

## **Damage Evaluations of Public School Buildings in Ibaraki Prefecture Suffered in 2011 Off The Pacific Coast of Tohoku Earthquake**

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### **ABSTRACT**

This study aims to evaluate the damages of buildings by investigation of all numbers of public school buildings in Ibaraki prefecture suffered in 2011 off the Pacific coast of Tohoku Earthquake. The database including the information of over 3,000 buildings in about 800 public-schools is constructed by questionnaire for 45 governing bodies (cities and prefecture). The database consists of basic information of the building (types of structure, constructed year, floor levels and dimensions), seismic capacity index ( $I_S$ ) and information of damages both for structural and non-structural components. The residual ratio of  $I_S$  ( $R$ ), which defined as the ratio of  $I_S$  of damaged building after earthquake divided by the  $I_S$  before earthquake is investigated to express the damage level of structural components.

According to the results of investigation, the damages of non-structural components, such as glass, ceiling, and wall, are unrelated with constructed year and the values of  $I_S$ . However, the relations with seismic capacity index( $I_S$ ) and the residual ratio( $R$ ) are confirmed. Some buildings with less than 0.7 of  $I_S$  show the low  $R$  value.

### **1. INTRODUCTION**

The 2011 off the Pacific coast of Tohoku earthquake of moment magnitude ( $M_w$ ) 9.0 occurred at 14:46 JST on March 11, 2011 and generated large ground motion and gigantic tsunami in Tohoku and Kanto areas of the northeastern part of Japan together with long-period ground motion in Ibaraki prefecture. This was a thrust earthquake occurring at the boundary between the North American and Pacific plates. This earthquake is the greatest in Japanese recorded history and the fourth largest in the world since 1900 (U.S. Geological Survey Website). As of 9th December 2011, people death reached 15,841 and totally collapsed houses reached 126,280 (mainly due to tsunami) according to the Japanese National Policy Agency.

The objective of this study is to evaluate the damage of the buildings based on the database including over 800 public schools all over the Ibaraki prefecture through the

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questionnaire survey in 45 public institutions. The database is consisted of basic information of buildings, such as types of structure, constructed year, number of floors, floor areas, seismic capacity index ( $I_S$ ) and information of damages both for structural and non-structural components. The residual ratio of  $I_S$  ( $R$ ) as shown in Eq.(1), which defined as the ratio of  $I_S$  of damaged building after earthquake divided by the  $I_S$  value before earthquake, is investigated to express the damage level of structural components.

$$R = {}_D I_S / I_S \quad (1)$$

${}_D I_S$  : seismic capacity index of structure that takes into account the seismic capacity reduction factor of the damaged members

$I_S$  : seismic capacity index of structure of pre-disaster

The total of 3139 buildings' information has been collected and investigated. They include 2216 RC buildings and 923 others.

## 2. Outline of database

### 2.1 Contents of database

The collected buildings' information is shown in Table 1. The major revisions of the building standard law of Japan had been carried out two times in 1971 and 1981. The aseismic behavior of buildings in Japan had been improved as these revisions. Therefore, the collected buildings are divided into 3 groups in accordance with periods of constructed year, i.e.;

1st period: constructed before and in 1971

2nd period: constructed between 1972 and 1981

3rd period: constructed in 1982 and after

The 3rd period buildings are regarded to the "New design code", which concepts have been still effective at present time in Japan, and it is being considered that they have enough aseismic performance. The seismic inspection, in which the aseismic performance and capacity is expressed by the value of seismic capacity index ( $I_S$ ), has been carried out for 1st period and 2nd period buildings. The seismic strengthening for 1st and 2nd period buildings has been conducted for several ten years, and is still going on in Japan. Before the design of seismic strengthening, the seismic inspection is done and necessity of seismic strengthening is judged. It is being considered that the building which has higher seismic capacity index ( $I_S$  is 0.6 or 0.7 and higher) has enough aseismic performance. In principle, seismic strengthening is carried out to have enough value of  $I_S$  higher than 0.7.

