Seismic Capacity Evaluation of Reinforced-Concrete School Buildings Damaged by the 2001 Geiyo Earthquake

Nanae MURAOKA*, Tadamachi YAMASHITA*, Masashi MATSUOKA*,
Fumio YAMAZAKI* and Koichi MINAMI**
*Earthquake Disaster Mitigation Research Center (EDM), NIED
2465-1 Mikiyama Fukui, Miki, Hyogo 673-0433, Japan.
E-mail: muraoka@edm.bosai.go.jp
**Fukuyama University
Sanzo, Gakuen-cho, Fukuyama, Hiroshima 729-0292, Japan.

Abstract

After the 1995 Hyogoken-Nanbu earthquake, the seismic capacity evaluation of public buildings become prevalent in Japan. Since school buildings are used as local evacuation centers, after disastrous earthquakes the reification of their seismic capacity verification is a pressing need. However, due to the lack of supportive funds many school buildings still remain unchanged. In order to check the seismic capacity of these buildings, a new low-cost short-term systematic action plan is necessary. The relationship between the structural damage and seismic capacity has been identified from various pervious studies. However, there is no reliable relationship yet mainly due to difficulty to grasp information on damaged and undamaged buildings.

In this study, the seismic capacity evaluation for the most school buildings in the affected area have been conducted following the March 24, 2001 Geiyo earthquake. We have identified vulnerable reinforced concrete school buildings in Kure City, Hiroshima Prefecture. All the possible structural elements, which significantly contribute to damage extent of the reinforced concrete school buildings, were determined using the seismic capacity and damage relationship. We found that the seismic indexes of school buildings in Kure City are generally low compared with the results obtained for other prefectures. Therefore, in this area larger structural damage is expected than other regions for a same magnitude event. In the 2001 Geiyo earthquake, many old buildings were damaged. In this study, a strong relationship between the strength of concrete and the extent of structural damage was observed. Also, the results indicate that more accurate evaluation can be obtained using a horizontal load-carrying capacity than using a seismic index, since the ground motion input due to this event exhibited a linear structural response in an elastic range.

1. Introduction

In past studies, seismic capacity evaluation was performed only for buildings with high damage levels in order to identify the relationship between the structural seismic index and the damage level. Therefore, the seismic performance of the observed buildings is generally lower than the overall seismic performance in that area. In other words, there were insufficient data for analyzing buildings suffered no damage. However, the seismic capacity evaluation for public buildings has been carried out extensively after the 1995 Hyogoken-Nanbu earthquake, including evaluation of buildings with no damage. Since the seismic performance of public elementary school and junior high school buildings in Kure City was already evaluated before the Geiyo earthquake, the relationship between the seismic performance and damage level could be analyzed.

2. Seismic Capacity Evaluation Method

In the target area, Kure City, the seismic safety of school buildings is examined using the seismic capacity method based on the seismic performance in existing Japanese reinforced-concrete building standards [1]. In this method the seismic index, *Is*, can be calculated as

$$I_S = E_0 S_D T, \tag{1}$$

where E_0 is the basic structural index for each story to a given direction. S_D represents the shape index function, which modifies E_0, estimated by irregularity of a structure. The construction age, T, that controls the E_0, is estimated from the decrepit conditions of buildings. The basic structural index, which can approach to the ultimate-limit states of the structure due to lateral forces using the story index, can be defined by

$$E_0 = C\,F\,\phi\,, \tag{2}$$

in which C and F are the structural strength and ductility indices, respectively. The compensation coefficient, ϕ, obtained from the inversion result of the normalized-design shear coefficients of a building, is used in the estimation of E_0. However, C and F can be obtained from the ultimate-story shear coefficient and the normalized ultimate-deformation capacity for four percent story-drift ratio, respectively. It should be noted that for most ductile columns, the ductility index F is assumed as 3.2 and it selected as 0.8 for short and extremely brittle columns.

For previous damaging earthquakes, the I_S index has demonstrated a fair correlation between the seismic capacity of a building and damage extent. Accordingly, I_S values of up to 0.3 were registered for severe and moderate damage ranks, and in the case of slight damage rank its estimated values were over 0.6. Therefore, the I_S index has been recognized and recommended to use as a criterion in judging building damage.

