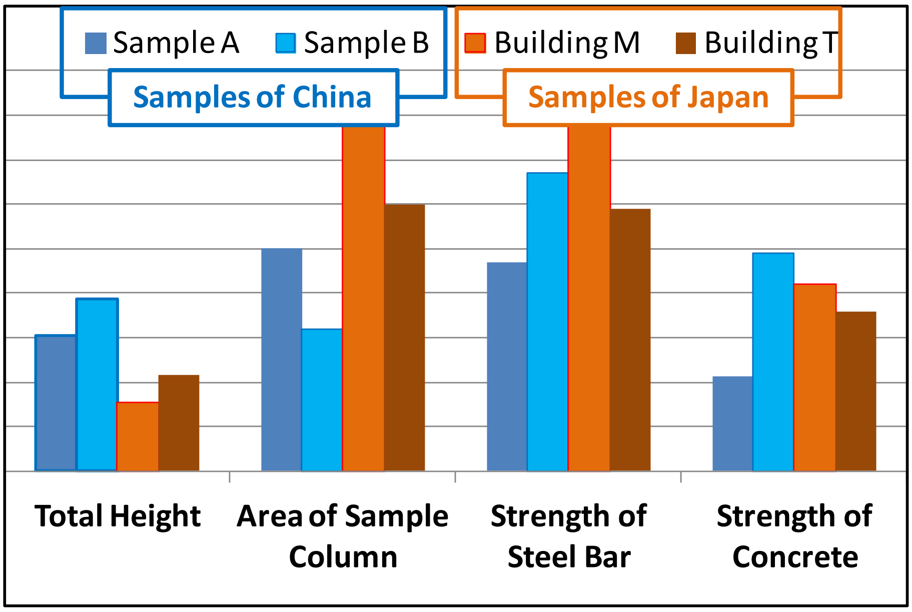


Figure 5-1 Characteristics and comparison of sample buildings

The comparison shows that sample buildings of Japan have larger columns, stranger steel bars and concretes even though the total heights of buildings are nearly half of sample buildings of China.

It suggests that probably seismic performance of sample buildings of Japan is better than that of China in general.

5.2 Comparison of Concept of Seismic Evaluation Methods

As shown in the following figure, although the calculations of seismic capacity index of two methods are not exactly the same, when we take their different judgment conditions into consideration, the final equations are getting to be similar.

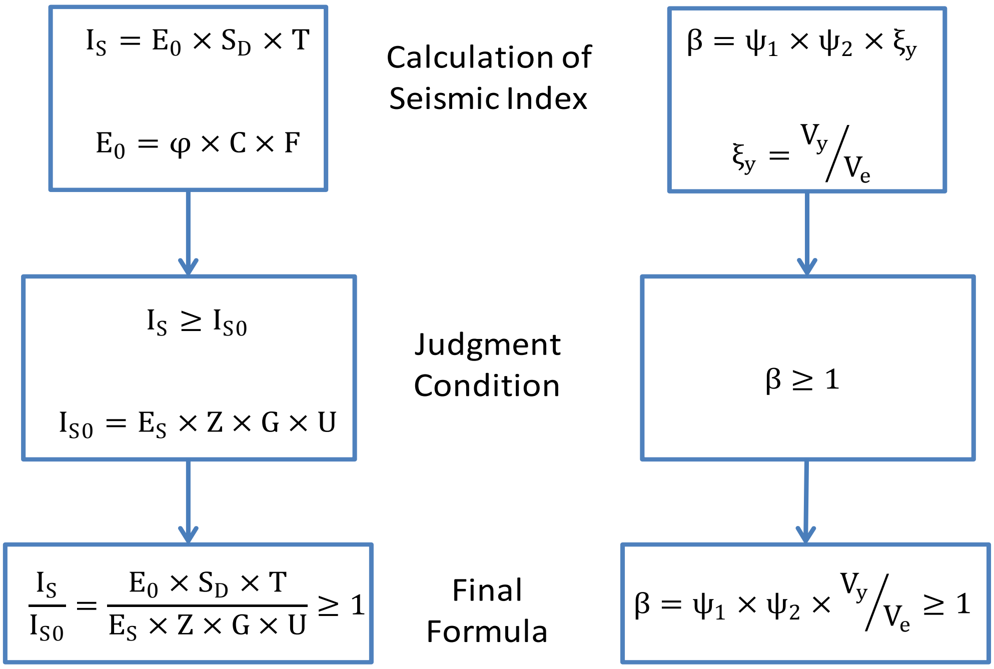


Figure 5-2 Calculation flow of two methods

Both of these two final equations mean that, basic capacity of structure should be larger than seismic demand with the influence of structural or nonstructural factors.

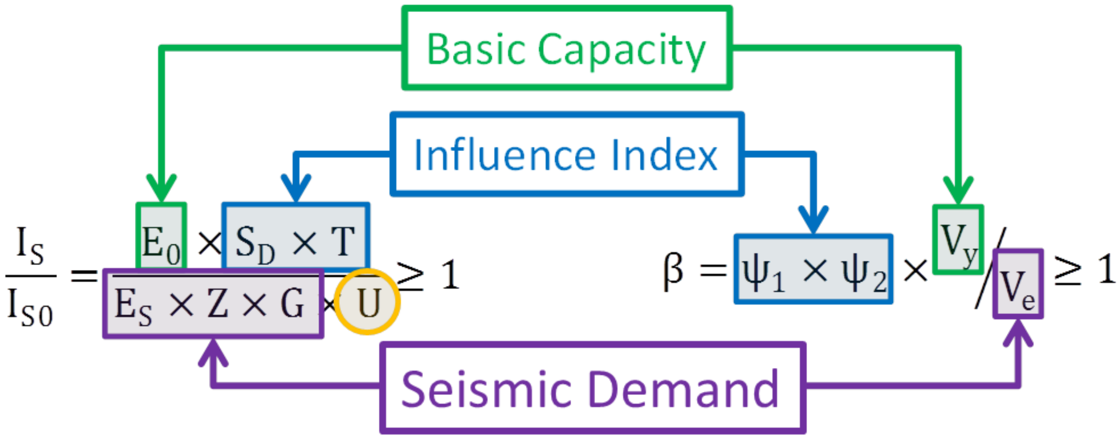


Figure 5-3 Same concept of two methods

Therefore, a common seismic index could be defined as the following equation, which equals to the ratio of basic capacity of structure to seismic demand expected in this area, multiplied by a modification index.

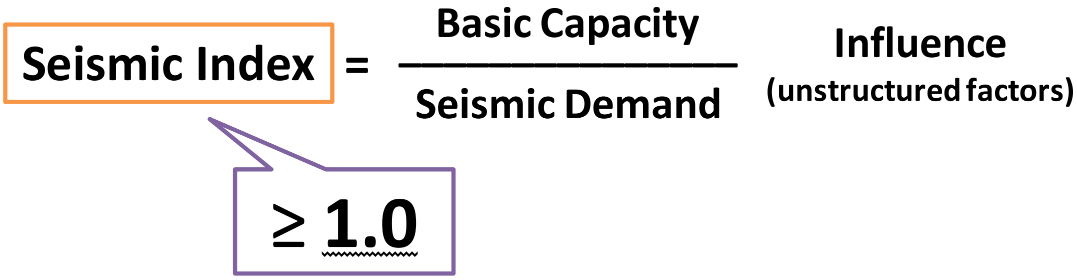


Figure 5-4 Definition of a common seismic index

Besides the similarity of concept, the following table shows several difference points between two methods of seismic evaluation general ideas.

Table 5-1 Comparison of concepts between Japan and China

	JBDPA_Japan	**GB50023_China**
Performance level	Safety limit during large earthquakes	No damage during slight earthquakes
Zone index	Z=0.7~1.0	Acc.=0.05g~0.40g
Ductility index	F=0.8 (short columns) F=1.0 (shear members) F=1.27~3.2 (flexural members)	Part of modification index
First level screening	Quantitative	Qualitative

Seismic force	Constant (0.2 or 1.0)	Decrease with period *T*

Generally, seismic evaluation method in China would get a larger value of basic capacity because of the expected better deformation ability, and a smaller seismic demand value because of the decreasing seismic force with the natural vibration period *T*, shown in the following graph:

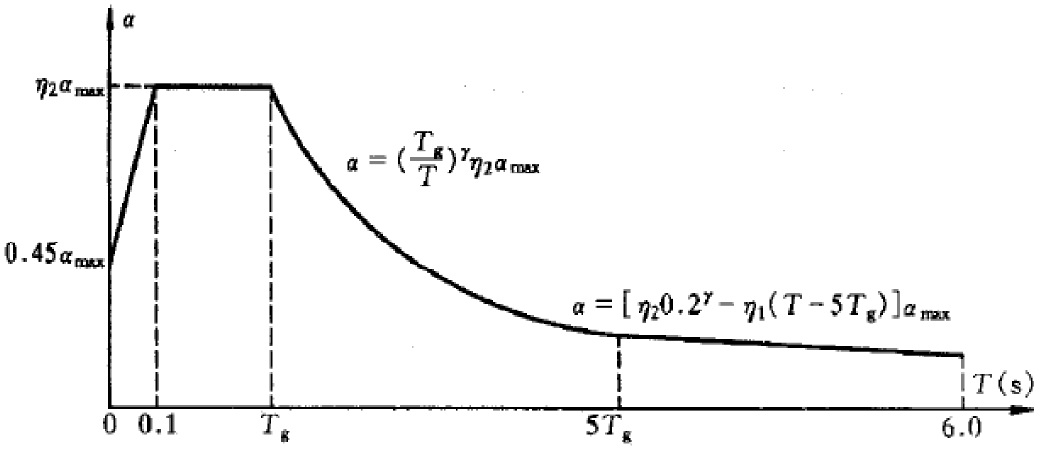


Figure 5-5 Damping of seismic demand index in China

Therefore, as the buildings getting higher, the natural vibration period *T* increases and seismic demand goes down.

5.3 Comparison and Discussion of Calculation Results

Since a common seismic index is defined in the former section, seismic results of a building calculated by two different methods could be unified into one graph with a standard demand that equals to 1.0.

From this point of view, four graphs below could be completed:

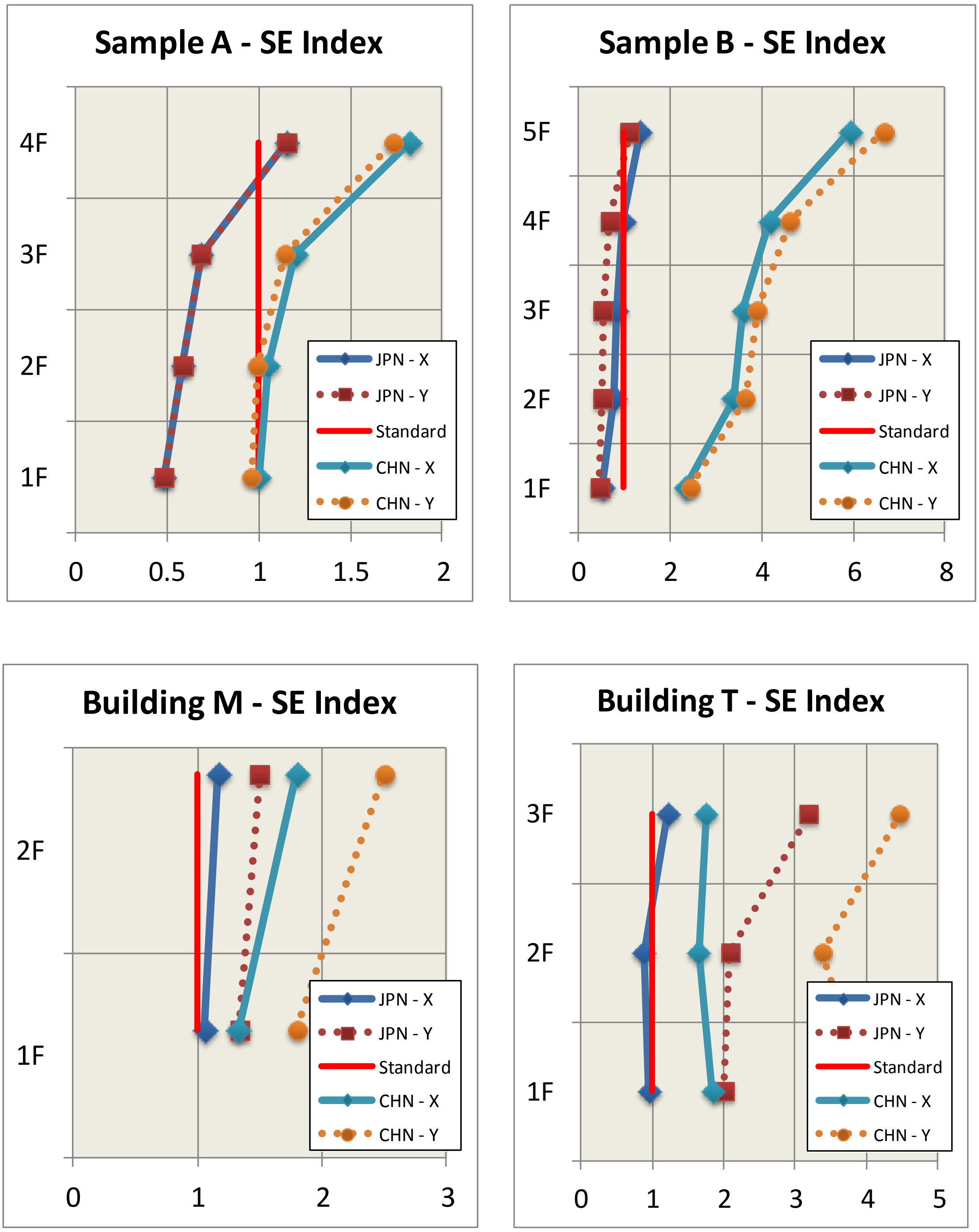


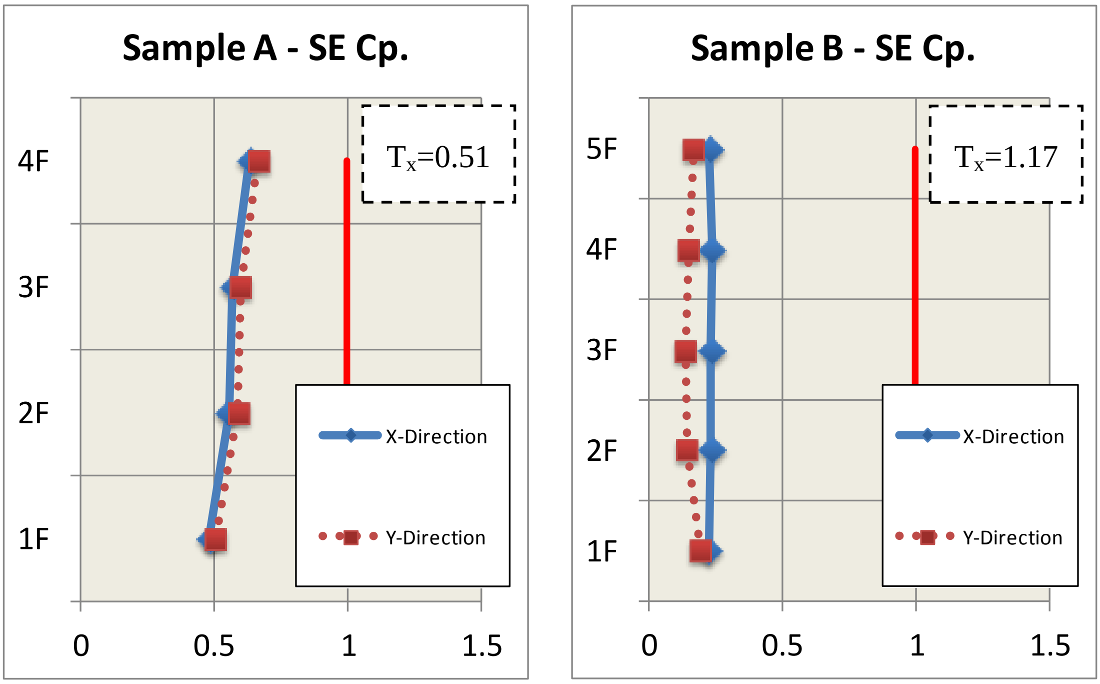
Figure 5-6 Results of all the sample buildings expressed by a common seismic index

From these graphs above, the similar tendencies, which mean the similar concept of two methods, is shown significantly.

And the prediction that same building is more likely to be identified as “safe” according to method in China is also confirmed by these graphs. Some of these sample buildings or frames failed according to the method in Japan but pass the 1.0 line according to the method in China.

In order to figure out how different between two results gotten from different methods, a seismic evaluation comparison is defined as the ratio of result in Japan to that in China, expressed by the *“SE Cp.”* graphs below.

$$\text{SE Cp.} = \frac{\text{common seismic index of Japan}}{\text{common seismic index of China}} = \frac{(I_S/I_{S0})}{\beta}$$



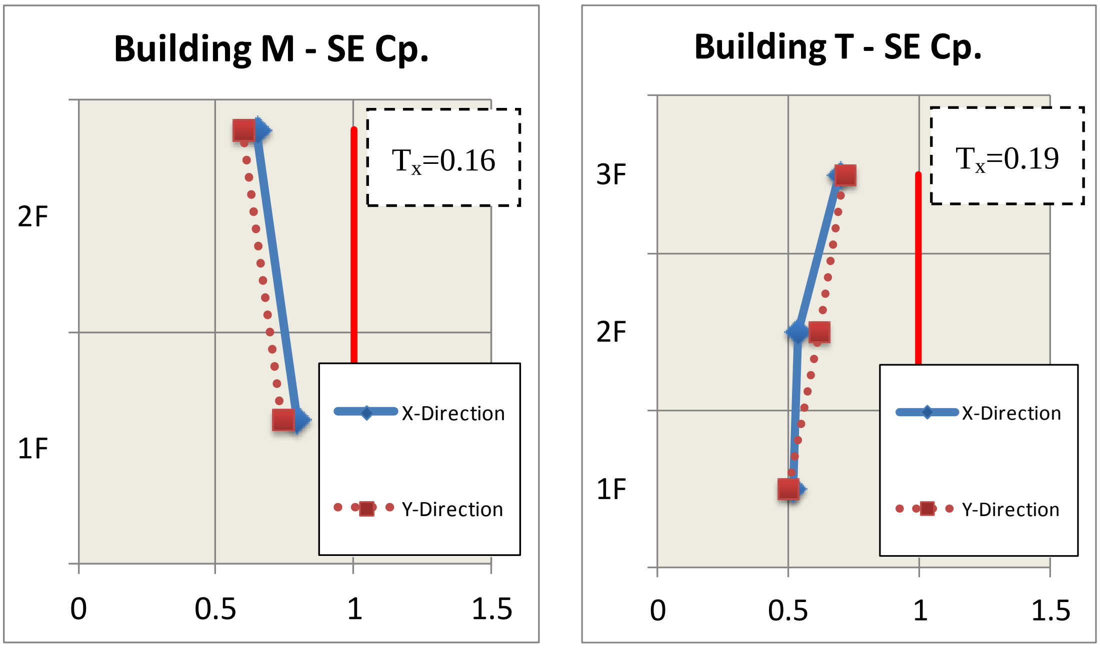


Figure 5-7 Comparison of common seismic indices of two methods

According to these results, the common seismic value of China is 15%~75% of the value of Japan.

Considering the building characteristics in the former section, as the building getting higher, the difference between two values also become larger, and the most similar results of two methods go to the two-storey sample building M.

Since there is also a relationship between building height and the natural vibration period *T*, the following graph was made to figure out the relationship between T and SE Cp. Index.

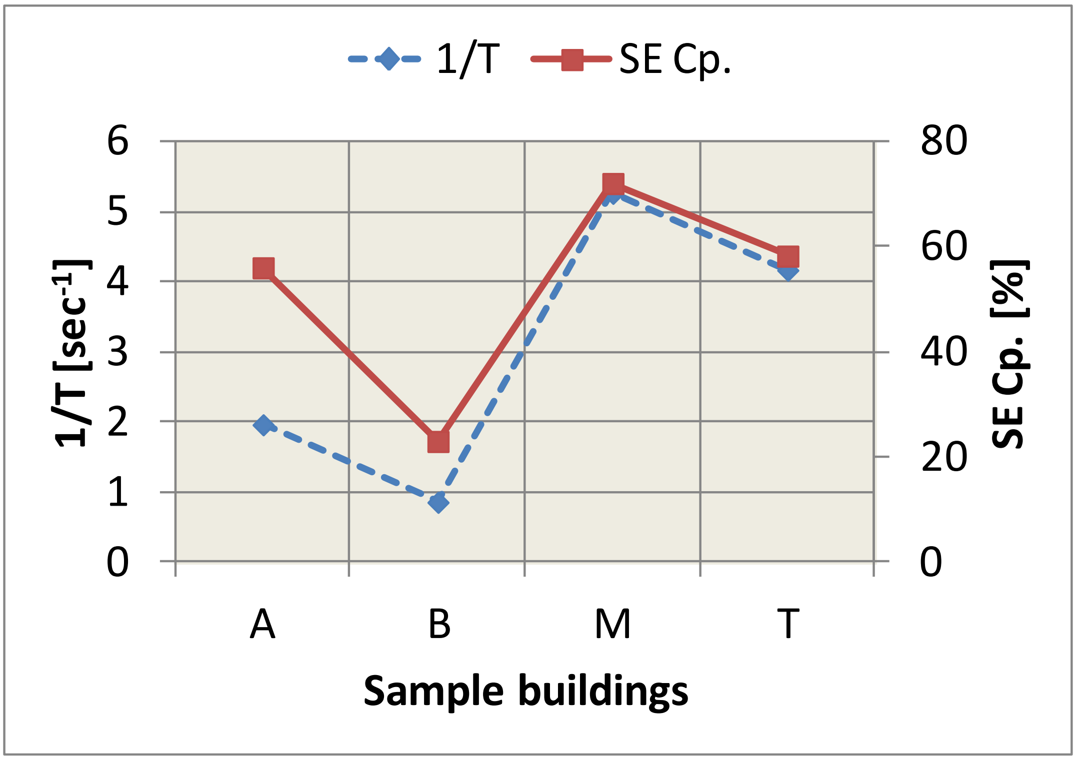


Figure 5-8 Relationship between *T* and SE Cp.

From this graph above, it is significant that, the SE Cp. Index is inversely proportional to the natural vibration period *T*.

In another word, building natural vibration period has influence on how much difference between seismic evaluation results from two methods.

Chapter 6. Conclusions and Future Extensions

6.1 Conclusions

Main conclusions of this research are summarized as follows:

- Seismic engineering has longer history in Japan than that in China, but general idea of seismic evaluation methods in two countries is similar.
- Both methods of seismic evaluation are based on the strength and deformation capacity of each member or frame, and combined with some influence of unstructured factors such as modification index.
- Evaluation of seismic demand in Japan is based on a large earthquake with an acceleration of ground motion 0.60g~1.00g. On the other hand, acceleration of ground motion is taken as 0.05g~0.40g in China.
- Deformation capacity of different RC buildings changes from F=0.8 to 3.2 in Japan, while deformation capacity of buildings in China is considered as unstructured influence and much better than that in Japan.
- Since seismic demand in China decreases with the natural vibration period *T* of the target building, difference between results from two methods is bigger in high-rise buildings.

6.2 Recommendations for Future Work

The following problems have been left and further researches are needed to be worked out:

- It is significantly beneficial to make further communications between countries, but only between Japan and China, and share experiences in field of seismic engineering.
- More sample buildings should be selected and investigated in order to get more universalistic and accurate results.
- Seismic evaluation results of different methods should also be compared with the actual damage occurred during the earthquakes or computer simulation results.

