EFFECTS OF SEISMIC RETROFITTING ON REINFORCED CONCRETE BUILDINGS SUFFERED DURING THE 2004 MID NIIGATA PREFECTURE EARTHQUAKE

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ABSTRACT

This study reports on the relation between seismic performance and damage of buildings during the 2004 Mid Niigata Prefecture Earthquake. Two buildings under construction for retrofitting were studied. One of them had light damage, another had negligible damage. A building with light damage had four columns with damage level of Ⅳ during the Earthquake. And the remaining seismic performance of the building was 89 %. Evaluated seismic performance index (Is value) of the long span direction of the building was 0.58~0.79. The lack of seismic performance was assumed to be a cause of the damage on the building. On the other hand the Is value of another building was 0.44~0.71 although the damage of the building was negligible. Finally the effect of the seismic retrofitting for two buildings was discussed comparing the relationship between damage level and the seismic performance indices which varied depending the retrofitting process.

Introduction

On October 23rd in 2004 a middle size earthquake (M=6.8) occurred around the mid Niigata prefecture area. But the depth of the epicenter was very shallow (13 km), which lead to serious damage of ground, railroad structures, bridges and buildings. The recorded acceleration of Tokamachi city located about 20 km south-west of the epicenter was 1716 gal. In this study two reinforced concrete high school buildings located in Tokamachi city which had been seismically retrofitted were examined.

TS-1 building of TS-High school was a 3 story building. TS-1 building of T-High school was a 4 story building. Seismic performances of these building had been evaluated and retrofitting with steel braces and postcast reinforced concrete shear walls and sidewalls was planned already. However, retrofitting of these buildings was not completed when the earthquake occurred. Among these buildings shear failure of short columns of TS-1 building of

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TS-High school was observed, whereas damage of another building was negligible.

Seismic performance indices of these buildings were evaluated according to the states of retrofitting process. And the damage level was discussed using these seismic indices.

Recorded ground motions near the site

Strong motion accelerometer of National Research Institute for Earthquake Science and Disaster Prevention (named K-NET) was settled in Tokamachi city at epicentral distance of 20 km, located about 500 m south from TS-High school and 1200 m west from T-High school. Maximum acceleration recorded by this accelerometer was 1716 gal in NS direction and 850 gal in EW direction. Maximum acceleration recorded by after shock occurred 38 minutes later the main shock was 816 gal in NS direction but the seismic intensity of this after shock motion (6+) was higher than that of main shock motion (6-). Figure 1 shows acceleration response spectrum of NS and EW components of main shock and NS component of maximum after shock. Although acceleration response of main shock was dominant in the period range shorter than 0.5 second, acceleration response of the main after shock was higher than those of main shock waveforms in the period range around 1.0 second. This means that damage of buildings could be larger by the aftershock rather than that by the main shock. By the way damage level of surrounding buildings including both reinforced concrete buildings and wooden buildings was observed as non or slight except for a few buildings including TS-high school.

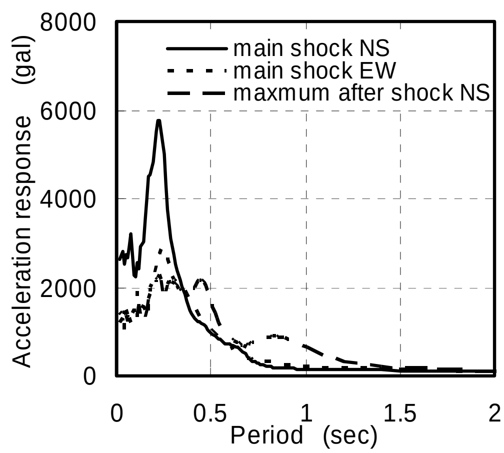

Figure 1. Acceleration response spectrum(h=0.05)

Seismic performance of lightly damaged building (TS-High school)

Outline of building

TS-High school is located 500m north of K-NET accelerometer. Table 1 shows outline of TS-1 building of this high school damaged lightly during this earthquake. This building was built in 1966 and 1967 according to former Japanese building law which was revised in 1981. Figure 2 shows plan of 1st floor of this building. This is a three story beam-column framed building and the main part of this building has nine bays in the long span direction and two bays in the short span direction. Although the cross section of columns of A frame and B frame is 500 cm ×

450~500 cm, that of rectangular columns of C frame is 180 cm × 700~1,000 cm. This building contains cantilever shear walls in the short span direction.