At March 11, 2011, in Ibaraki prefecture, there were 523 buildings (RC:362, S:93, RC+S:68) which is completed seismic strengthening, 1325 buildings (RC:924, S:321, RC+S:80) for which seismic inspection had finished. These percentages for the total number of 1st period and 2nd period buildings (2053) are 25.5% and 64.5%. About half of buildings are designed by "New design code" and already strengthened, which are regarded to have enough aseismic performance.

The contents of database are shown in Table 2.

**Table 1 Outline of database**

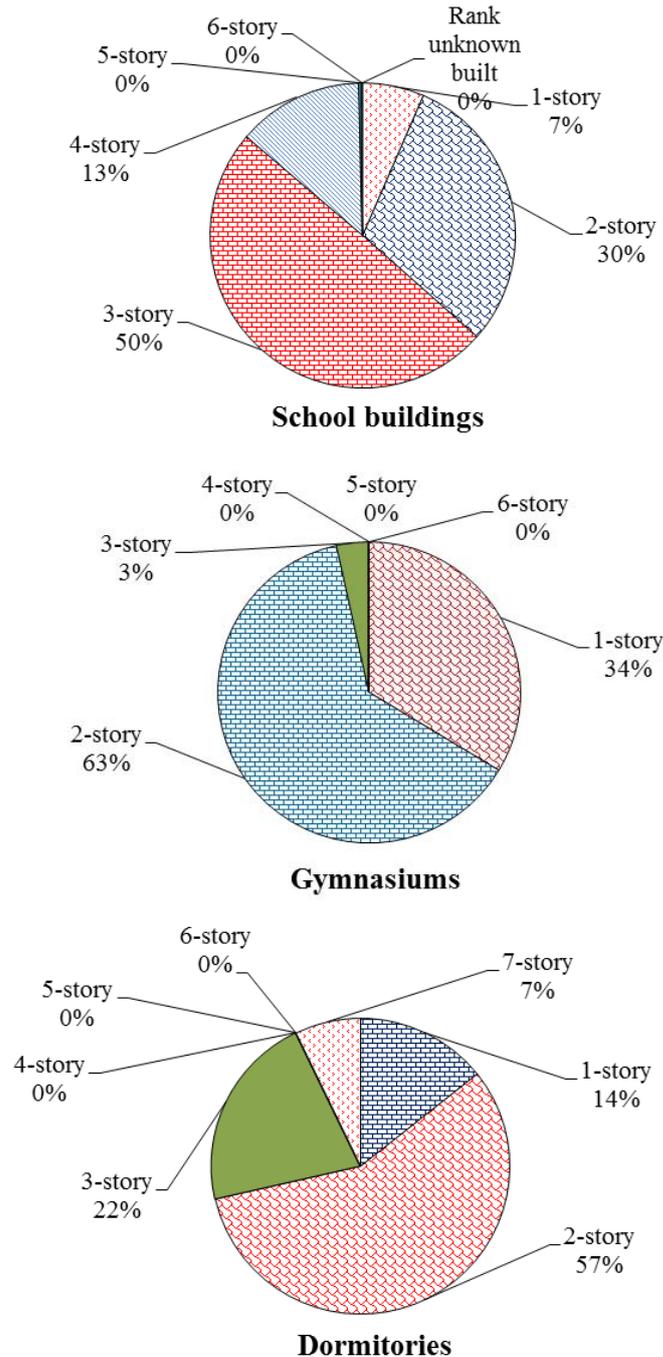
Type	Use	School building	Gymnasium	Dormitory	Total
Structure type	RC	1911	291	14	2216
	S	201	488	0	689
	RC+S	17	136	0	153
	Other / Unknown	44	37	0	81
Total		2173	952	14	3139
RC buildings Constructed year	~1971	385	16	4	405
	1972~1981	966	81	3	1050
	1982~	560	194	7	761
	Total	1911	291	14	2216
RC buildings seismic inspection, strengthening	Seismic inspection	865	51	8	924
	Seismic strengthening	336	26	0	362
	Not inspected / new design code	710	214	6	930
	Total	1911	291	14	2216
S buildings Constructed year	~1971	58	70	0	128
	1972~1981	68	264	0	332
	1982~	69	127	0	196
	Total	195	461	0	656
S buildings seismic inspection, strengthening	Seismic inspection	103	218	0	321
	Seismic strengthening	12	81	0	93
	Not inspected / new design code	86	169	0	255
	Total	201	488	0	689
RC+S buildings Constructed year	~1971	5	33	0	38
	1972~1981	9	91	0	100
	1982~	0	2	0	2
	Total	14	126	0	140
RC+S buildings seismic inspection, strengthening	Seismic inspection	8	72	0	80
	Seismic strengthening	6	62	0	68
	Not inspected / new design code	3	2	0	5
	Total	17	136	0	153

