Seismic Capacity and Vulnerability of Existing RC Public Buildings in Korea

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Abstract

The main objective of this paper is to provide the basic information regarding seismic capacities of existing reinforced concrete buildings in Korea. In this paper, seismic capacities of 14 existing reinforced concrete public buildings in Korea are evaluated based on *the Japanese Standard for Evaluation of Seismic Capacity of Existing Reinforced Concrete Buildings* and the relationship of seismic capacities between buildings in Korea and those damaged due to severe earthquakes in Japan is discussed.

1. Introduction

In Korea, countermeasures against earthquake disasters such as the seismic capacity evaluation and/or retrofit schemes of buildings have not been fully performed since Korea had not often experienced destructive earthquakes in the past. However, due to more than 400 low to moderate intensity earthquakes centered in the off-coastal or inland of Korea during the past 20 years, and due to the recent great earthquake disasters in neighboring countries, such as the 1995 Hyogoken-Nambu Earthquake with more than 6,500 fatalities in Japan and the 1999 Chi-Chi Earthquake with more than 2,500 fatalities in Taiwan, the importance of the future earthquake preparedness measures is highly recognized in Korea.

The main objective of this paper is to provide the basic information regarding seismic capacities of Korean buildings. This paper will focus on 1) seismic capacity of 14 existing reinforced concrete (referred to as RC subsequently) public buildings in Korea based on *the Japanese Standard for Evaluation of Seismic Capacity of Existing Reinforced Concrete Buildings*, 2) the relationships of seismic capacities between typical RC buildings in Korea and those in Tokyo, Japan and 3) the relationships of seismic capacities between RC buildings in Korea and those damaged due to severe earthquakes in Japan.

2. Investigated Buildings

Table 1 shows the outline of 14 Korean buildings investigated in this paper. They are existing RC public buildings having 3 through 5 stories, which were constructed before the code revision in 1988. Since seismic design provisions for Korean building structures were introduced in 1988, those investigated herein were not designed to seismic loads. Most of the design strengths of concrete (F_C) were 18 N/mm^2 (180 kgf/cm^2) and 21 N/mm^2 (210 kgf/cm^2), and the typical cross section of columns was 400 mm x 400 mm, whose hoop was arranged at the spacing of more than 300 mm. The structures are RC frames with a few or no shear walls both in the longitudinal (referred to as X-direction subsequently) and transverse direction (referred to as Y-direction subsequently) as shown in ***Figure 1***.

3. Seismic Capacity of Existing RC Buildings in Korea

3.1 Basic Concept of the Japanese Standard

The Standard [Ref. 1] evaluates the seismic capacity at each story and in each direction of a building by the following seismic capacity index I_S defined in ***Eq.*** (1).

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Table 1: Outline of investigated Korean buildings*1

Building ID	No. of Stories	Span (m) Longitudinal Direction	Span (m) Transverse Direction	F_C *2 (N/mm²)	σ_y (σ_{wy})*3 (N/mm²)	Typical Cross Section of Columns B x D (rebars and hoops)
1	3	7@4.5	2.5+7.5	15	240 (240)	400 x 400 (8-D19, D10@280 mm)
2	3	15@4.5	2.5+7.5	18	240 (240)	400 x 400 (8-D19, D10@330 mm)
3	3	11@6.0	6.3+6.6+6.6	21	400 (240)	400 x 500 (8-D22, D10@300 mm)
4	3	7@4.5	6.0+6.0+6.0	21	400 (240)	400 x 400 (8-D22, D10@300 mm)
5	4	14@4.5	2.5+7.5	15	240 (240)	450 x 400 (8-D19, D10@250 mm)
6	4	12@4.5	2.5+7.5	18	240 (240)	400 x 400 (8-D19, D10@330 mm)
7	4	14@4.5	2.5+7.5	18	240 (240)	400 x 400 (8-D19, D10@340 mm)
8	4	8.0+10@4.0	4.2+2.4+8.1	21	400 (240)	400 x 400 (8-D19, D10@300 mm)
9	4	19@4.5	2.4+3.6+3.9	21	400 (240)	400 x 400 (8-D19, D10@330 mm)
10	4	8@4.4	9.9	21	400 (240)	400 x 400 (16-D22, D10@300 mm)
11	4	13@4.5	2.5+7.5	18	240 (240)	400 x 400 (8-D19, D10@400 mm)
12	5	22@4.4	4.0+9.9	21	400 (240)	500 x 500 (16-D22, D10@300 mm)
13	5	11@8.8	7.5+7.5+7.5+2.7	21	400 (240)	400 x 500 (14-D25, D10@250 mm)
14	5	10@8.1	6.0+3.3+8.4	24	400 (240)	500 x 500 (12-D25, D10@300 mm)