In 2004 seismic performance of this building was evaluated according to Standard for Evaluation of Seismic Capacity of Existing reinforced Concrete Buildings [1] and seismic retrofitting plan was designed. Figure 2 shows the location of assumed installed steel braces, postcast reinforced concrete shear walls and postcast reinforced concrete side walls to enhance seismic performance of this building. However actual retrofitting construction was not completed when the earthquake occurred. Figure 2 shows that only right half of the retrofitting had been completed. Photo 1 shows installed steel braces of A frame of this building.

Table 1. Outline of building (TS-1 building of TS-High school)

Name: TS-1 Building, TS High School
Structure: Reinforced concrete
Story: 3 story
Long span direction:
beam-column frame (9 span)
Short span direction:
beam-column frame with shear wall (4 span)
Foundation:
Spread foundation
Built year: 1966, 1967

Retrofit design: planed in 2004
Retrofitting method:
Steel brace (partly installed in 2004)
Postcast shear wall (partly installed in 2004)
Postcast side wall (partly installed in 2004)

Photo 1. General view (TS-1 building of TS-High school)

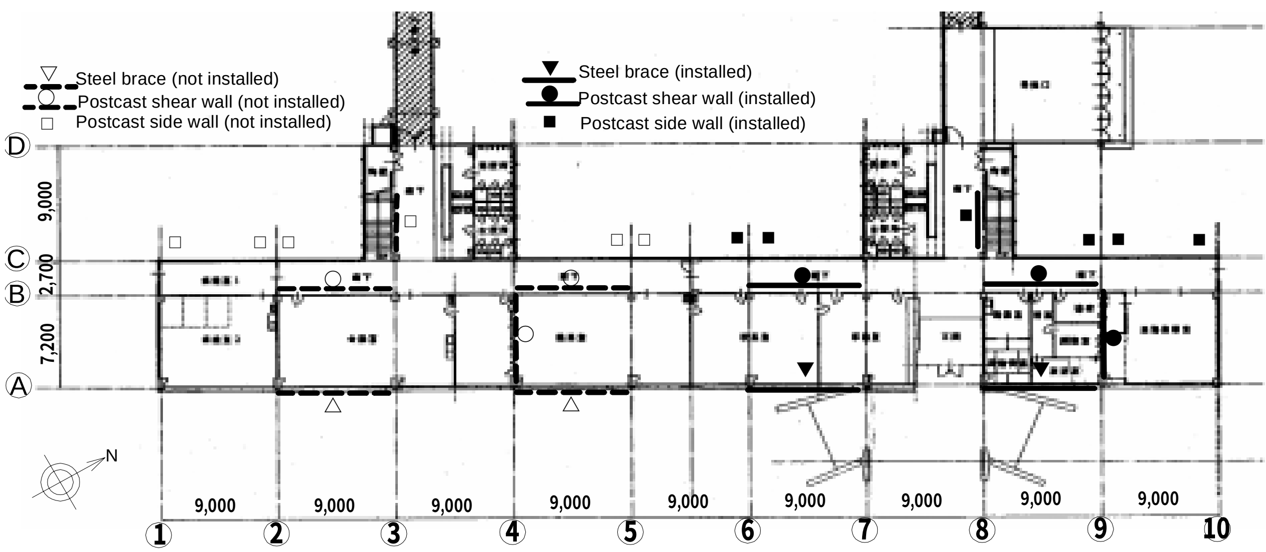

Figure 2. Plan of 1st floor (TS-1 building of TS-High school)