3. Evaluation of Damaged Buildings in Kure City

The Geiyo earthquake occurred at 15:28 (local time) on March 24, 2001. It has a magnitude of 6.7 on the Japan Meteorological Agency (JMA) scale. The epicenter of this earthquake is located at 34.125N, 132.713E, in the southern part of Hiroshima Prefecture, with a focal depth of 51 km. The Geiyo and the 2000 Tottori-ken Seibu (M_{JMA} = 7.3) earthquakes caused slight to moderate damage to structures. The Geiyo earthquake resulted in two casualties and 818 collapsed or severely damaged wooden houses. In the Geiyo event, the maximum acceleration was registered as 425 cm/s^2 at the Kure, Kyoshin Network (K-NET) station (HRS019) of the National Research Institute for Earth Science and Disaster Prevention (NIED).

As can be seen in Figure 1, Kure City is located in the southwest part of Hiroshima Prefecture. This city has been developed in cliffy areas, with high steep slopes. There are a total of fifty-four public elementary and junior high schools in this region. Figure 1 shows the location of the schools in Kure City. Among them, the forty-nine schools with one hundred twelve buildings were constructed before 1981. Most of the school buildings are three-story. The number of buildings that were built before 1971 is the same as those constructed between 1971 to 1981 period.

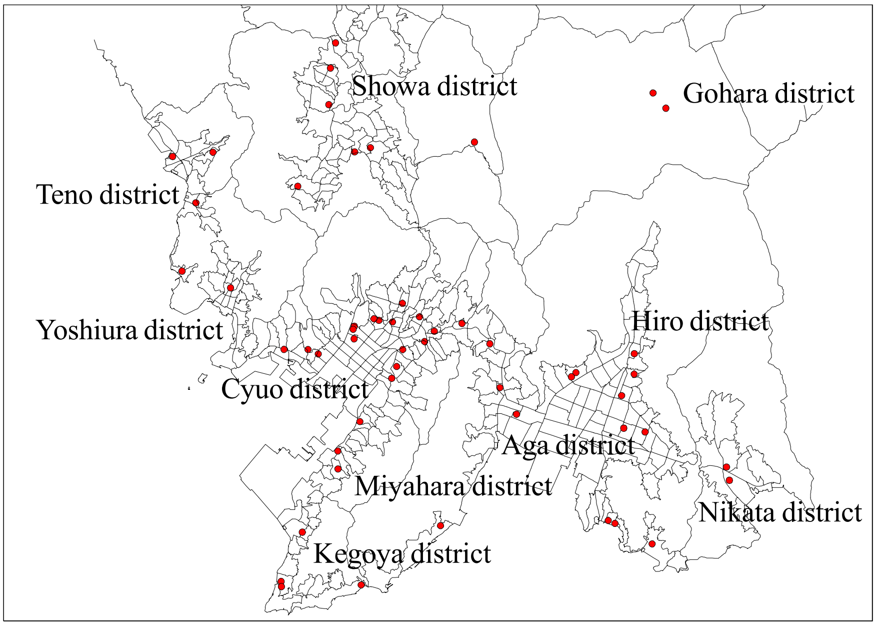
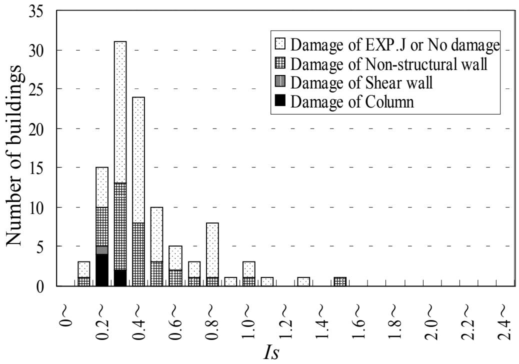


Figure 1. Location of public elementary schools and junior high schools in Kure city

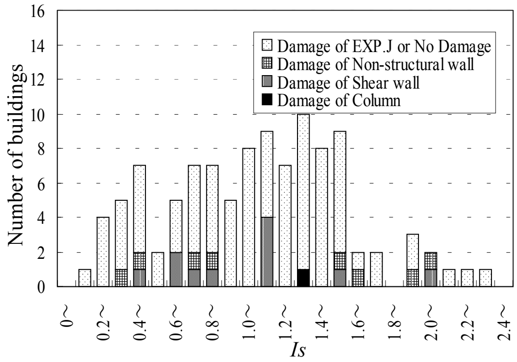
Immediately after the Geiyo earthquake, many researchers conducted building damage surveys. Since there is no standard scheme of building damage classification in Japan, it is very difficult to assign a proper building damage class. Therefore, the present authors first tried to establish a standard judgment scheme of possible damage categories for the Geiyo earthquake following our field surveys conducted in the period between May 28 and 31 in 2002. As a result of this survey, the structural damage patterns of the school buildings can be summarized as follows: cracks on columns (6 school buildings) and shear-walls (10 buildings), damage on non-structural walls (29 buildings), and expansion structural-joints (69 buildings). We also found that most of 4-story school buildings suffered severe damages on their structural members.