**Table 2 Contents of database**

<ul style="list-style-type: none"> <li>• <b>Identification:</b> school name, building name</li> <li>• <b>Building basic information:</b> type of structure, number of floors, constructed year, constructed area, total floor area</li> <li>• <b>Aseismic performance (results of seismic inspection):</b> shape index <math>S_D</math>, aging index <math>T</math>, story shear coefficient <math>C_T S_D</math>, seismic capacity index <math>I_S</math></li> <li>• <b>Damage Overview:</b> Damage of structural components, glass breakage, leakage, ceiling damage, wall (structural or nonstructural) damage, EXP.J damage, settlement, liquefaction, exterior damage</li> <li>• <b>Damage of structural components (results of damage inspection):</b> residual ratio <math>R</math></li> <li>• <b>Information of ground motion:</b> peak ground acceleration (PGA), peak ground velocity (PGV), value of Spectral Intensity (SI)</li> </ul>
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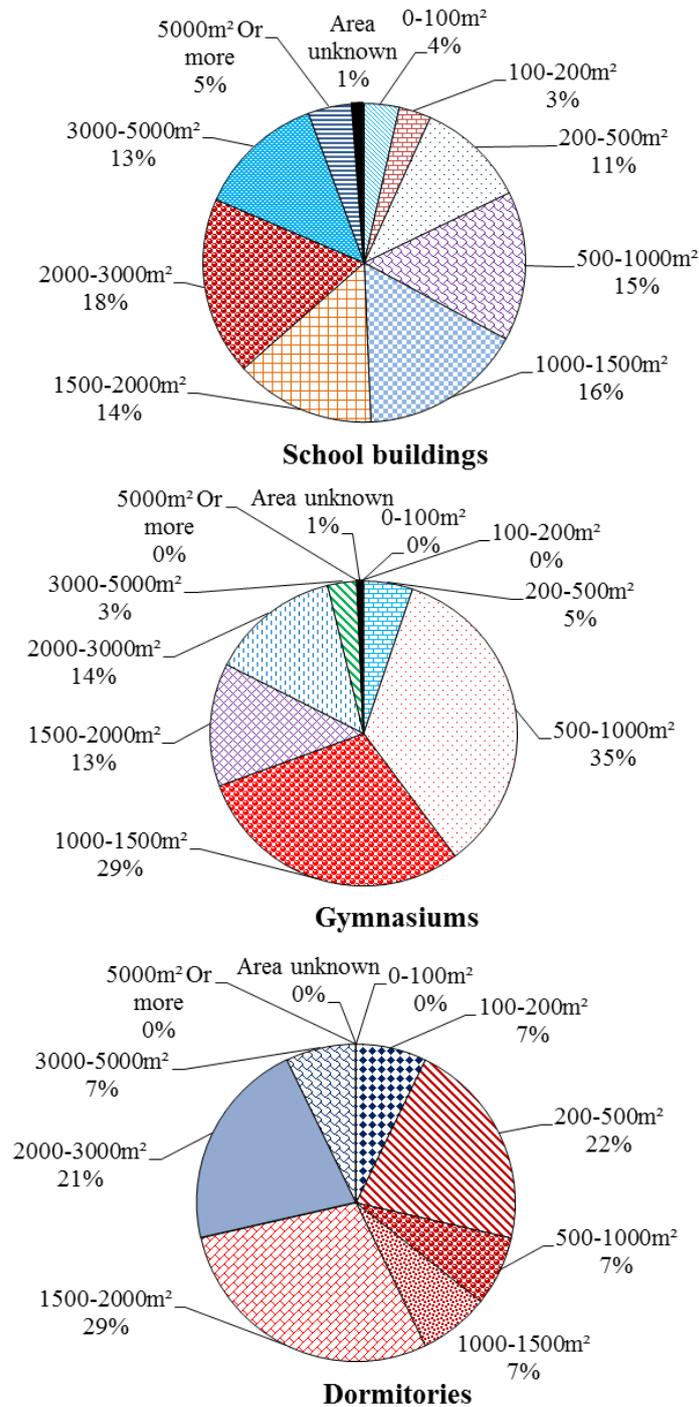
## 2.2 Attribute of data