Outline of damage

Figure 3 shows observed damage level of all members of this building evaluated according to Ref. [2]. Damage level is classified under 5 levels, i.e. Ⅰ: slight damage, Ⅱ: light damage, Ⅲ: moderate damage, Ⅳ: heavy damage and Ⅴ: collapse. Damage level of 1st floor member is listed at the bottom part of damage level group of each member. Two columns with damage level of Ⅳ were observed in C frame of the first floor. Also two columns with damage level of Ⅳ were observed in C frame of the second floor. Photo 2 shows an example of columns with damage level of Ⅳ in the second floor indicating shear failure and buckling of main bars. This column is a rectangular column and the column height becomes short due to deep beams connecting to this column. Damage of columns in A frame and B frame were not observed but slight damage such as hair cracks around opening of walls of C frame were observed.

Figure 4 shows observed crack patterns of C frame indicating crack width in mm unit. Maximum crack width of columns with damage level of Ⅳ was 5 mm. Those crack patterns

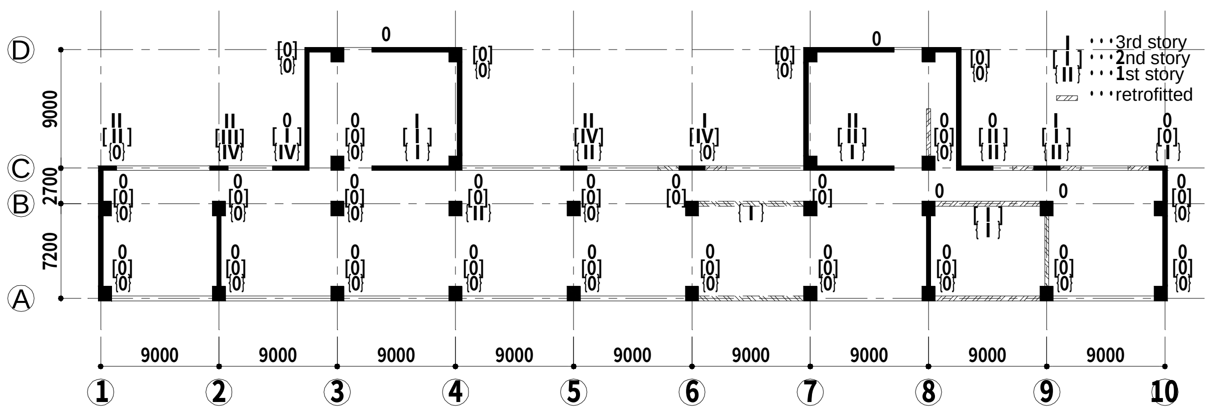

Figure 3. Damage level of column and wall members (TS-1 building of TS-High school)

Photo 2. Damage of column (damage level Ⅳ) of 2nd floor (TS-1 building of TS-High school)

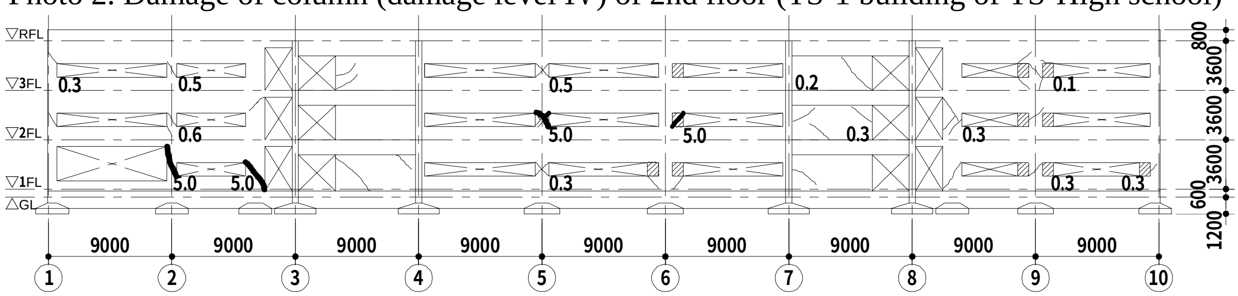

Figure 4. Crack pattern of C frame (TS-1 building of TS-High school)