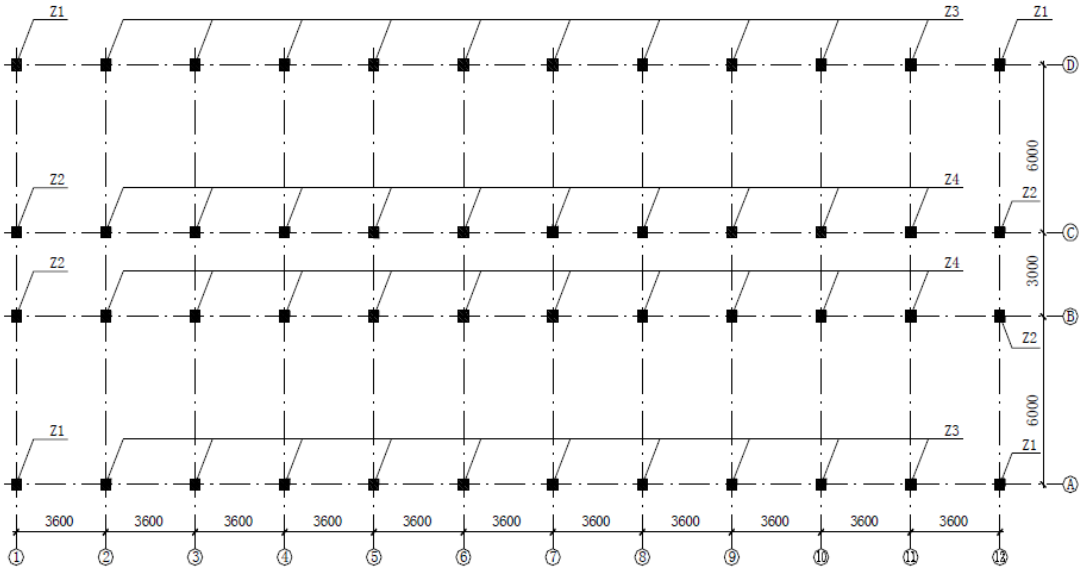
Part of pushover analysis result of Building M is given in the Appendix C.

- Calculation should be made more deeply and minutely to make the qualitative conclusions more quantitative, figure out more fine distinctions in order to find weakness of each method and to make a improvement in the future.
- Plentiful information concealing in the influence factors should be also analyzed since the nonstructural members are playing important roles in modern buildings and create humanitarian crisis during disasters.

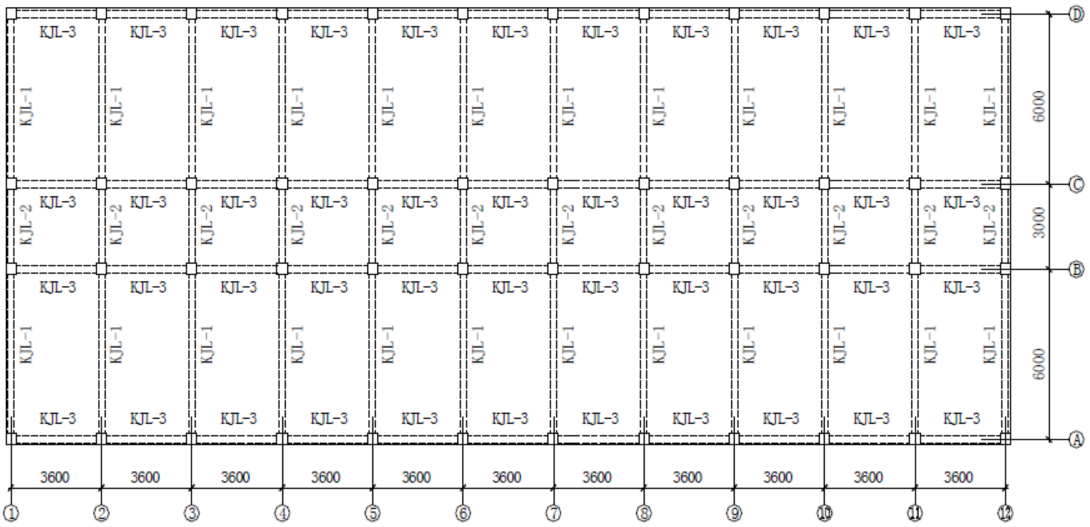
Appendix A Detailed Drawings of Sample Buildings