Classifications of number of stories are shown in Fig. 1 for school buildings, gymnasiums and dormitories. For school buildings, 80% of buildings are 2 or 3-story ones as corresponding with the use for elementary school (6-year schooling in Japan) and junior-high school (3-year schooling). Most of 4-story buildings are for high school. For gymnasiums, most of buildings are 1 or 2-story. For dormitories, 13 buildings in the total of 14 buildings are 3-story or less than.



**Fig. 1** Story classification

The classifications of total floor area are shown in Fig. 2 for school buildings, gymnasiums and dormitories. For school buildings, the total floor area varies in the wide range. The total floor area does not directly relate to the scale of schools because the large scale school has the many numbers of buildings. For gymnasium, buildings which have less than 1000m<sup>2</sup> floor area are for elementary school, and the larger size buildings are for junior-high school and high school.



**Fig. 2 Total floor area classification**

### 2.3 Structural aseismic performance

The seismic inspection has been carried out for the 1st and 2nd period buildings. The seismic capacity index is evaluated by Eq. (2).

$$I_S = E_0 \cdot S_D \cdot T \quad (2)$$

$E_0$ : energy absorption index

$S_D$ : shape index

$T$ : aging index

$$E_0 = \alpha \cdot \sqrt{\sum (E_i)^2} \quad (3)$$

$\alpha$ : reduction coefficient for stories

$$E_i = C_i \cdot F_i \quad (4)$$

$C$ : story shear coefficient =  $Q_u / \Sigma W$

$F$ : ductility index

$Q_u$ : ultimate strength

$\Sigma W$ : weight of above floors

Fig. 3 shows  $I_S$  distributions for 1st and 2nd period buildings. X-direction almost corresponds to long span direction, and Y-direction corresponds to short span direction. The school buildings in Y-direction generally have shear wall, therefore  $I_S$  is larger. On the other hand, the gymnasiums and dormitories  $I_S$  have no significant difference the value from the point of view of the direction.