*1) The investigated buildings were constructed before the code revision in 1988.
*2) Design strength of concrete.
*3) σ_y: Yield strength of main reinforcing bars in columns , σ_{wy}: Yield strength of hoop bars in columns.

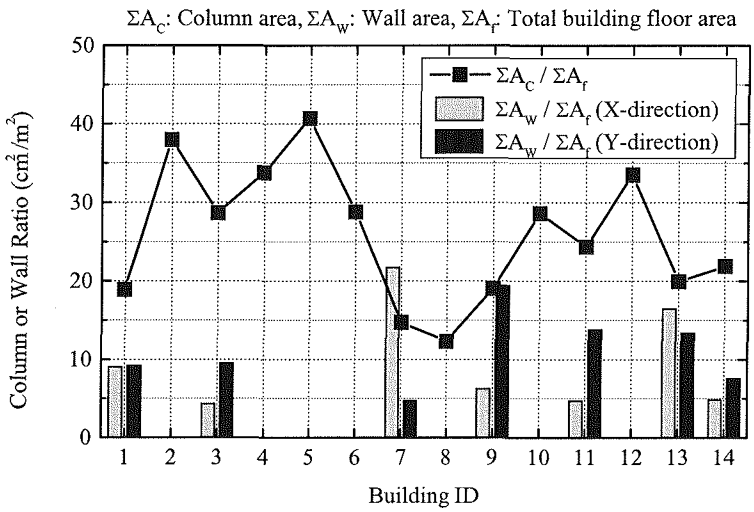

Figure 1: Column and wall ratios in the first story of investigated buildings

$$I_S = E_O \times S_D \times T \quad (1)$$

where,

E_O : Basic structural index calculated by ultimate horizontal strength, ductility, number of stories and story level concerned.
S_D : Structural design index to modify E_O-index due to the irregularity of building shape and the distribution of stiffness along the building height.
T : Time index to modify E_O-index due to the deterioration of strength and ductility.

The standard values of S_D- and T-index are 1.0. E_O-index for a single structural system can be expressed by the product of the ultimate horizontal strength index in terms of story shear coefficient (C), ductility index (F) and story index (ϕ). ϕ-index at the first story level is 1.0. E_O-index at the first story level of a simple structure, therefore, can be defined as:

$$E_O = C \times F \qquad (2)$$

The Standard consists of three level procedures; first, second and third level procedure. In the first level procedure, F-index in ***Eq. (2)*** is 0.8 or 1.0 neglecting member ductility for simplified calculations. In the second and third level procedures, F-index is 0.8 or 1.0 for brittle columns and 1.27 to 3.2 for ductile columns depending on the shear span-to-depth ratio, shear-to-flexural strength ratio etc.