Appendix A Detailed Drawings of Sample Buildings

1. Sample building A

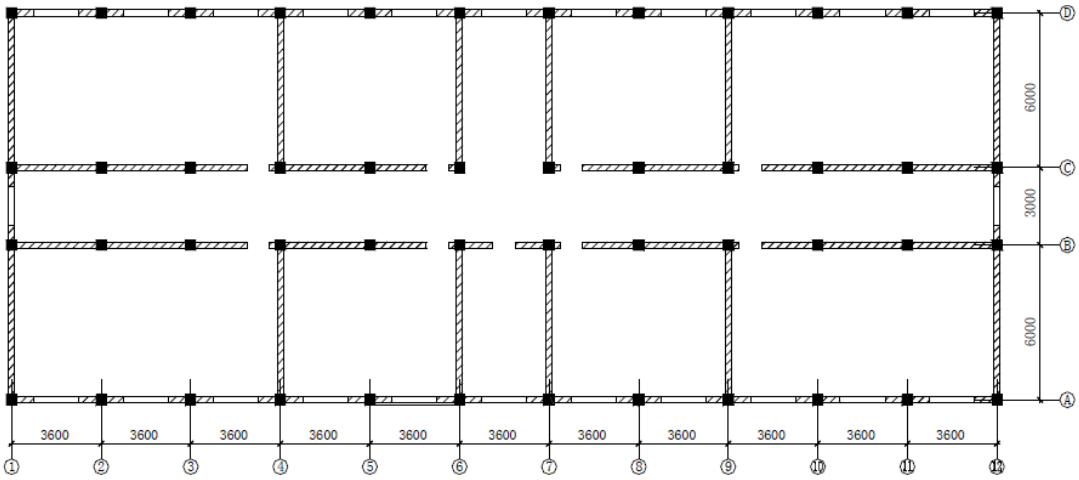


Column arrangement

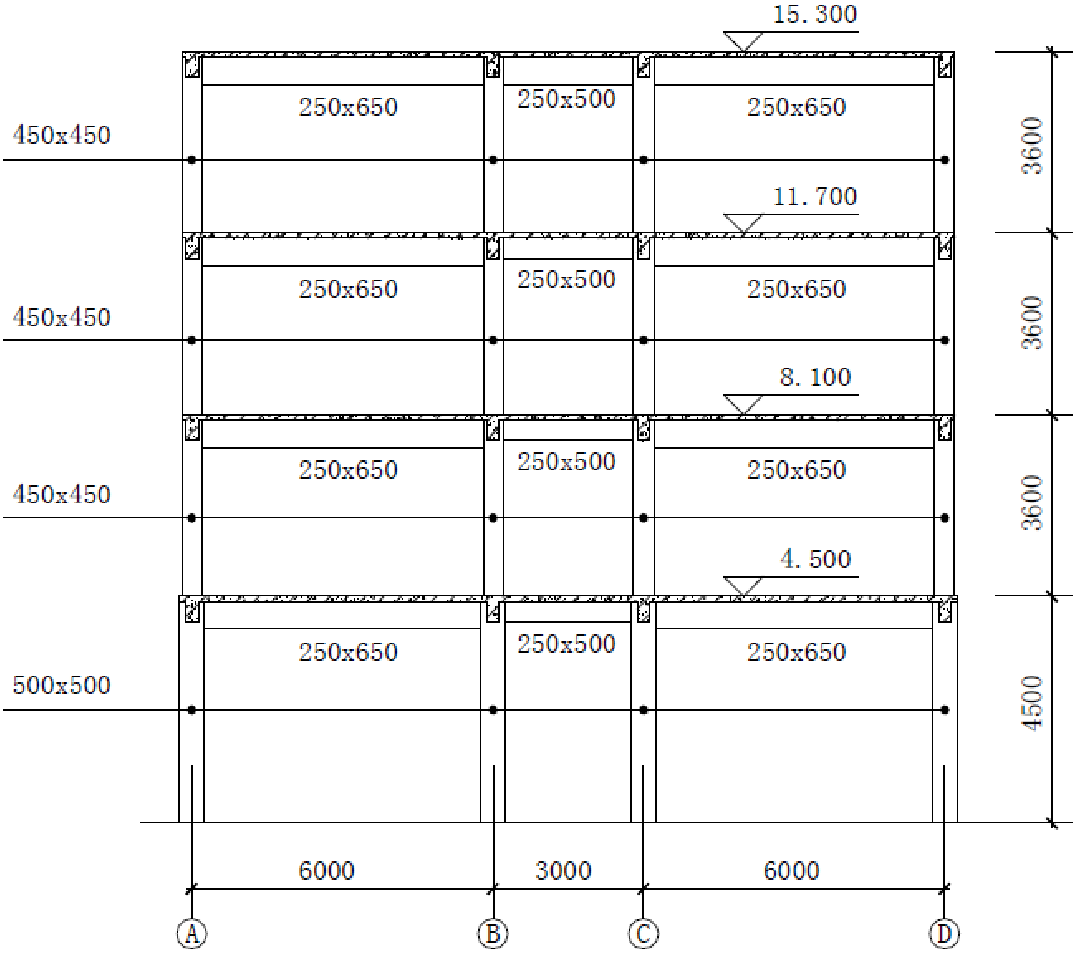


Beam arrangement

Appendix A Detailed Drawings of Sample Buildings



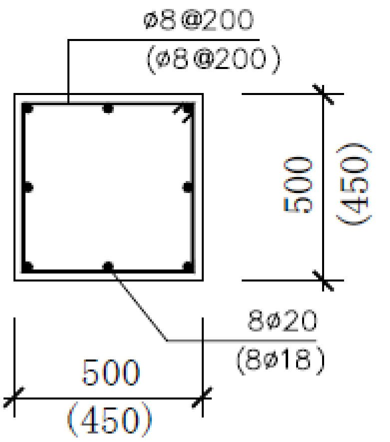
Infill walls



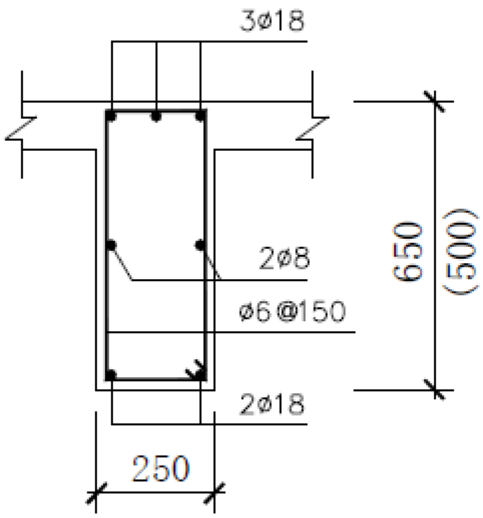
Typical section

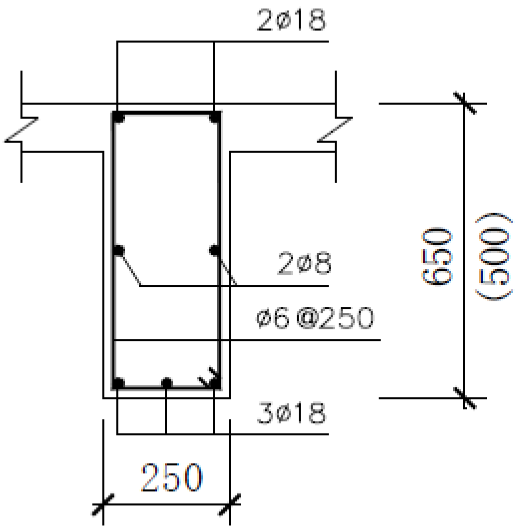
A

Typical columns

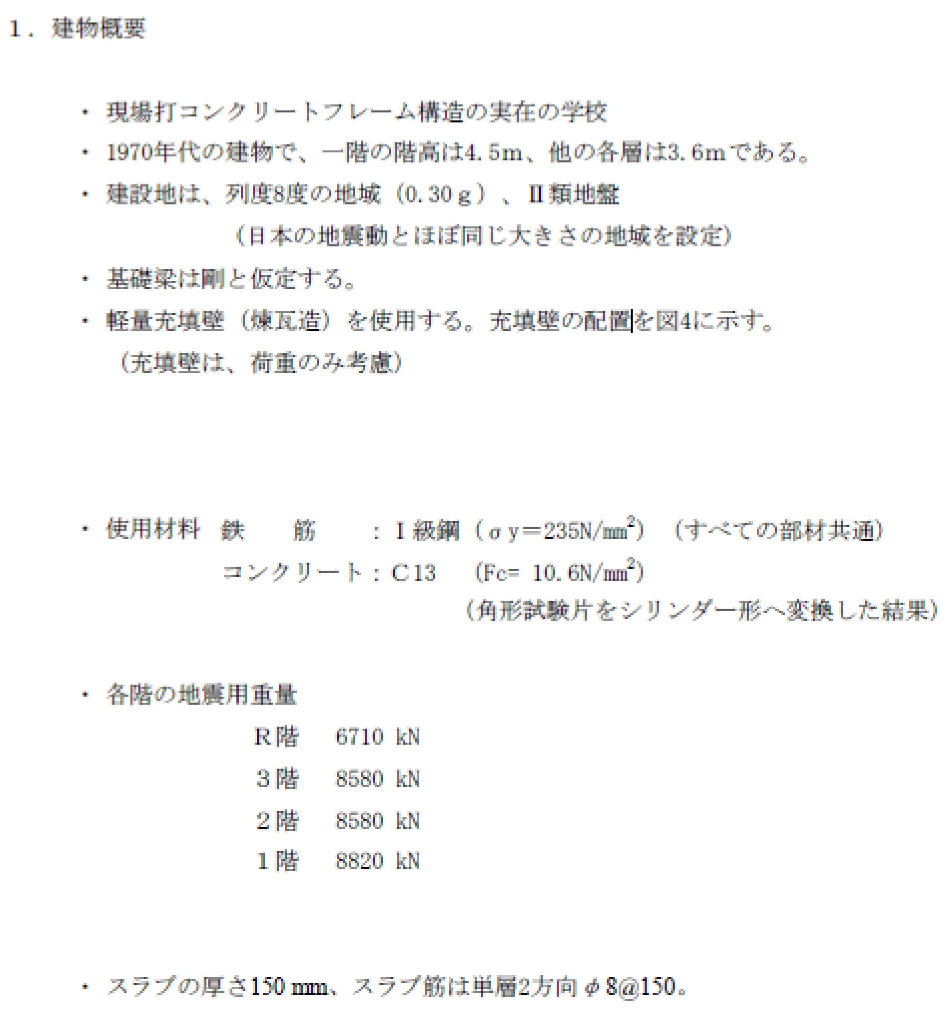


Typical beams





Appendix A Detailed Drawings of Sample Buildings



1．建物概要

- 現場打コンクリートフレーム構造の実在の学校
- 1970年代の建物で、一階の階高は4.5m、他の各層は3.6mである。
- 建設地は、列度8度の地域（0.30ｇ）、Ⅱ類地盤
  （日本の地震動とほぼ同じ大きさの地域を設定）
- 基礎梁は剛と仮定する。
- 軽量充填壁（煉瓦造）を使用する。充填壁の配置を図4に示す。
  （充填壁は、荷重のみ考慮）

- 使用材料　鉄　　筋　　：Ⅰ級鋼（$\sigma y=235\mathrm{N/mm^2}$）（すべての部材共通）
  コンクリート：C13　（$Fc=10.6\mathrm{N/mm^2}$）
  （角形試験片をシリンダー形へ変換した結果）