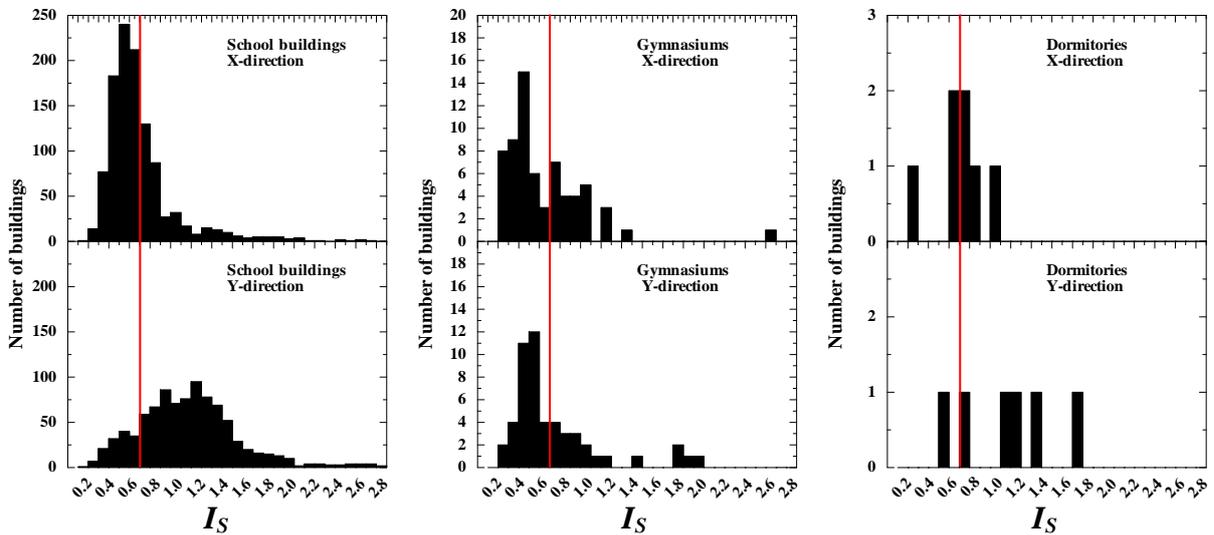
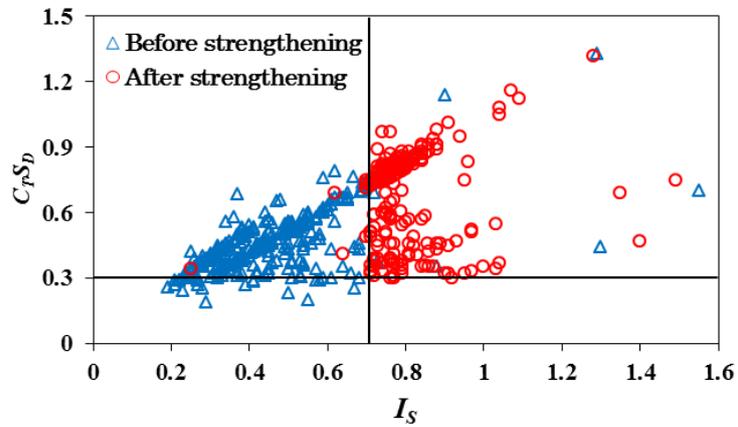


Fig. 3  $I_S$  distributions for X and Y-direction

Fig. 4 shows the relationship between  $I_S$  and  $C_T S_D$  for strengthened buildings of 1st and 2nd period.  $C_T$  is the accumulated story shear coefficient to determine  $I_S$ . As easy explanation, the value of  $C_T S_D$  multiplied by ductility index and aging index becomes  $I_S$ . The plots are varied by the before or after strengthening. Of course the target value of  $I_S$  for seismic strengthening is larger than 0.7, strengthened buildings have larger  $I_S$ .

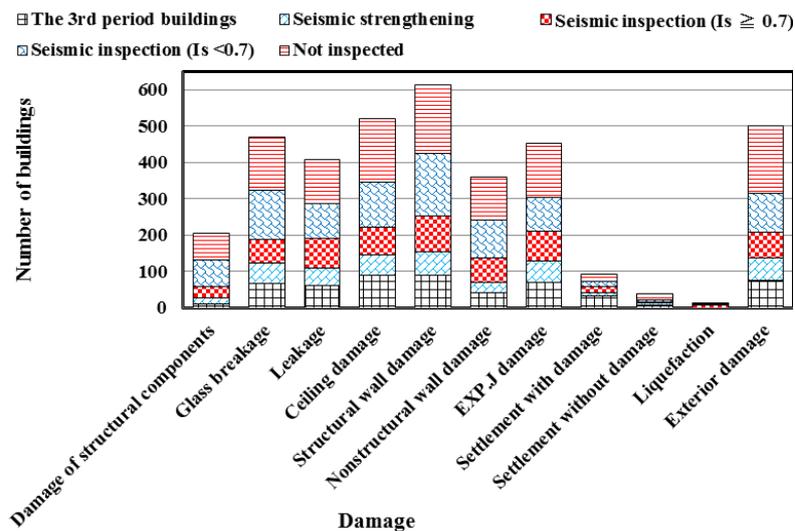
The number of plots exists around the proportional line that  $C_T S_D = I_S$ . This means the value of ductility index is almost 1, corresponding with deformation capacity of shear failure of RC columns.