4. Relationship Between Seismic Performance and Damage Extent

Many researchers have pointed out that the seismic performance index correlates well with the building damage level [2][3][4]. In this objective, we estimated the *Is* index for the damaged school buildings by the 2001 Geiyo earthquake in the Kure City. Figure 2 shows the calculated *Is* values and their corresponding damage levels. It can be seen that in the longitudinal direction, the building damage ratio is relatively high and the damage level is also large. On the other hand, in the span direction, the relationship between the seismic index and damage level is not clear.



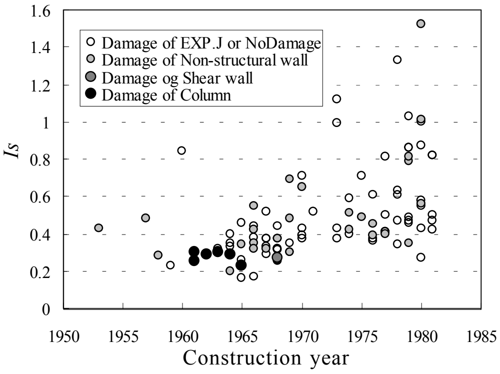
(a) Longitudinal direction



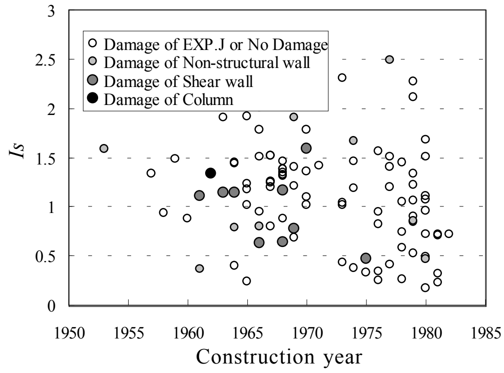
(b) Span direction

Figure 2. Number of buildings for *Is* value ranges

Figure 3 presents the relationship between the construction year of buildings and *Is* values for two building directions. As shown in this figure, many buildings do not show significant seismic performance for the longitudinal direction. Especially, this tendency is much remarkable for the buildings constructed before 1971. We also found that the estimated *Is* values for the buildings suffered damage to their structure members are less than 0.3 and there is no effect of the construction year in the span direction through the estimated values. For new school buildings, the *Is* index shows a descending trend in the longitudinal direction that may explain the large damage extent in this area. However, for the span direction it is too difficult to predict and clarify the factor that explains the damage from the relationship between the construction year and *Is*.



(a) Longitudinal direction



(b) Span direction

Figure 3. Relationship between *Is* and construction year

Figure 4 shows the relationship between the concrete strength and construction year. The concrete strength in seismic capacity evaluation is compared with a smaller *Is* value, the compressive strength of a concrete core or the specified design strength. In order to investigate the relationship between the concrete strength and damage level, the result of compressive strength tests is used. For the seismic capacity evaluation, it is assumed that an average compressive strength of concrete from two or more cores should be extracted from each floor of an individual building. The solid line in Figure 4 shows the specified design strength. It is well known that the expected damage level decreases with increasing the concrete strength. All the structural members are possible to experience serious damage when their concrete strengths become smaller or equal to 18 N/mm^2. Thus, the concrete strength has significant effects on structural damage. It is necessary to select an actual concrete strength in order to evaluate the proper earthquake performance. However, in the lack of infomation such a strength value, the specified-design strength is usually used in seismic capacity evalution.