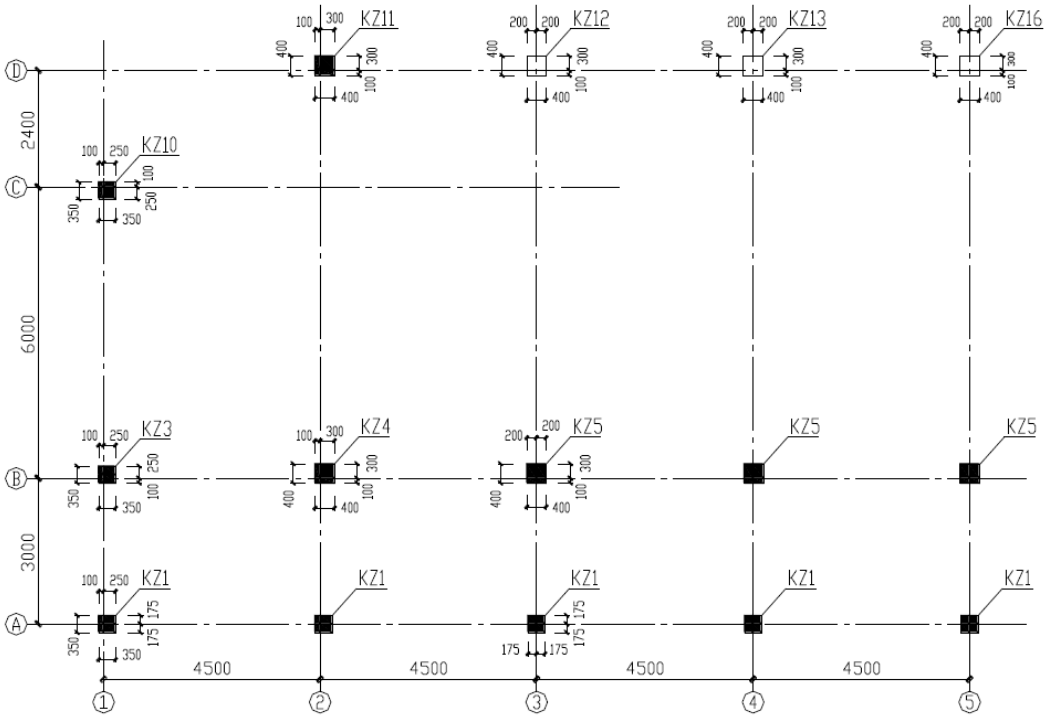
- 各階の地震用重量

R階	6710 kN
3階	8580 kN
2階	8580 kN
1階	8820 kN

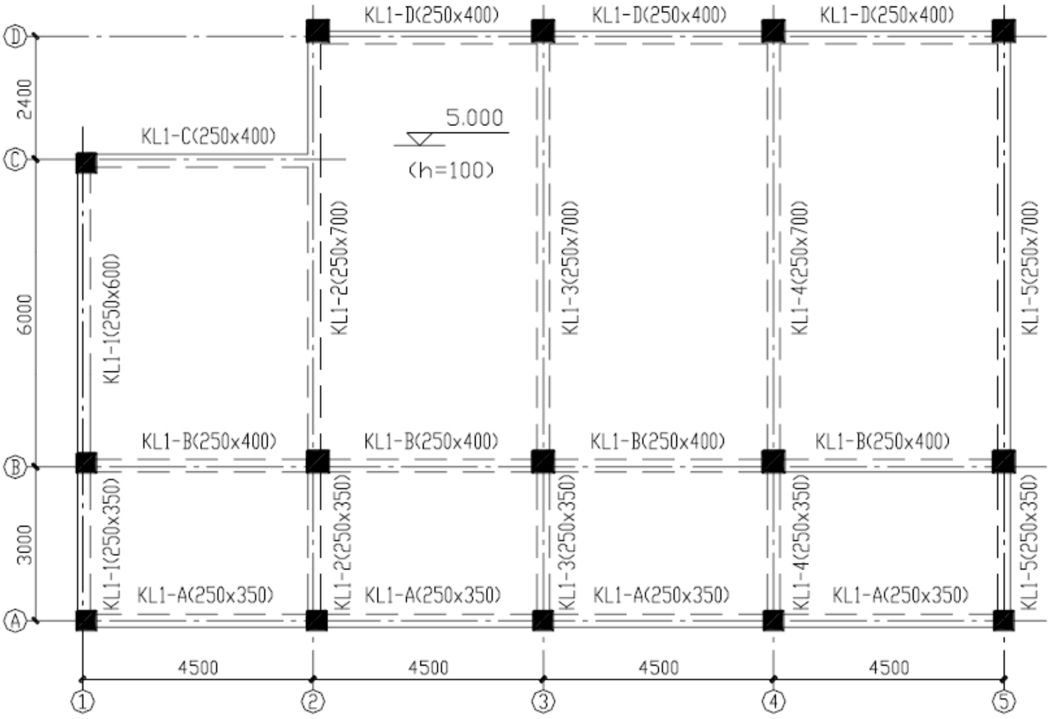
- スラブの厚さ150 mm、スラブ筋は単層2方向 ϕ 8@150。

Building information for seismic evaluation

2. Sample building B

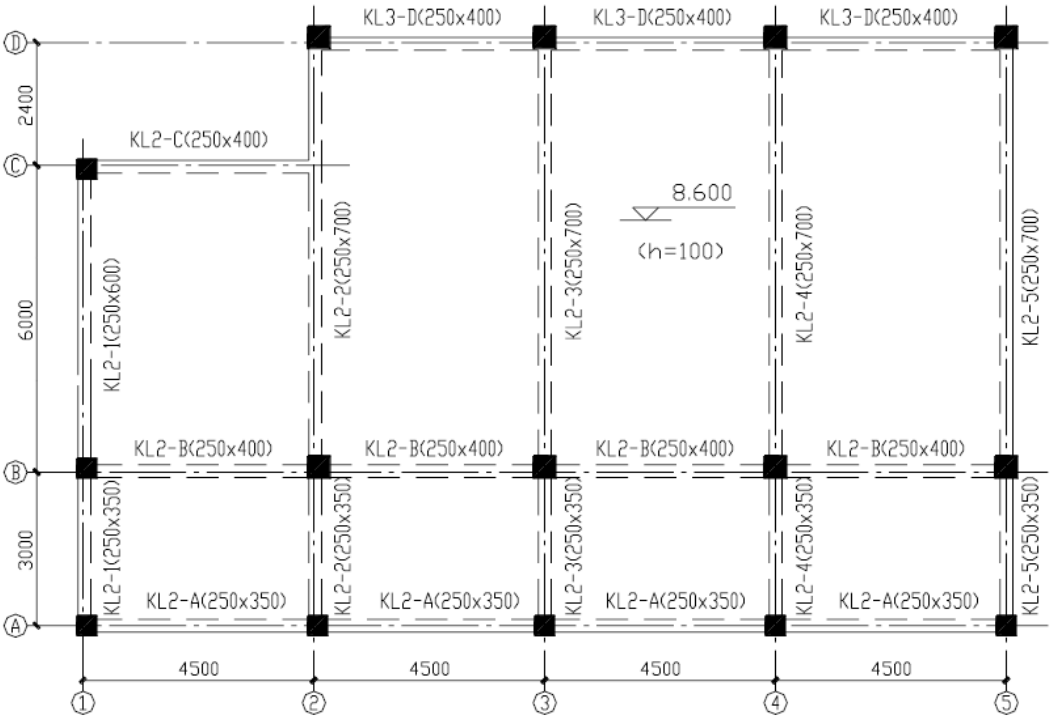


Column arrangement

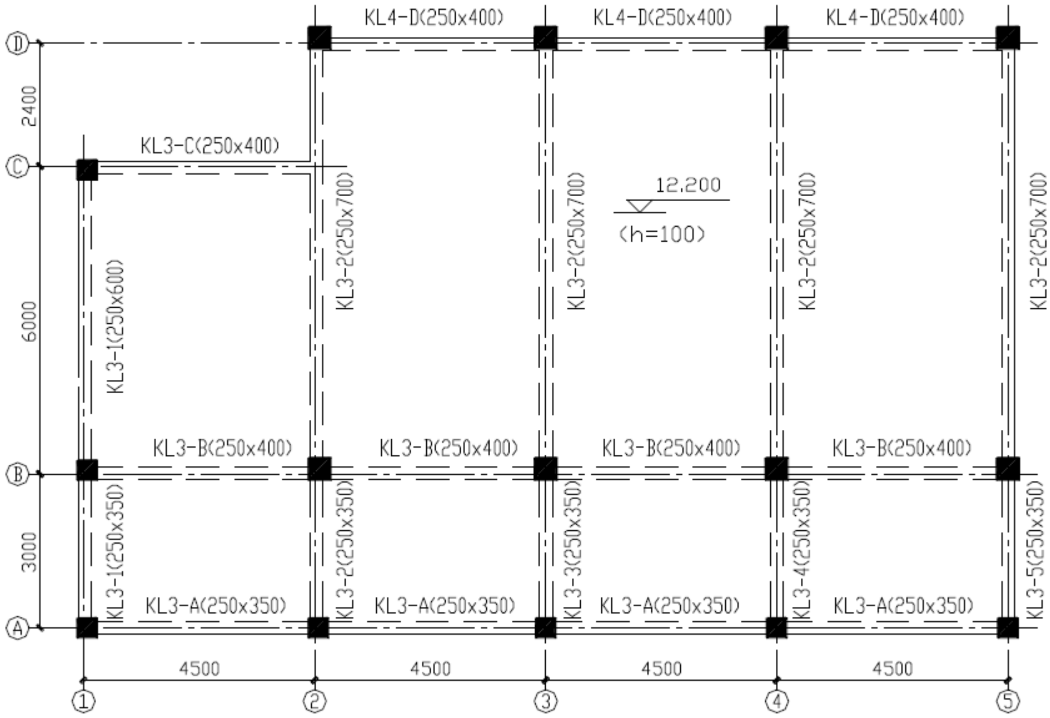


Plan of 1st floor

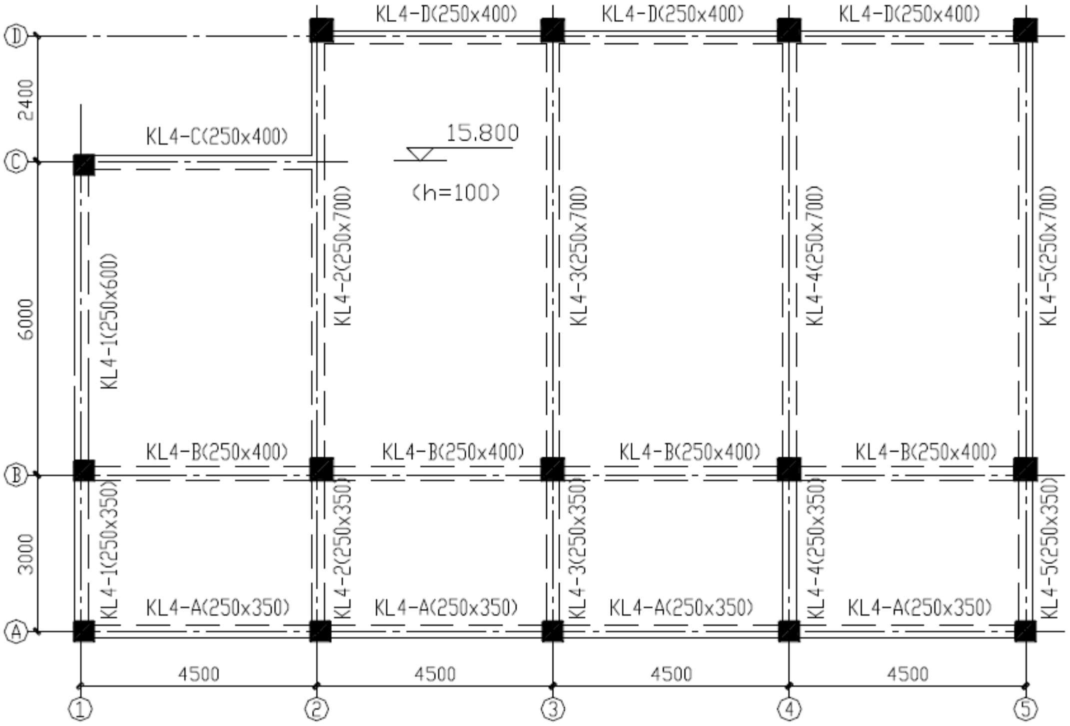
Appendix A Detailed Drawings of Sample Buildings



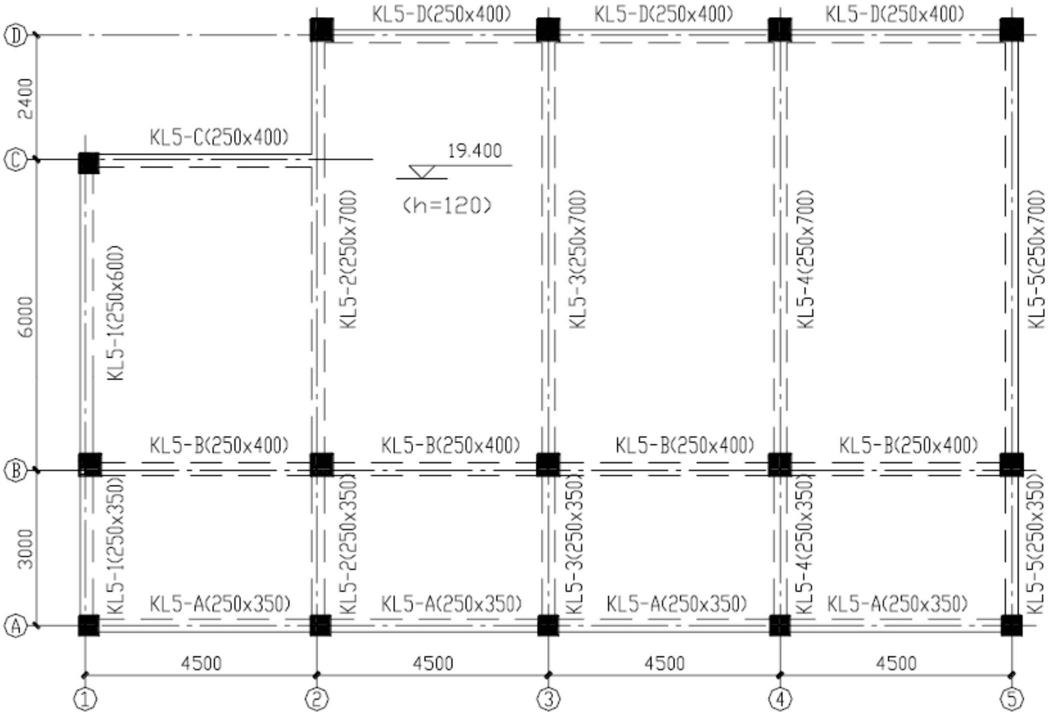
Plan of 2nd floor



Plan of 3rd floor

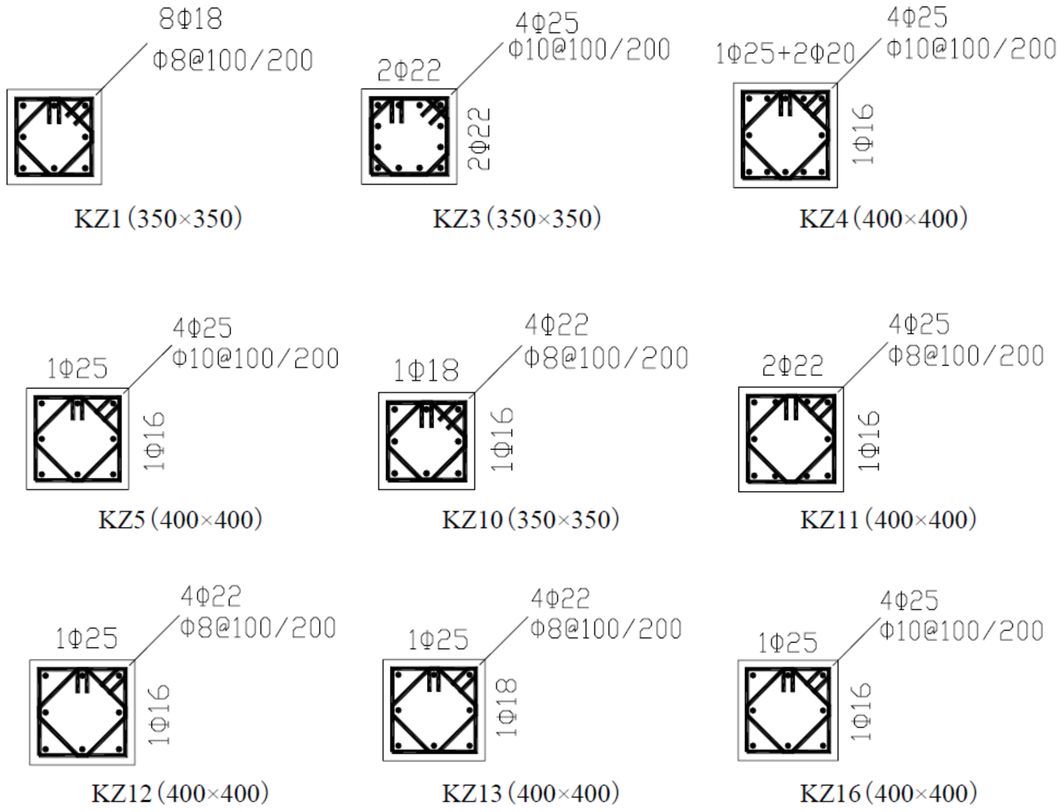


Plan of 4th floor



Plan of 5th floor

Appendix A Detailed Drawings of Sample Buildings



KZ1 (350×350) KZ3 (350×350) KZ4 (400×400)

KZ5 (400×400) KZ10 (350×350) KZ11 (400×400)

KZ12 (400×400) KZ13 (400×400) KZ16 (400×400)

Section of columns

コンクリートの強度等級は C30（日本の fc=24.5 に相当する)。

規格値（単位 N/mm^2）:

軸圧縮応力 f_{ck}=20.0、曲げ圧縮応力 f_{cmk}=22.0、軸引張応力 f_{tk}=2.0

設計値（単位 N/mm^2）:

軸圧縮応力 f_{ck}=15.0、曲げ圧縮応力 f_{cmk}=16.5、軸引張応力 f_{tk}=1.5

弾性係数：3.0*10^4 N/mm^2

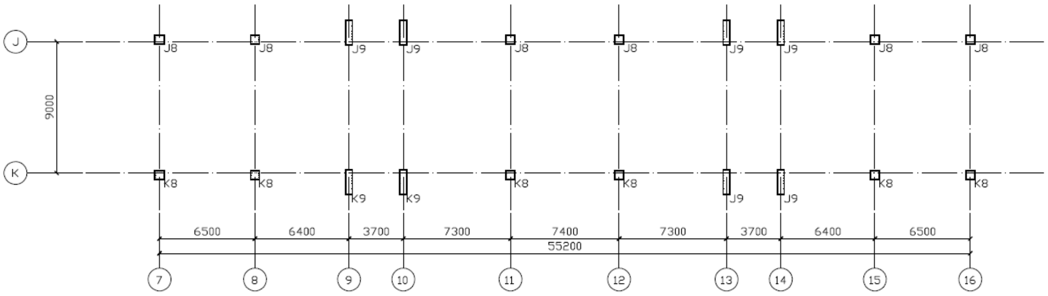
部材の主筋は、旧 II 級鋼を用いる。

強度規格値 f_{yk}=335 N/mm^2、設計値 f_y=310 N/mm^2。

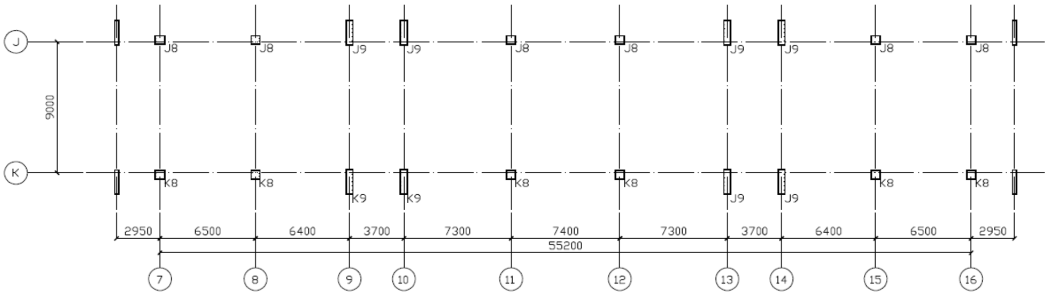
部材の肋筋は、旧 I 級鋼を用いる。

強度規格値 f_{yk}=235 N/mm^2、設計値 f_y=210 N/mm^2。

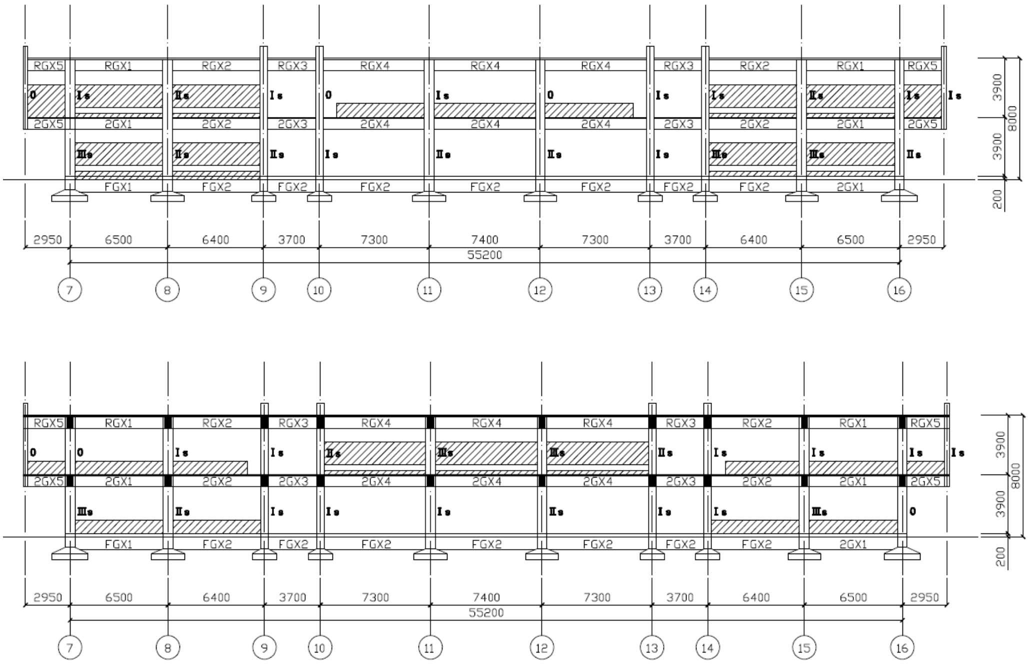
3. Sample building M



Plan of 1st floor

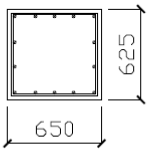
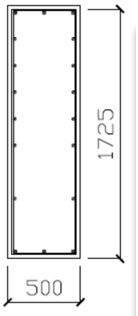
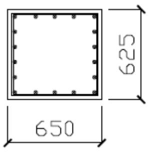
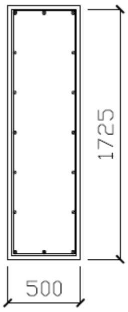


Plan of 2nd floor



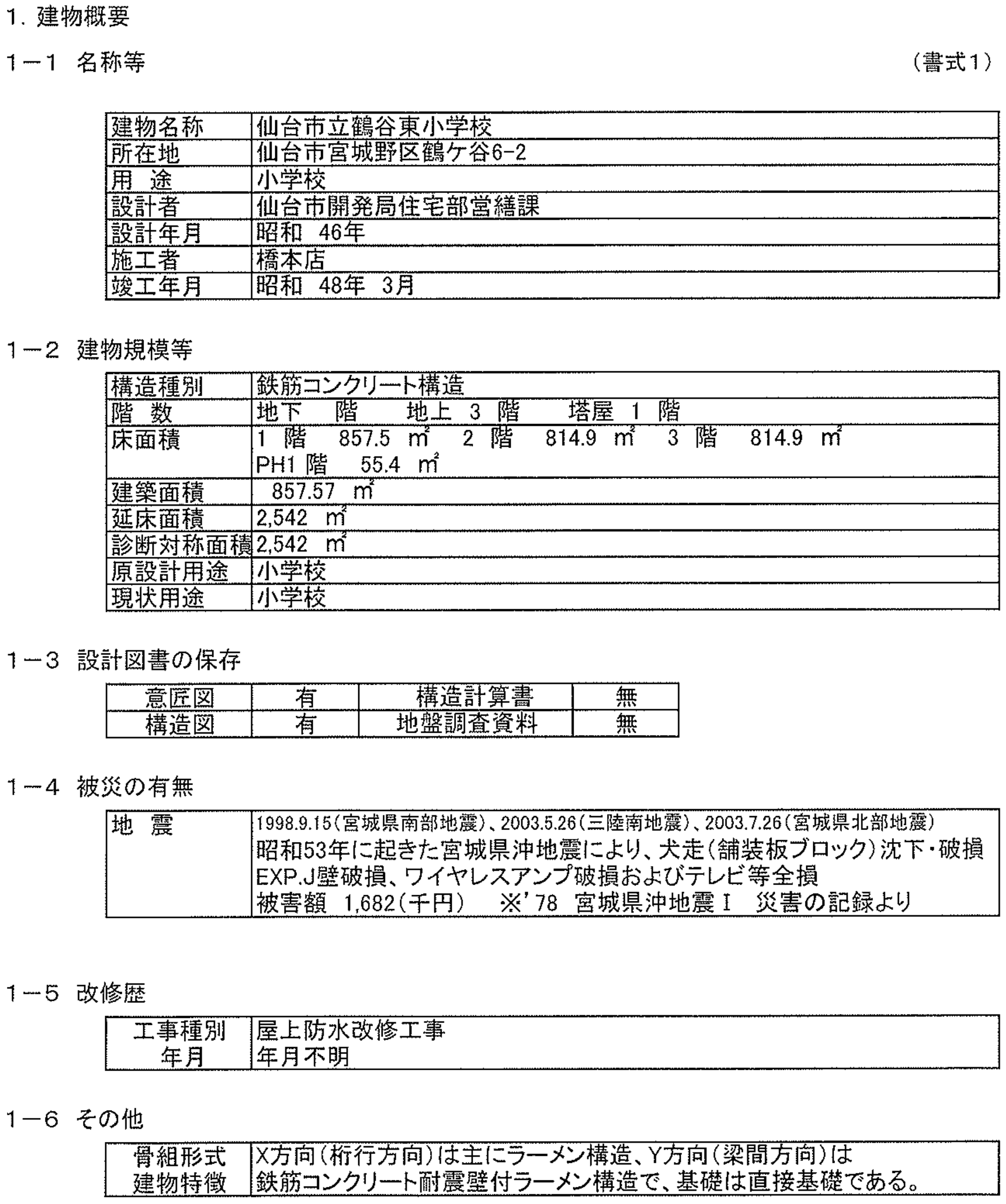
Sections

Appendix A Detailed Drawings of Sample Buildings

Column		Section	Steel bar	X direction	Y direction	Hoop
1F	K8/J8		18-D25	5-D25	6-D25	ϕ9@250
	K9/J9		6-D25, 12-D22	3-D25	2-D25, 6-D22	ϕ9@250
2F	K8/J8		14-D22	5-D22	4-D22	ϕ9@250
	K9/J9		6-D25, 10-D22	3-D25	2-D25, 5-D22	ϕ9@250

Typical columns and beams

4. Sample building T



１．建物概要

１－１　名称等

（書式１）

建物名称	仙台市立鶴谷東小学校
所在地	仙台市宮城野区鶴ケ谷6-2
用　途	小学校
設計者	仙台市開発局住宅部営繕課
設計年月	昭和　46年
施工者	橋本店
竣工年月	昭和　48年　3月

１－２　建物規模等

構造種別	鉄筋コンクリート構造
階　数	地下　　階　　地上　3　階　　塔屋　1　階
床面積	1　階　　857.5　㎡　　2　階　　814.9　㎡　　3　階　　814.9　㎡ PH1 階　　55.4　㎡
建築面積	857.57　㎡
延床面積	2,542　㎡
診断対称面積	2,542　㎡
原設計用途	小学校
現状用途	小学校

１－３　設計図書の保存

意匠図	有	構造計算書	無
構造図	有	地盤調査資料	無

１－４　被災の有無

地　震	1998.9.15（宮城県南部地震）、2003.5.26（三陸南地震）、2003.7.26（宮城県北部地震） 昭和53年に起きた宮城県沖地震により、犬走（舗装板ブロック）沈下・破損 EXP.J壁破損、ワイヤレスアンプ破損およびテレビ等全損 被害額　1,682（千円）　※'78　宮城県沖地震Ⅰ　災害の記録より