**Fig. 4** Relationship of  $I_S$  and  $C_T S_D$

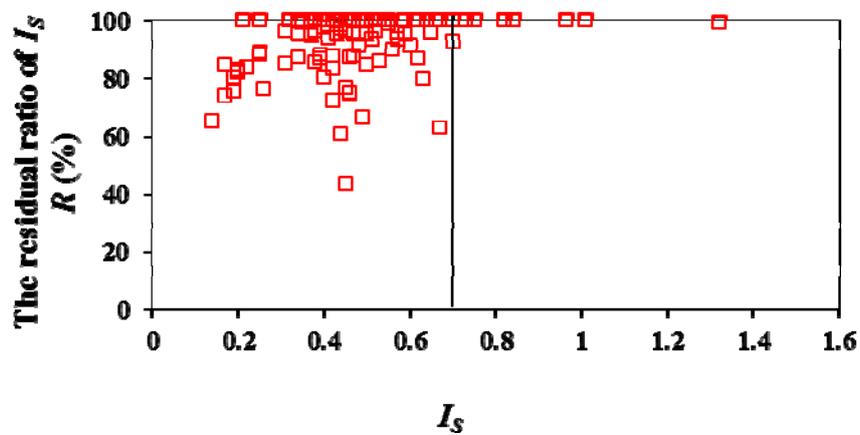
### 3. Damage of non-structural, structural components

The questionnaire for 45 governing bodies (cities and Ibaraki prefecture) covers questions for the overview of the damages of buildings as shown in Table 2. The answers of the questions are shown in Fig. 5. The buildings are classified into 5 types, these are; inspected buildings which have lower  $I_S$  than 0.7 or higher, seismic strengthened buildings, and 3rd period buildings (New design code) and not-inspected buildings (1st and 2nd period). The damages of glass (including glass and frame), leakage (including equipment damage), ceiling, wall (structural or nonstructural), and EXP.J are recognized having no relations with seismic capacity of buildings. About 15 – 20 % of school buildings had some damages in Ibaraki prefecture.