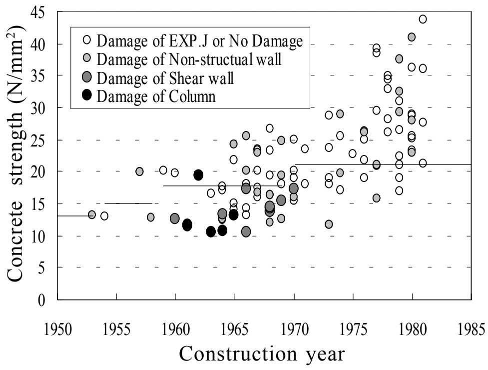
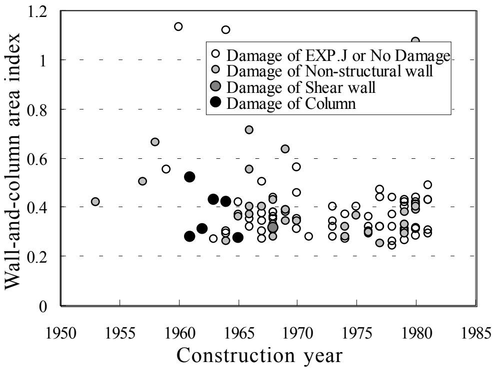


Figure 4. Relation between construction year and strength of concrete

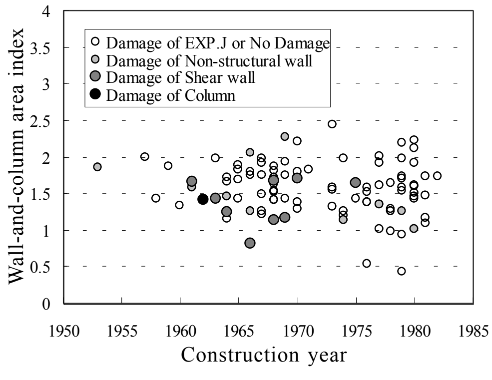
As for the school buildings constructed in the 1950's and 1960's, their damage levels are different though the concrete strengths are equal. Actually the difference between the buildings constructed during 1950's and after 1960's is mainly that in plans. Therefore, the damage extent of those buildings reflected the structural dimensions of walls and columns in addition to the concrete strength. Figure 5 shows the wall-and-column area index and it is calculated by

$$ {}_0C_{CW} = \frac{\sum 25 A_W + \sum 7 A_C}{ZWA_i} \tag{3} $$

where A_W and A_C are the sum of wall sectional areas and total column sectional areas for each floor in a target direction. Z represents the regional index for the ground motion intensity in a corresponding seismicity zone, W is the building weight summed upper than a reference floor, and A_i shows a distribution of the story shear force of building in the vertical direction. The ultimate shear stresses of the wall and column are 25kg/cm^2 and 7kg/cm^2, respectively.



(a) Longitudinal direction



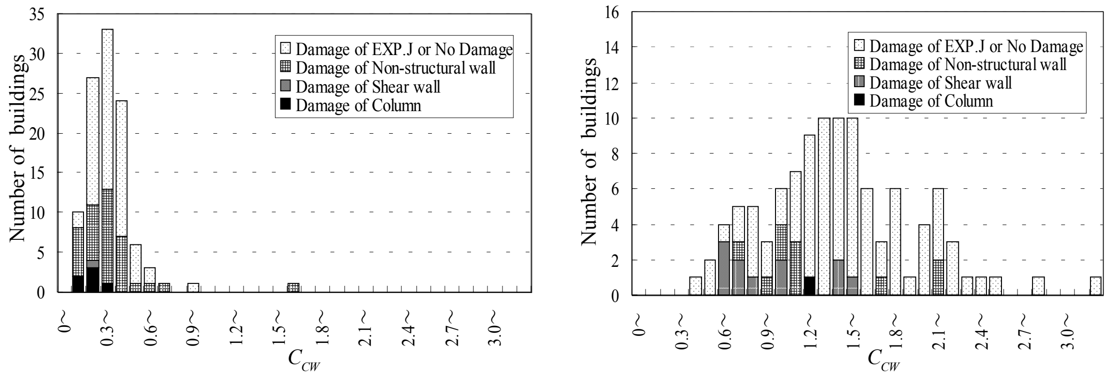
(b) Span direction

Figure 5. Relationship between the construction year and wall-and-column area index

The school buildings belonging to the 1950's construction period have a larger wall-and-column area index than those after 1960's and this fact may explain the smaller damage for the buildings built in mentioned period. The strength of a building, which depends on the concrete strength and wall-and-column area index, is given by

$$C_{CW} = \frac{\sum 25 A_W + \sum 7 A_C}{ZWA_i} \left(F_C / 200\right) \tag{4}$$