１－５　改修歴

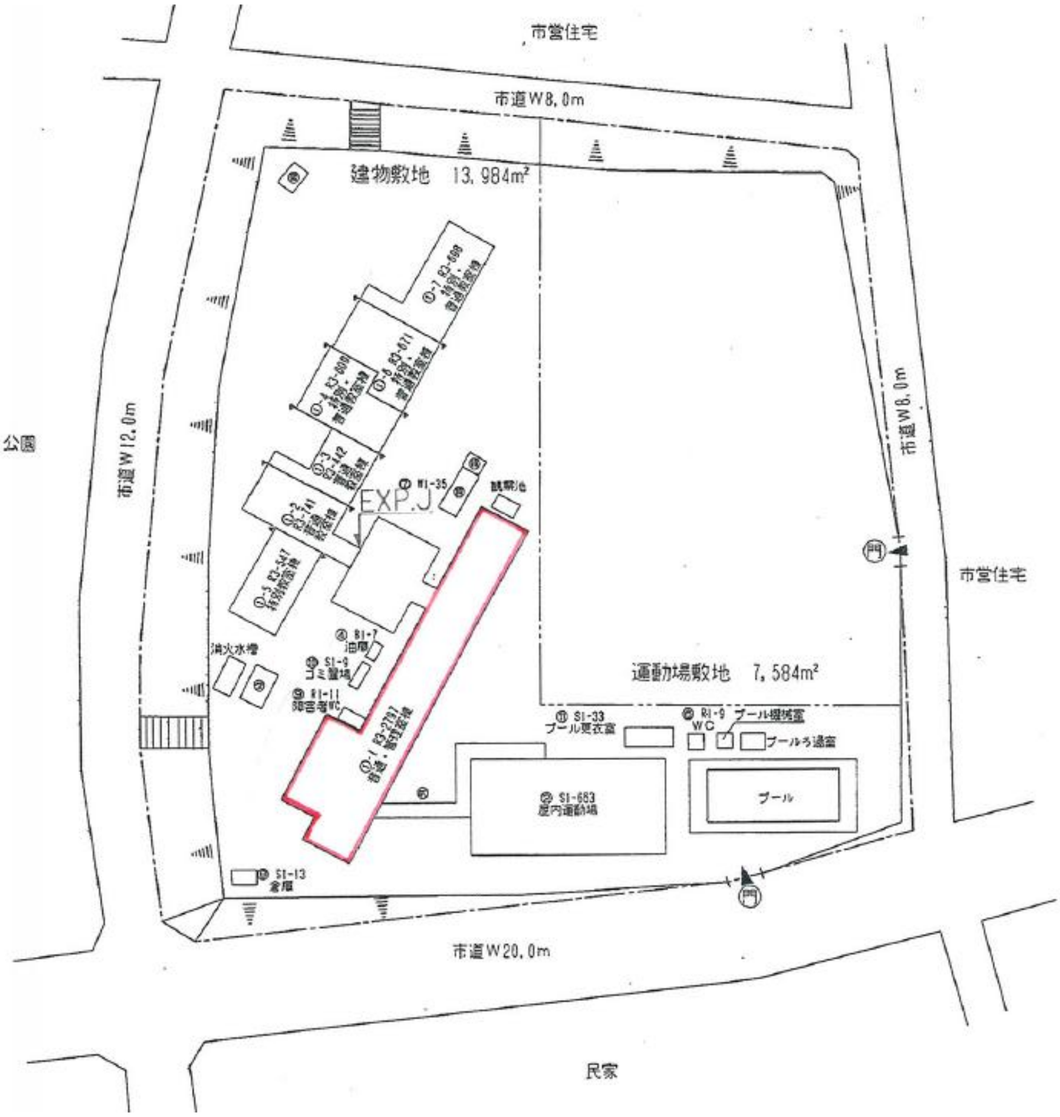
工事種別	屋上防水改修工事
年月	年月不明

１－６　その他

骨組形式	X方向（桁行方向）は主にラーメン構造、Y方向（梁間方向）は
建物特徴	鉄筋コンクリート耐震壁付ラーメン構造で、基礎は直接基礎である。

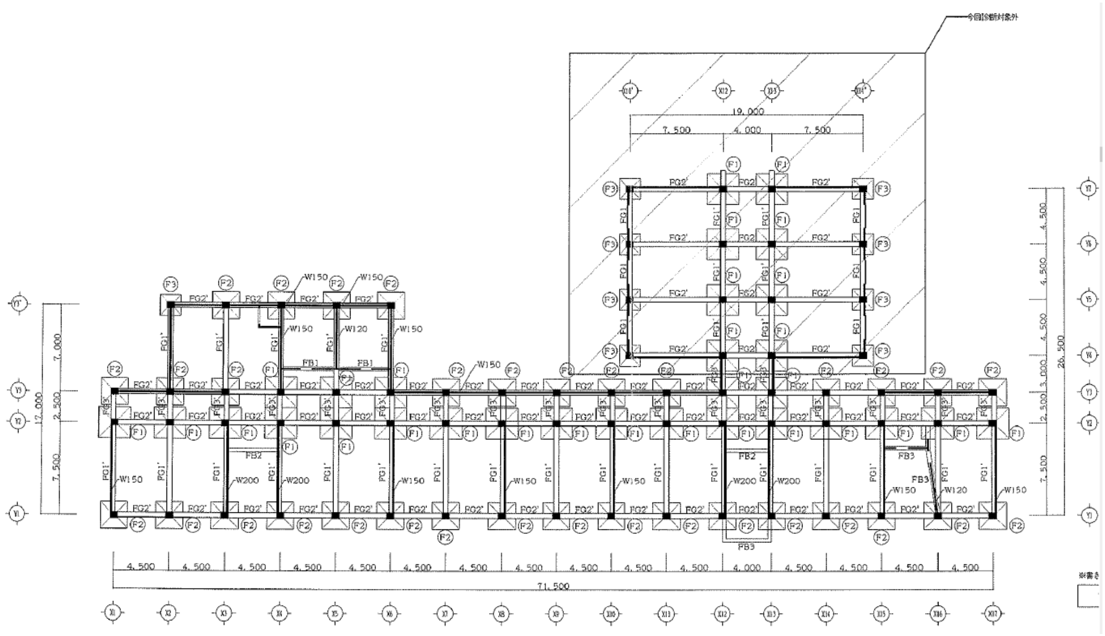
Building information

Appendix A Detailed Drawings of Sample Buildings

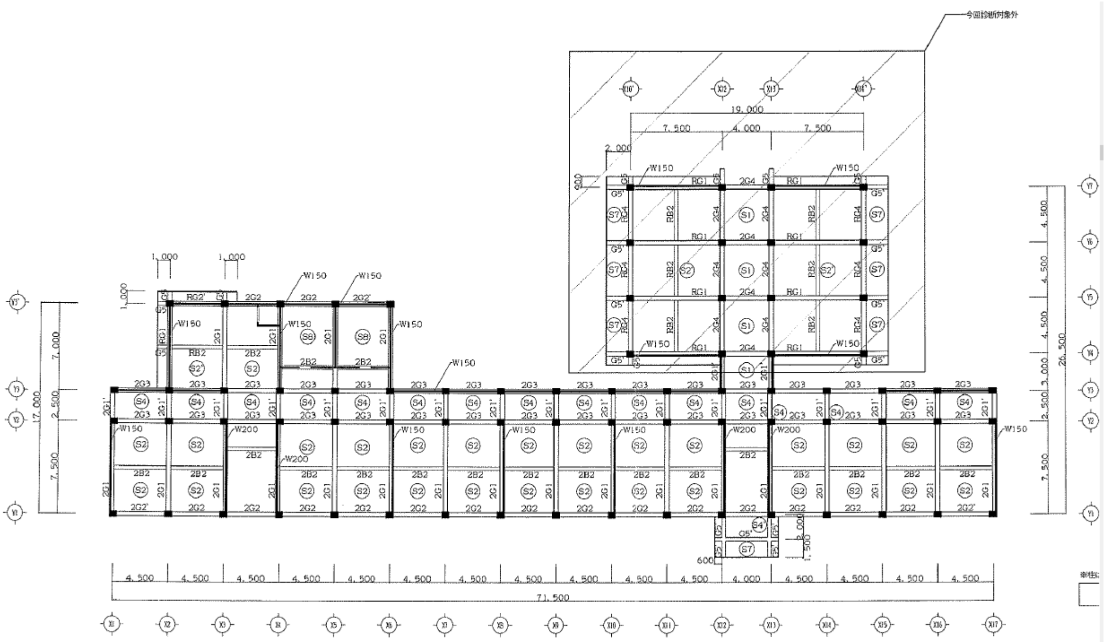


Location and surroundings

A

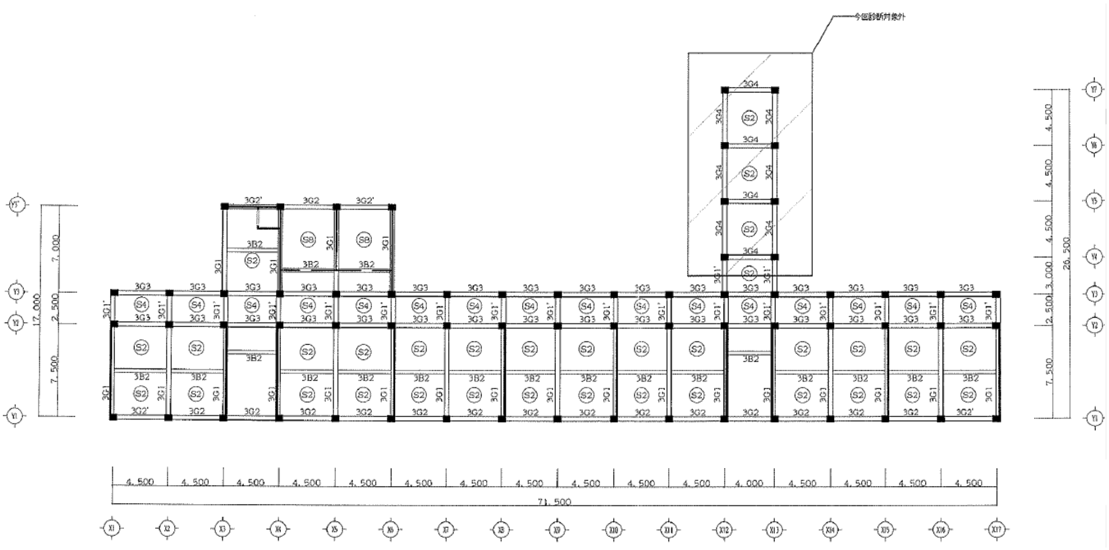


Plan of 1st floor

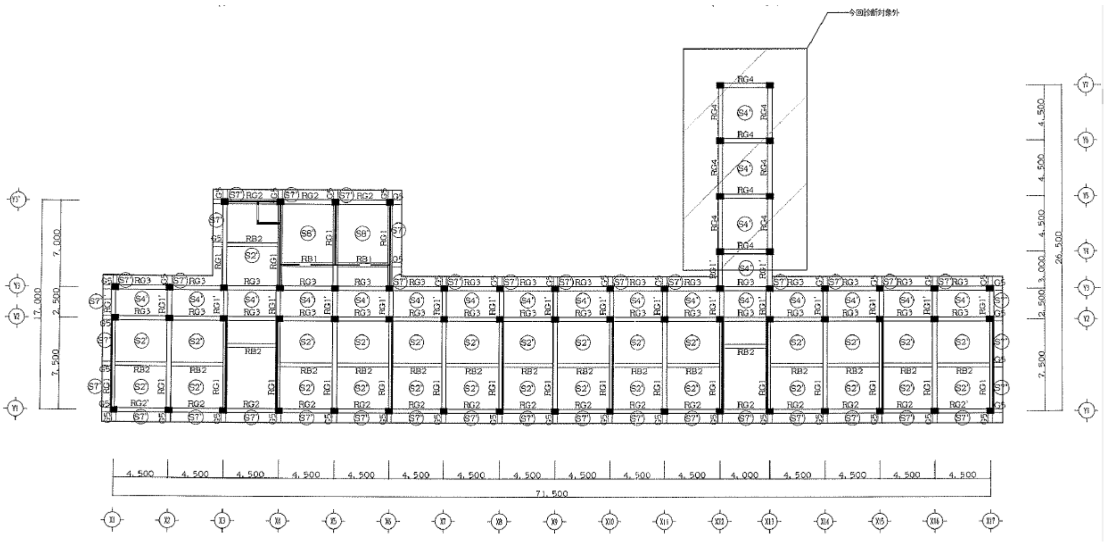


Plan of 2nd floor

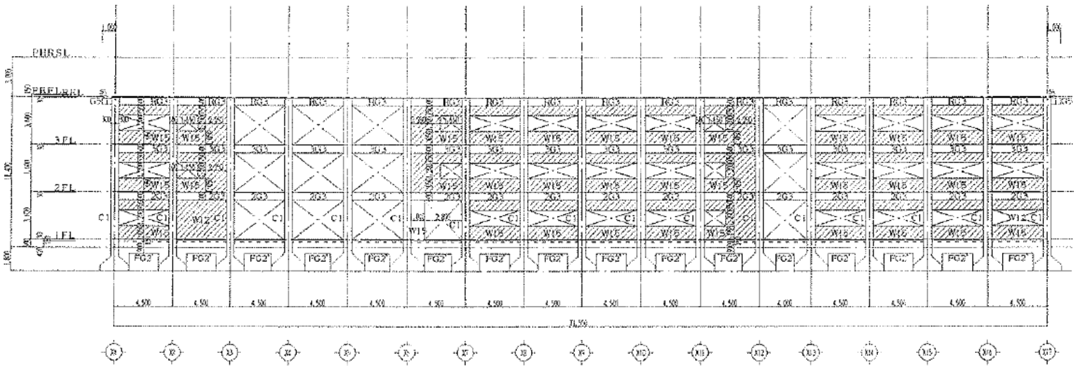
Appendix A Detailed Drawings of Sample Buildings



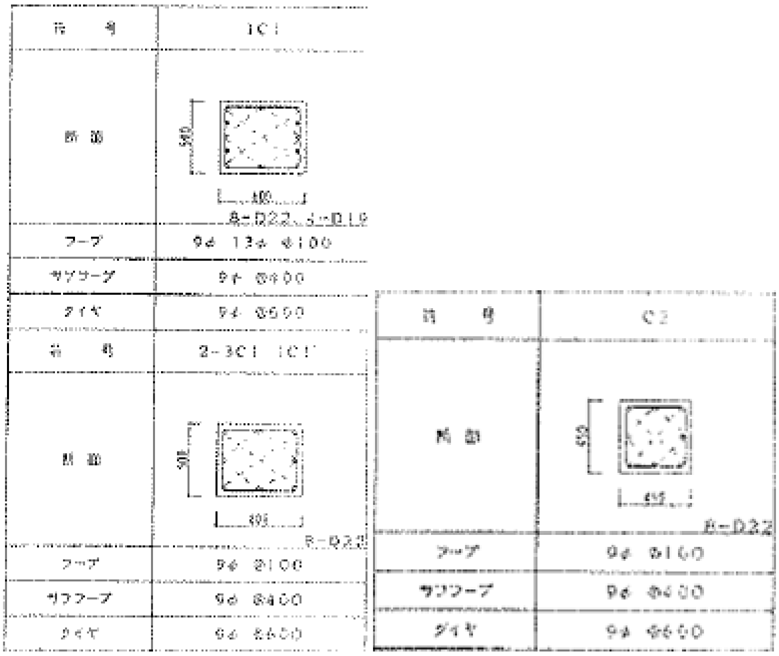
Plan of 3rd floor



Plan of roof



Section



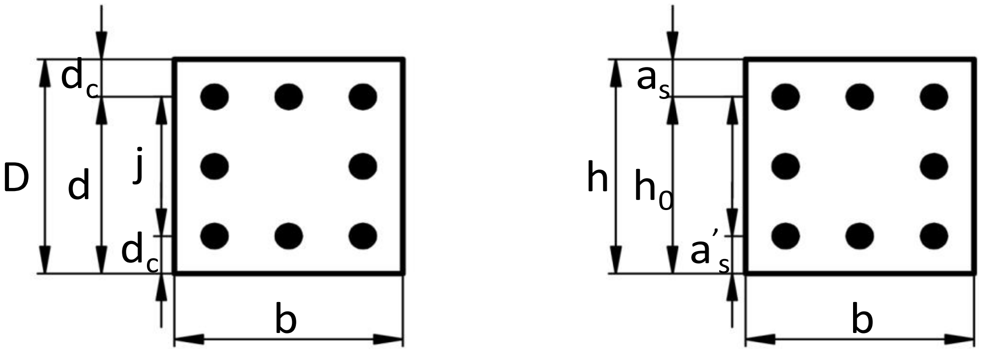
符　号	1C1
断面	500 400 8-D22, 4-D19
フープ	9φ 13φ @100
サブフープ	9φ @400
ダイヤ	9φ @600