3.2 Assumptions in Seismic Evaluation

To evaluate the seismic capacities of each building, the following assumptions are employed:

(1) Non-structural elements such as brick walls are neglected in evaluating seismic capacities.
(2) Building weight per unit area is assumed 9.8 kN/m^2 (1.0 tf/m^2).
(3) The dimension of structure is determined according to the structural drawings.
(4) T-index which signifies deterioration after construction is assumed 1.0.
(5) The seismic capacities are evaluated by the first and the second level procedure [Ref. 1], using the computational program [Ref. 2] coded according to *the Standard.*

3.3 Seismic Capacities of X- and Y-direction

Figure 2 shows the relationship of seismic capacities between X-direction and Y-direction, where I_S-indices in the first story of Korean buildings by the first and the second level procedures are plotted, together with those of Japanese RC buildings discussed in Ref [3]. As shown in the figure, Korean buildings have approximately equal seismic capacities in both X- and Y-direction, while Japanese buildings generally have higher capacity in Y-direction than in X-direction. This is because Korean buildings generally have few shear walls in both X- and Y-direction as shown in ***Figure 1***, while Japanese buildings have more walls in Y-direction than in X-direction.

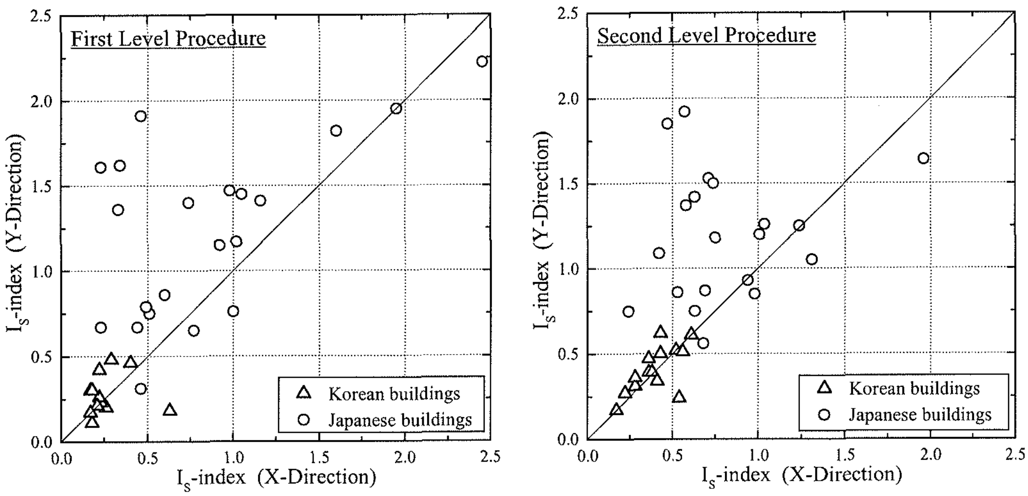

Figure 2: Seismic capacities in X-direction and Y-direction

3.4 Seismic Capacities of First and Second Level Procedure

Figure 3 compares the seismic capacity indices by the first level procedure with those by the second level procedure. Both Korean and Japanese buildings show higher seismic capacity indices by the second level procedure than by the first level procedure when they have low wall ratios. In particular, 7 Korean buildings without shear walls (14 data shown by "■" for Building ID 2, 4, 5, 6, 8, 10 and 12) show significantly higher capacities in the second level procedure than in the first level procedure. This result is consistent with the commentary found in Ref. [1] that the first level procedure which neglects member ductility may underestimate seismic capacities of buildings when they have few shear walls.

3.5 Distribution of Seismic Capacities

Figure 4 shows the distribution of seismic capacity of Korean and Japanese buildings [Ref. 3], where I_S-indices by the second level procedure in both directions of each building are plotted. As can be found in the figure, Korean buildings have a narrower distribution of seismic capacities and they are relatively lower than Japanese buildings.