indicate that crack width of non retrofitted columns and columns retrofitted by one side wall on one side only is larger than that of columns retrofitted by two side walls on both sides, which means the use of retrofitting by sidewalls.

Evaluated remaining seismic performance of building

Remaining seismic performance of the building can be evaluated using damage levels of members shown in Fig. 3. Figure 5 shows evaluated remaining seismic performance of this building calculated according to Ref. [2]. Remaining seismic performance is expressed by ratio of seismic performance of damaged building to that of original non damaged building. In Fig. 5 ratio of seismic performance of building before retrofitting is also shown for comparison.

Figure 5 indicates that remaining seismic performance of second floor was 89% of original building, which was classified into light damage according to Ref. [2]. Note that seismic performance of this building before retrofitting was lower than that of present damaged building, which indicates that damage level would be worse if this building was not retrofitted.

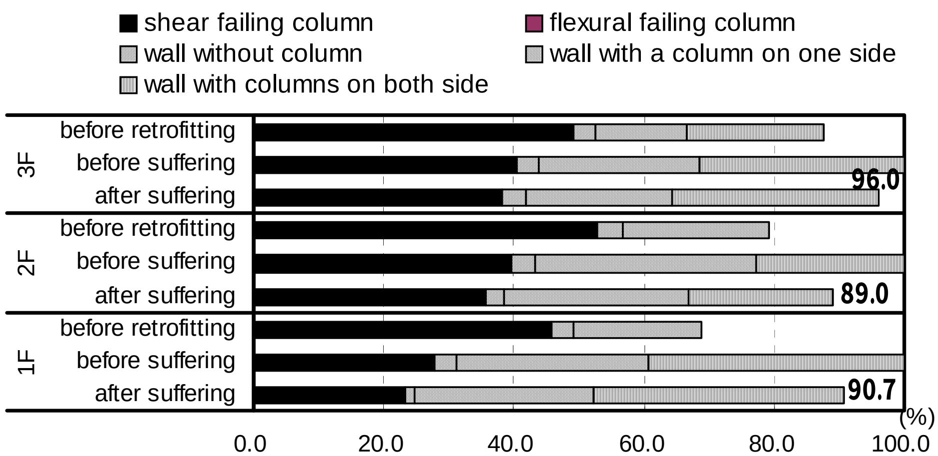

Figure 5. Remaining ratio of seismic performance of building in the long span direction (TS-1 building of TS-High school)

Evaluated seismic performance

Seismic performance indices of this building were evaluated according to Ref. [1]. Seismic performance index Is and strength index $C_{TU}S_D$ are expressed as follows.

$$Is = Eo \times S_D \times T / Z \qquad (Eo = C \times F)$$
$$C_{TU} \cdot S_D = C \times S_D / Z$$

where, Eo is basic seismic performance index of the building, C is potential strength factor obtained as lateral strength of a story divided by building weight supported by the story, F is potential ductility factor, S_D is index to evaluate the property of structure such as eccentricity, T is index for time dependent deterioration and Z is zone factor based on seismicity of the area (=0.9 in Niigata prefecture). In this standard three different level of evaluations are provided and the second level was used in this report.