符　号	2-3C1 1C1'
断面	500 405 8-D22
フープ	9φ @100
サブフープ	9φ @400
ダイヤ	9φ @600

符　号	C2
断面	450 455 8-D22
フープ	9φ @100
サブフープ	9φ @400
ダイヤ	9φ @600

Typical columns

Appendix B Coincidence Relation of Parameters



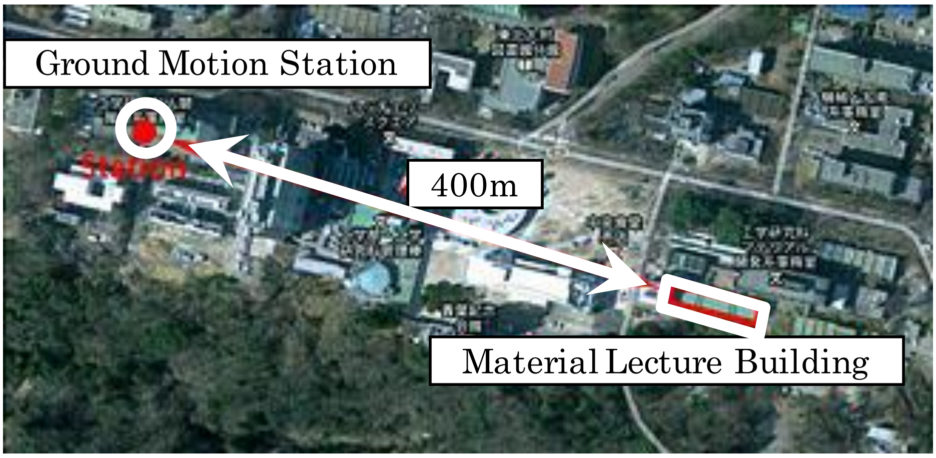
Section of sample column

Japan	**China**	**Meaning**
Measurement		
b	b	column width (mm)
D	h	column depth (mm)
d (D-50)	h_0 (h-a_s)	effective depth of column (mm)
(h_0/2d)	λ ($H_n/2h_0$)	ratio of shear span to effective depth (mm)
j (0.8D)	(h_0-a'_s)	distance between centroids of tension and compression forces (mm)
d_c	a'_s	
a_t	A_s	total cross sectional area of tensile reinforcing bars (mm^2)
a_w	A_{sv}	total cross sectional area of shear reinforcing bars (mm^2)

Appendix B Coincidence Relation of Parameters

p_t (a_t/bD)	(A_s/bh)	tensile reinforcement ratio (%)
p_w (a_w/bx)	(A_{sv}/bs)	shear reinforcement ratio
x	s	spacing of hoops (mm)
H_0	H_n	clear height of the column (mm)
Material		
F_c	f_{cmk}	compressive strength of concrete (N/mm^2)
σ_y	f_{yk}	yield strength of reinforcing bars (N/mm^2)
σ_{wy}	f_{yvk}	yield strength of shear reinforcing bars (N/mm^2)
σ_0 (N/bD)	f_{ck}	axial stress in column (N/mm^2)
Force & Strength		
N	N	axial force for each column (N)
M_u	M_{cy1}	ultimate flexural strength of column (N·mm)
Q_{mu}	V_{cy1}	shear force at the ultimate flexural strength of column (N)
Q_{su}	V_{cy2}	ultimate shear strength of column (N)
M/Q (h_0/2)	(H_n/2)	shear span length (mm)

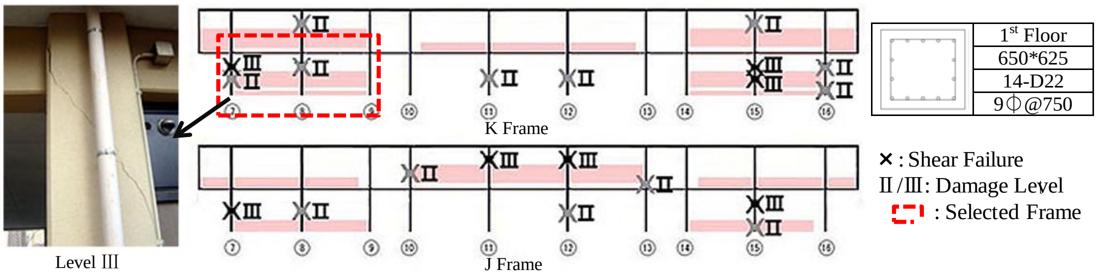
Appendix C Pushover Analysis of Sample Building M



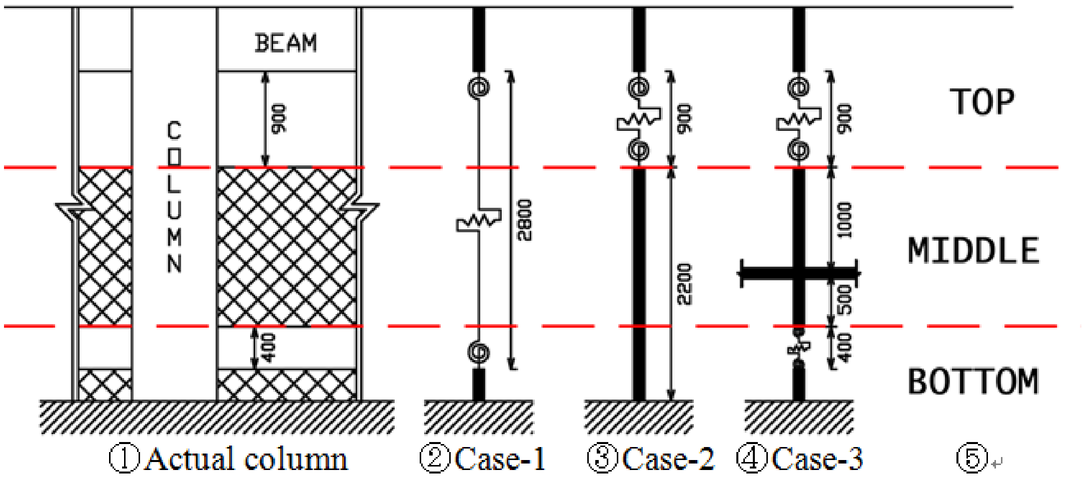
Location of building and ground motion station

Floor	Area (m²)	Weight (ton)
1st	496.8	742.3
2nd	550.8	599.9

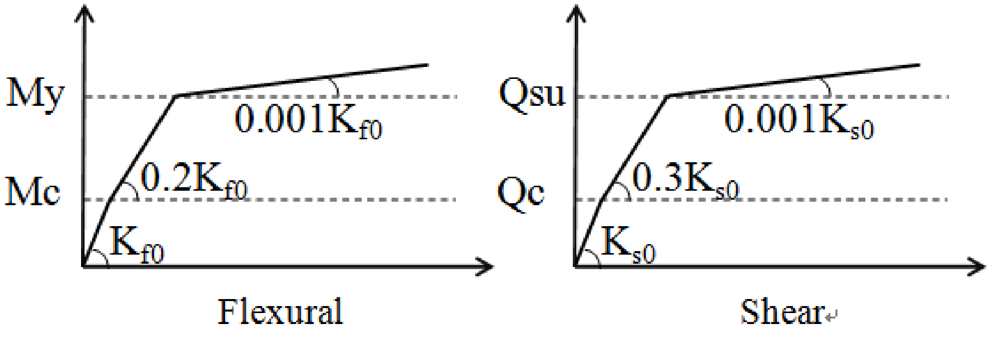
View of building and partial walls



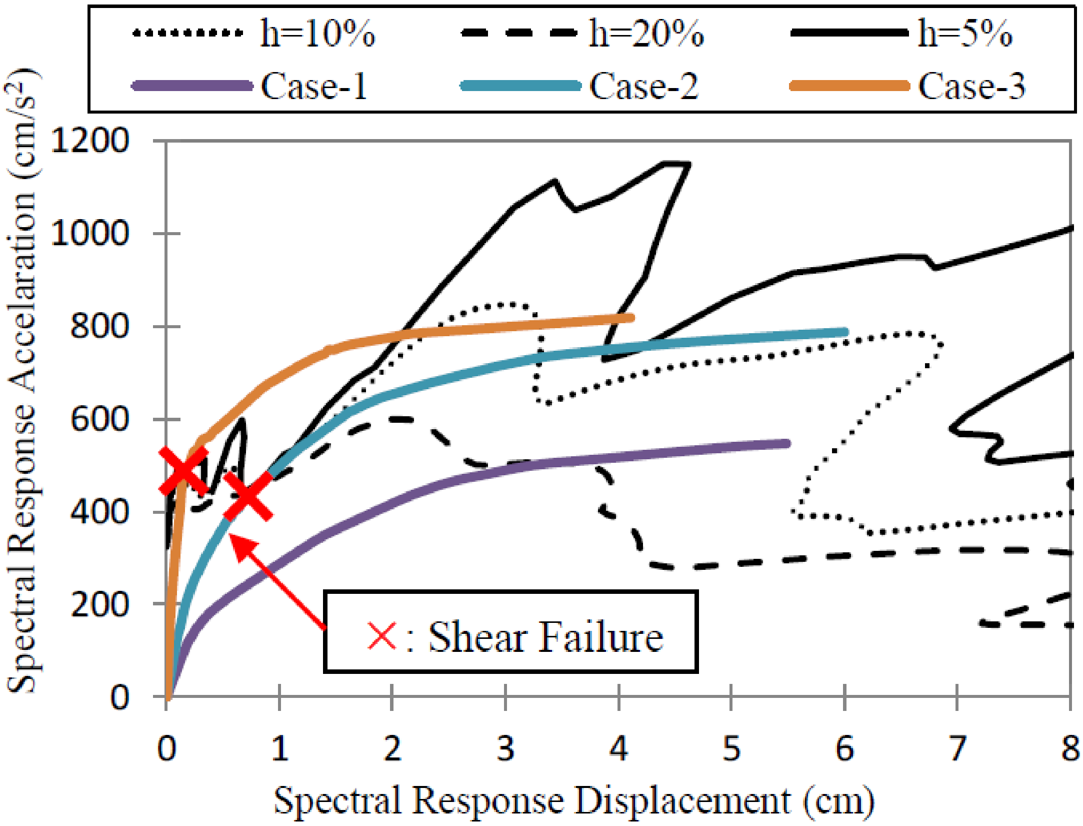
Column Characteristic and Damage



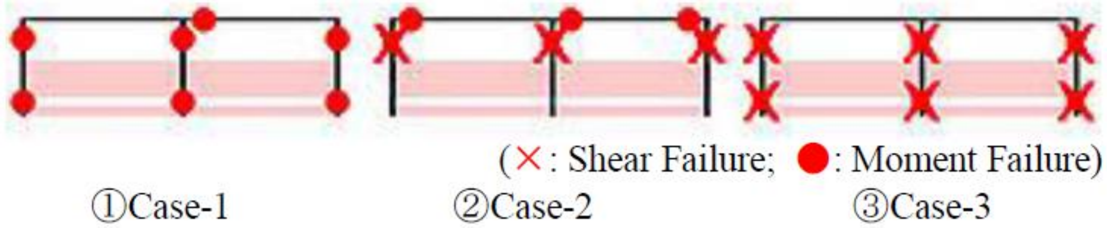
Actual construct and three cases



Tri-linear model used



Sa-Sd Graph



Damage mode and location

References

JBDPA (the Japan Building Disaster Prevention Association)/ *Standard for Seismic Evaluation and Guidelines for Seismic Retrofit of Existing RC Buildings* (1991, 2001)

JBDPA (the Japan Building Disaster Prevention Association)/ *Standard for Seismic Evaluation of Existing Reinforced Concrete Buildings*, (Translated by Building Research Institute) 2001

The Ministry of Housing and Urban-Rural Development & General Administration of Quality Supervision, Inspection and Quarantine of the People's Republic of China/ *Standard for seismic appraiser of buildings (GB50023)* 2009

The Ministry of Housing and Urban-Rural Development & General Administration of Quality Supervision, Inspection and Quarantine of the People's Republic of China/ *Code for seismic design of buildings (GB50011)* 2001

China Institute of Building Standard Design and Research & JICA (Japan International Cooperation Agency)/ *Workshop Discussions* 2012-2013

Summary