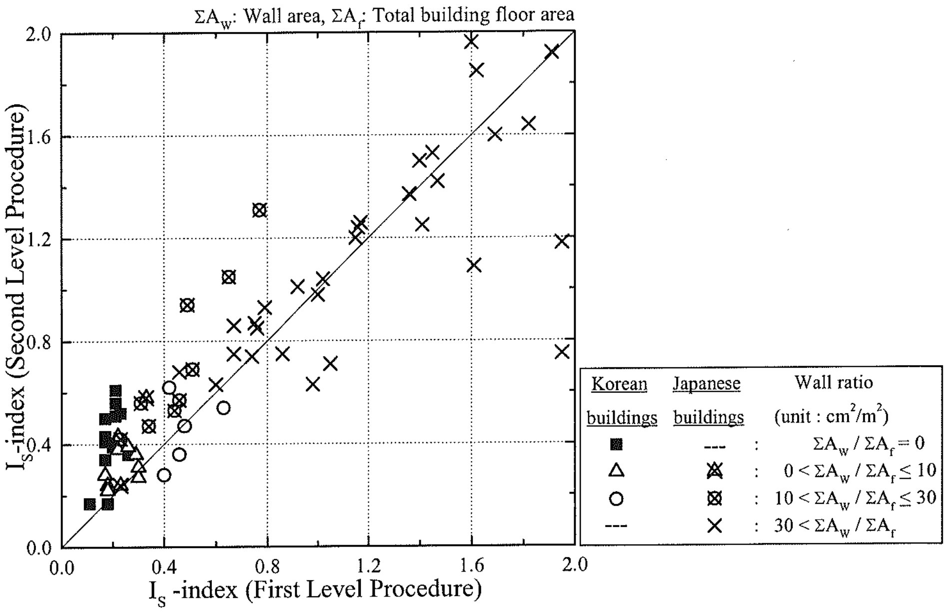

Figure 3: Seismic capacities by the first and second level procedures

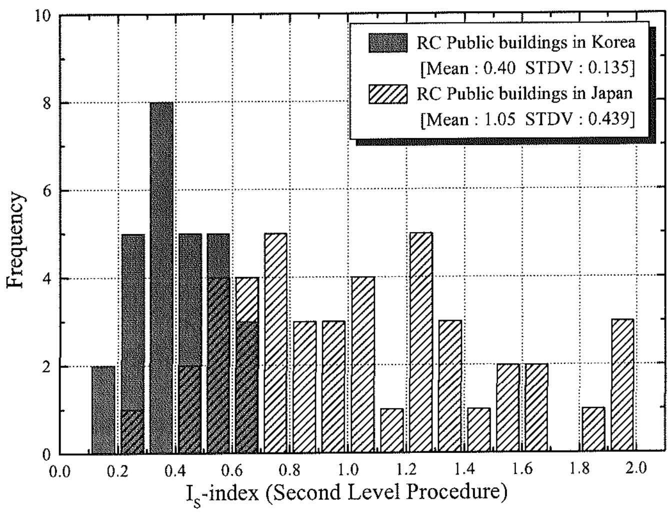

Figure 4: Distribution of seismic capacities

3.6 Seismic Capacities and Estimated Seismic Vulnerability

Figure 5 shows the relationship of I_S-indices between buildings in Korea and those damaged by 1968 Tokachi-oki [Ref. 1], 1978 Miyakiken-oki [Ref. 1], 1978 Izuoshima-kinkai [Ref. 1] and 1995 Hyogoken-Nambu earthquakes in Japan [Ref. 4]. As shown in the figure, Japanese buildings within the shaded area had high possibility of severe damage. Most of Korean buildings investigated herein fall in the shaded area, and they are expected to have severe damage under the earthquake intensity level experienced in Japan mentioned above.

3.7 Distribution of ductility index

Figure 6 shows the distribution of ductility index (F) of 14 Korean buildings by the second

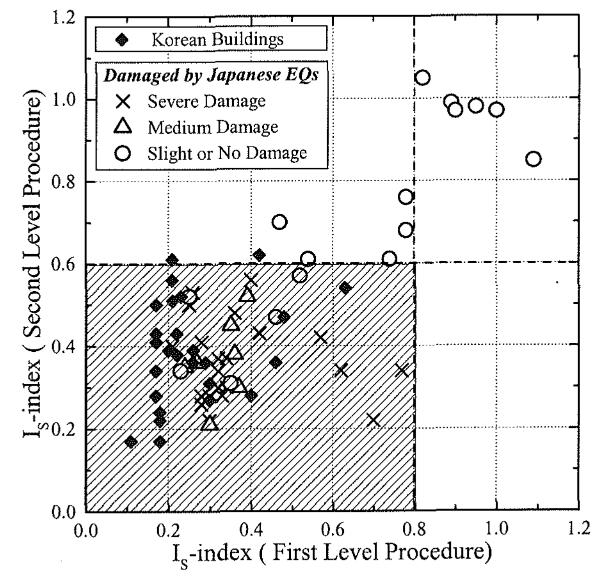

Figure 5: Relationship of I_S-indices between buildings in Korea and those damaged in Japan