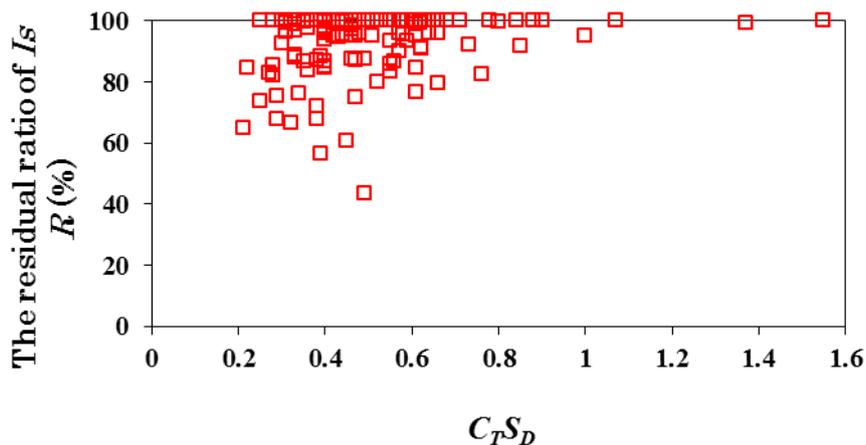


**Fig. 5** Overview of the damage by questionnaire investigation

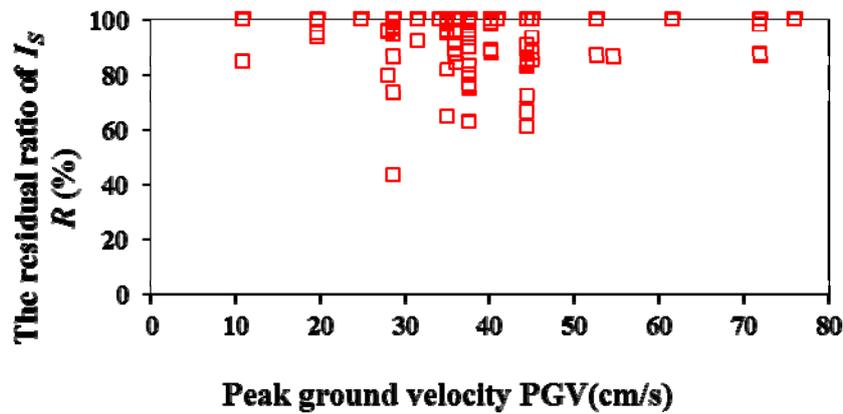
The relationships between residual ratio of  $I_S$  and seismic capacity index  $I_S$ , accumulated story shear coefficient  $C_{TS_D}$ , peak ground acceleration PGA and peak ground velocity PGV are shown in Fig. 6, 7, 8 and 9, respectively. Almost the buildings show enough residual ratio of higher than 80%, that means the structural components damage is small or slight even if the values of  $I_S$  and  $C_{TS_D}$  are relatively small. The buildings which residual ratio are smaller than 80% distribute under 0.7 of  $I_S$  and 0.5 of  $C_{TS_D}$ . It can be said that the target value and criteria of  $I_S$  is suitable concerning structural damage. The clear tendency between residual ratio and PGA, PGV is not recognized.



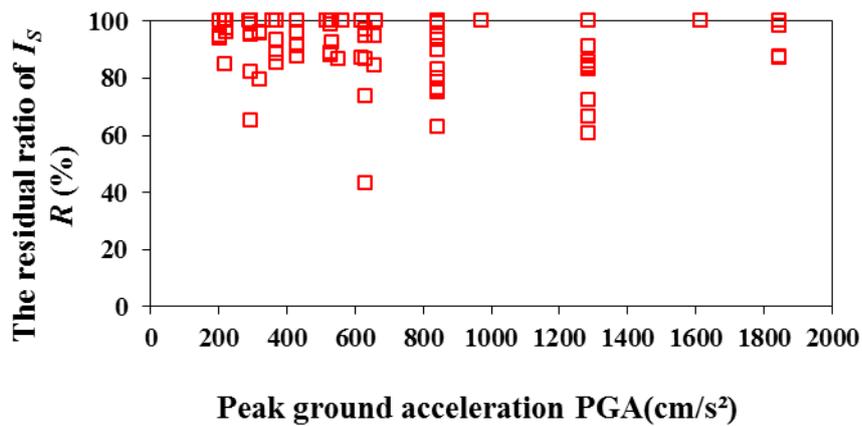
**Fig. 6** Residual ratio of  $I_S$  and seismic capacity index



**Fig. 7** Residual ratio of  $I_S$  and  $C_{TS_D}$



**Fig. 8** Residual ratio of  $I_S$  and peak ground acceleration



**Fig. 9** Residual ratio of  $I_S$  and peak ground velocity

#### 4. Conclusions

The overview of the damages of structural and nonstructural components, residual ratio of seismic capacity index  $I_S$  are investigated by the results of questionnaire for 45 governing bodies (cities and prefecture).

According to the results of investigation, the damages of non-structural components, such as glass, ceiling, and wall are unrelated with constructed year and the values of  $I_S$ . However, the relations are confirmed with seismic capacity index,  $I_S$  and the residual ratio,  $R$ . Some buildings with less than 0.7 of  $I_S$  show the low  $R$  value.

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