Figure 6 shows evaluated relations between C value and F value, which represents the relations between lateral load and lateral deformation of the floor. Relations of three states depending on the retrofitting process are shown in each figure; i.e. non retrofitted original building, partly retrofitted present state and imaginary state after scheduled retrofitting. Using these relations seismic performance indices Is of the present state were obtained as shown in Table 2. On the other hand seismic safety of a building is judged by seismic judgment index I_{SO} shown as follows.

$$I_S > I_{SO}$$

A building which satisfies this inequation is assumed to be safe during supposed earthquake motions. School buildings in Japan are required as follows.

$$I_{SO} = 0.7$$

Table 2. Evaluated Seismic Performance Indices (long span direction) (TS-1 building of TS-High school)

Story	C	F	E0	SD	T	Is	CTUSD
3	(1.060)	(0.80)	0.901	0.88	0.99	0.79	0.89
	1.351	1.00					
	0.440	1.10					
2	(0.726)	(0.80)	0.670	0.88	0.99	0.58	0.64
	0.838	1.00					
	0.153	1.10					
1	(0.663)	(0.80)	0.816	0.88	0.99	0.71	0.72
	0.816	1.00					
	0.214	1.10					

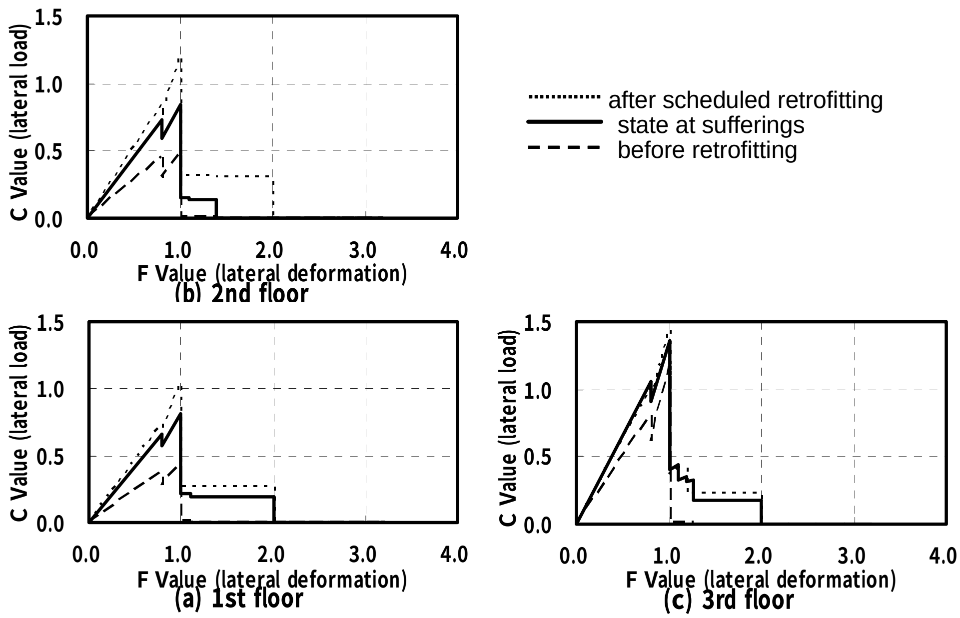

Figure 6.Relation between C Value and F Value (TS-1 building of TS-High school)

Figure 7 shows relations of Is values between long span direction and short span direction. Relations of three states depending on the retrofitting process shown in Fig. 6 are also compared in this figure. Broken lines in this figure represent required I_{SO} value for school buildings(0.7).This figure indicates that evaluated Is values of non retrofitted original building in the long span direction are much smaller than the required value and Is value of the second floor of the present building with partly retrofitting is also smaller than the required value. This can explain the fact that the damage of the second floor of the building was severer than other floors. And it should be noted that Is values of imaginary building after scheduled retrofitting are large enough in both directions which means that this building could survive during the earthquake without any damage if scheduled retrofitting had been completed.