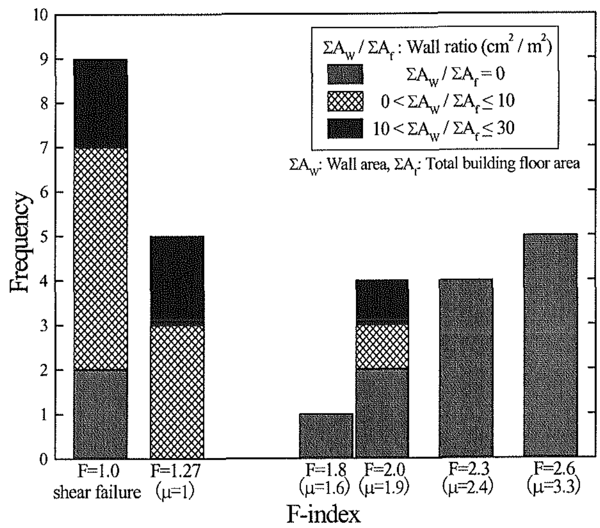

Figure 6: Ductility index distribution of Korean buildings

level procedure. As shown in the figure, the ductility index of buildings with higher wall ratio is generally lower than that with lower wall ratio, because shear walls are expected to fail in a brittle manner ($F = 1.0$) and their capacities are highly contributing to the overall seismic capacity.

The Standard defines the ductility index (F) of a building by the expected ductility μ which is primarily based on the shear-to-flexural capacity ratio (V_{Su}/V_{Mu}). The result found in ***Figure 6*** shows that F-index for half buildings investigated in this study varies from 1.8 to 2.6, which corresponds to $\mu = 1.6$ to 3.3. It should be pointed out, however, that the ductility expected in these buildings may need to be re-examined, since most buildings investigated herein have the hoop spacing wider than 300 mm, and such high ductility calculated by *the Standard* may be overestimated. This may result in lower seismic capacities and higher seismic vulnerability of Korean buildings than presented in this paper.

5. Concluding Remarks

The seismic capacities of 14 existing RC public buildings in Korea are evaluated based on *the Japanese Standard for Evaluation of Seismic Capacity of Existing Reinforced Concrete Buildings* and the results are compared with those of Japanese buildings. The relationship of seismic capacities between Korean buildings and Japanese buildings damaged due to severe earthquakes is also discussed. The results can be summarized as follows.

1) Korean buildings have approximately equal seismic capacities in both X- and Y-direction, while Japanese buildings generally have higher capacity in Y-direction than in X-direction. This is because Korean buildings have few shear walls in both X- and Y-direction, while Japanese buildings have more walls in Y-direction than in X-direction.
2) Korean buildings have a narrower distribution of seismic capacities and they are relatively lower than Japanese buildings.
3) The relationship of I_S-indices between buildings in Korea and those damaged due to severe earthquakes in Japan shows that Korean buildings investigated in this study are expected to have severe damage under the earthquake intensity level experienced in Japan.
4) Half of Korean buildings investigated in this study have F-index ranging from 1.8 ($\mu = 1.6$) to 2.6 ($\mu = 3.3$). It should be pointed out, however, that the ductility expected in these buildings may need to be re-examined, since most buildings investigated herein have the hoop spacing wider than 300 mm, and such high ductility obtained from *the Standard* may be overestimated. This may result in lower seismic capacities and higher seismic vulnerability of Korean buildings than presented in this paper.
5) These findings shown above reveal that the urgent development of seismic capacity evaluation method suitable for Korean buildings and technically sound and cost-effective seismic retrofit schemes is most needed.

References

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