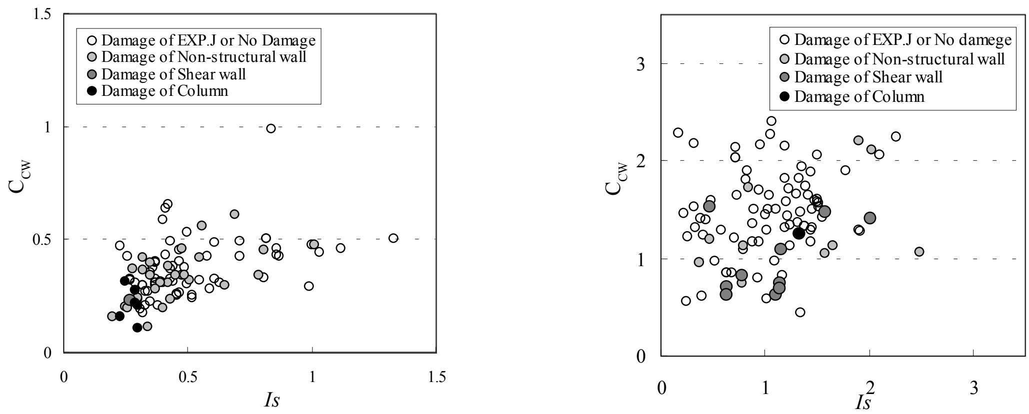
in which *Fc* is the concrete strength that is assigned from the average of compression test results for concrete cores. Figure 6 demonstrates the number of buildings for each C_{CW}. From this figure it can be seen that the damage level of a school building has an inverse relationship with the building strength, C_{CW} index in the both longitudinal and span directions. As for the damaged reinforced-concrete school buildings by the Geiyo earthquake, the C_{CW} correlates well with the existing damage pattern rather than *Is* does.



(a) Longitudinal direction (b) Span direction

Figure 6. Number of buildings for C_{CW} ranges

Figure 7 shows the relationship between the C_{CW} that is simply evaluated from the building strength and *Is* that is determined by the strength and ductility of a building. The concrete strength is given for a safety side during the evaluation of *Is*, therefore, it does not always represent the actual strength of a building. As for a large ductility building, where C_{CW} is constant, *Is* can be obtained in its maximum level. In the longitudinal direction, buildings with small *Is* and C_{CW} values will experience damage to their structural members. In spite of this fact, it is difficult to classify a damage level by *Is* in the span direction of a building with many walls and columns.



(a) Longitudinal direction (b) Span direction

Figure 7. Relationship between *Is* and C_{CW}

5. Concluding Remarks

In this study, we analyzed the factors affecting the damage of school buildings, using the result of damage surveys and those from seismic capacity evaluation for the 2001 Geiyo, Japan earthquake. Then the relationships between the structural damage and the seismic index, *Is*, and the structural damage the building strength,

C_{CW}, were investigated. The major results obtained by this research are summarized as follows:

(1) The concrete strength, the wall area index, and the column area index have significant influence for the level of damage. The calculated C_{CW} by these indices shows a better correlation with the damage levels of reinforced-concrete school buildings in Kure City than *Is*.

(2) Since the concrete strength is evaluated for a safety side, *Is* cannot grasp the strength of a building.

REFERENCES

[1] Japan Building Disaster Prevention Association, "Standard for Evaluation of Seismic Capacity of Existing Reinforced Concrete Buildings", 2001 (in Japanese).

[2] T. Okada, T. Kabeyasawa, Y. Nakano, M. Maeda, A. Tasai, D. Kato, T. Ichinose and K. Kitayama, "Seismic Performance Indices and Observed Damages of Reinforced Concrete School Buildings", *The First Symposium of Japan Association for Earthquake Engineering*, 1998 (in Japanese).

[3] T. Okada, "Needs to Evaluate Real Seismic Performance of Buildings –Lessons from the 1995 Hyogoken-Nanbu Earthquake-", *INCEDE Report 15* (Jointly with ERS and KOBE net), 1999.

[4] K. Lee, Y. Nakano, F. Kumazawa and T. Okada, "Seismic Capacity of Reinforced Concrete Buildings Damaged By 1995 Hyogoken-Nanbu Earthquake", *INCEDE Report 15* (Jointly with ERS and KOBE net), 1999.