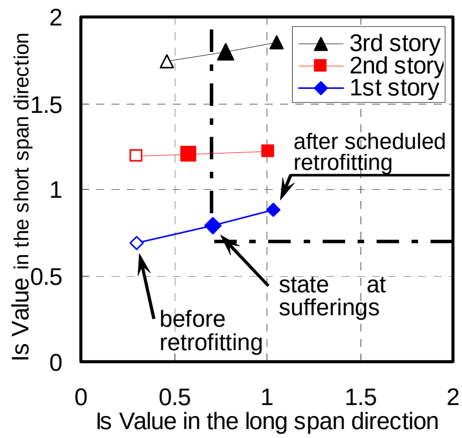

Figure 7. Is Value (second level evaluation) (TS-1 building of TS-High school)

Seismic performance of non damaged building (T-High school)

Outline of building

T-High school is located 1200m east of K-NET accelerometer. Table 3 shows outline of T-1 building of this high school damaged negligibly during this earthquake. This building was built from 1973 to 1979 according to former Japanese building law which was revised in 1981. Figure 8 shows plan of 2nd floor of this building and figure 9 shows a framing elevation of G frame. This is a four story beam-column framed building and the main part of this building has twenty three bays in the long span direction and eight bays in the short span direction. The cross section of columns is 700cm X 450~500 cm. Photo 3 shows general view of this building.

In 2003 seismic performance of this building was evaluated according to Standard for Evaluation of Seismic Capacity of Existing reinforced Concrete Buildings [1] and seismic retrofitting plan was designed. Figure 8 shows the location of assumed installed steel braces, slits in walls, wrapping CF sheets and new postcasted column around existing column to enhance seismic performance of this building. However actual retrofitting construction was not completed when the earthquake occurred. Figure 8 shows that only left half of the retrofitting had been completed.

Table 3. Outline of building (T-1 building of T-High school)

Name: T-1 Building, T High School
Structure: Reinforced concrete
Story: 4 story
Long span direction:
beam-column frame with shear wall (23span)
Short span direction:
beam-column frame with shear wall (8span)
Foundation: pile foundation
Built year: 1973-79

Retrofit design: planed in 2003
Retrofitting method:
Steel brace (partly installed in 2003, 2004)
Slit in wall (partly put in 2003, 2004)
Wrapping CF sheets (done)
Postcast around column (done)

Photo 3. General view (T-1 building of T-High school)

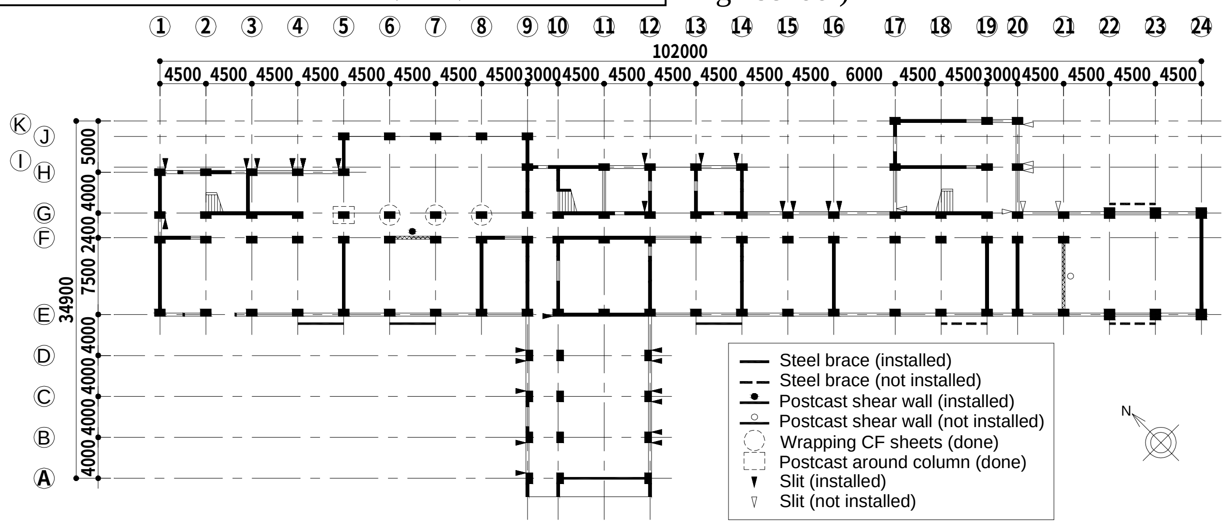

Figure 8. Plan of 1st floor (T-1 building of T-High school)

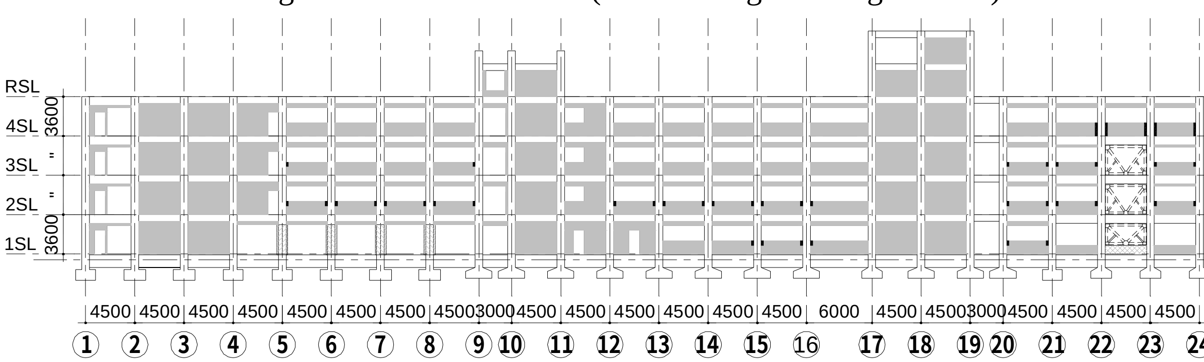

Figure 9. Framing elevation of G frame (T-1 building of T-High school)

Outline of damage

This building had negligible damage. Some columns with damage level of Ⅰ were observed during the Earthquake, but no column with damage level of Ⅱ through Ⅴ was observed in this building.

Evaluated seismic performance

Figure 10 shows evaluated relations between C value and F value. Relations of three states depending on the retrofitting process are shown in each figure; i.e. non retrofitted original building, partly retrofitted present state and imaginary state after scheduled retrofitting. Using these relations seismic performance indices Is of the present state were obtained as shown in Table 4.

Figure 11 shows relations of Is values between long span direction and short span

Table 4. Evaluated Seismic Performance Indices (long span direction) (T-1 building of T-High school)

Story	C	F	E0	SD	T	Is	CTUSD
4	0.118	0.80	0.576	0.90	0.95	0.55	0.70
	0.794	1.00					
	0.833	1.0-3.2					
3	(0.044)	(0.80)	0.747	0.90	0.95	0.71	0.73
	0.579	1.00					
	0.578	1.0-3.2					
2	0.073	0.80	0.460	0.90	0.95	0.44	0.53
	0.604	1.00					
	0.034	1.0-3.2					
1	(0.041)	(0.80)	0.746	0.90	0.95	0.71	0.67
	0.546	1.00					
	0.287	1.27-3.2					

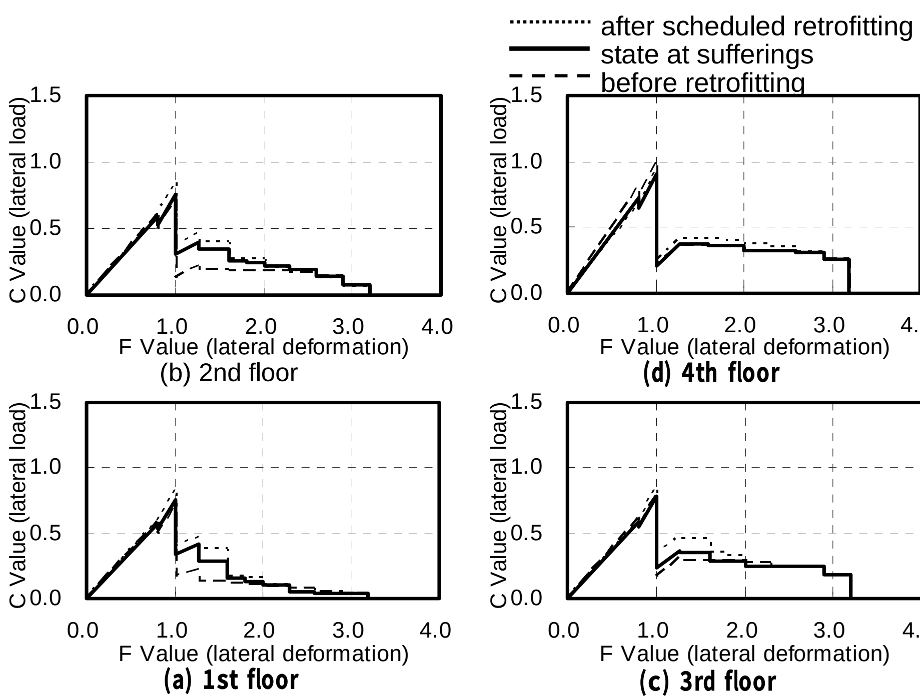

Figure 10. Relation between C Value and F Value (T-1 building of T-High school)

direction. Relations of three states depending on the retrofitting process shown in Figure 10 are also compared in this figure. Broken lines in this figure represent required I_{SO} value for school buildings(0.7). This figure indicates that evaluated Is values of the 1st, 2nd and 4th floor of non retrofitted original building in the long span direction are smaller than the required value and Is values of the 2nd and 4th floor of the present building with partly retrofitting are also smaller than the required value. But the damage of the 2nd and 4th floor was negligible. It is necessary to verify the relation between the negligible damage and the small Is value.

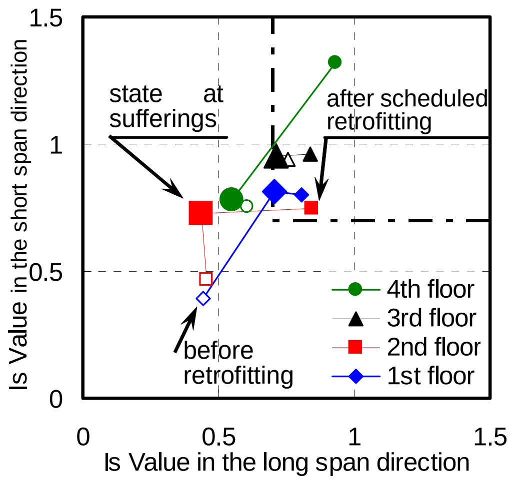

Figure 11. Is Value (second level evaluation) (T-1 building of T-High school)

Conclusions

TS-High school under construction for retrofitting had light damage during the 2004 Mid Niigata Prefecture Earthquake. It had four columns with damage level of 4 during the Earthquake. And the remaining seismic performance of the building was 89%. Evaluated Is value of the building was 0.58~0.79. The lack of seismic performance was assumed to be a cause of the damage.

T-High school under construction for retrofitting had negligible damage during the Earthquake. Evaluated Is value of the building was 0.44~0.71 although the damage of the building was negligible. It is necessary to verify the relation between the negligible damage and the small Is value.

Acknowledgments

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References

[1]Standard for Evaluation of Seismic Capacity of Existing reinforced Concrete Buildings, The Japan Building Disaster Prevention Association, 1990(in Japanese)

[2]Standard for Judgment of Damage Level of Buildings Suffered from Earthquake, The Japan Building Disaster Prevention Association, 2001(in Japanese)