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EVALUATION OF THE SEISMIC PERFORMANCE OF AN EXISTING REINFORCED-CONCRETE BUILDING DAMAGED BY THE 2007 NIIGATA CHUETSU-OKI EARTHQUAKE - DAMAGE RATING OF THE BUILDING CONSIDERING THE FAILURE MECHANISM OF COLUMNS -

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ABSTRACT

A reinforced-concrete school building (referred to as S-building) was moderately damaged by the 2007 Chuetsu-oki Earthquake. The residual seismic capacity ratio is 63.1% for the first floor and 77.0% for the second floor. The anticipated design failure modes of most of the columns of the building were flexure, although most of the columns actually failed through shearing. A previous study conducted static loading tests for varying lengths of cutoff bars and presence of spandrel walls. The conclusions derived from these tests were that the deformation capacity of a column with cutoff bars degraded tremendously under the conditions that the yielding hinge was located at the cutoff point, the diagonal cracks generated from the cutoff point were inclined at approximately 50–60 degrees and the effect of the presence of spandrel walls on deformation capacities was small. In this study, structural models with various conditions of cutoff bars and spandrel walls were used in earthquake response analysis. The earthquake ground motion observed at the Oguni municipal office about 3 km from S-building was used as input. The failure type of most columns agreed with the failure type of the real damage when a model considered a column with cutoff bars and spandrel walls. The residual seismic capacity ratio of the model is close to the residual seismic capacity ratio of the real damage of S-building.

INTRODUCTION

The Niigata Chuetsu-oki Earthquake that struck off the coast of Japan on July 16, 2007 caused damage to buildings. The earthquake was M6.8 and had a maximum Japanese Meteorological Agency seismic intensity scale of upper 6 in the city of Nagaoka, Niigata. The subject of this study is a three-story reinforced-concrete building that was constructed in 1963 and is part of the S elementary school; the name S is used to keep the privacy of the school, and the building is referred to hereafter as S-building. It is located in the town of Oguni in Nagaoka and was damaged moderately during the earthquake. Nagahashi et al. (2009) and Kato and Nagahashi (2011) calculated that most of the columns of the building would have been expected to fail through flexure, although most of them actually failed through shearing. The difference between calculated and observed failure modes of the first-floor columns was not impossible to explain in a parametric study of parameters including the strength of

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concrete, hoop spacing and subjected axial force. However, the difference cannot be explained for the second-floor columns. To determine why second-floor columns failed in shear mode, Kato et al. (2012, 2013) conducted static loading tests for varying lengths of cutoff bars and spandrel walls. These experiments showed that the deformation capacity of a column with cutoff bars degraded under the conditions that the yielding hinge is located at the cutoff point and the diagonal cracks generated from the cutoff point are inclined at approximately 50–60 degrees. From these conclusions, the failure mechanism of columns of S-building damaged during the 2007 Niigata Chuetsu-oki earthquake can be explained.

In this study, earthquake response analysis was conducted for structural models with various conditions of the cutoff bars and spandrel walls. The failure type of most columns in a model considering a column with cutoff bars and spandrel walls agreed with the failure type of the real damage. The residual seismic capacity ratio of the model is close to the residual seismic capacity ratio of the real damage of S-building.

OVERVIEW OF S- BUILDING

S elementary school is located approximately 3 km north of Oguni Town Hall, where seismic intensity of upper 6 was observed. Figure 1 shows the location of S-building and Oguni Town Hall (seismic observation point). Figure 2 shows acceleration response spectra with a damping factor of 0.05 derived from earthquake motion recorded at Oguni Town Hall. The dotted lines show the spectra for the north–south and east–west directions and the solid lines show the spectra for the longitudinal and transverse directions of S-building. Earthquake motion in the longitudinal direction was stronger than that in the transverse direction. These motion records were used as input motion for the earthquake response analysis of S-building. Oguni is a snow-covered area in winter. The structural design of S-building considered the possibility of a snow depth of 3.2 meters.

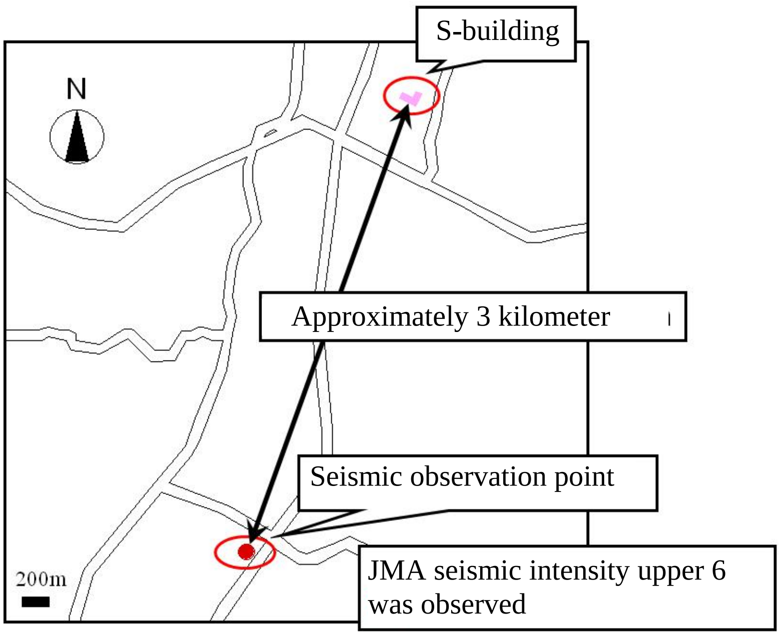


Figure 1 Locations of S-building and the seismic observation point

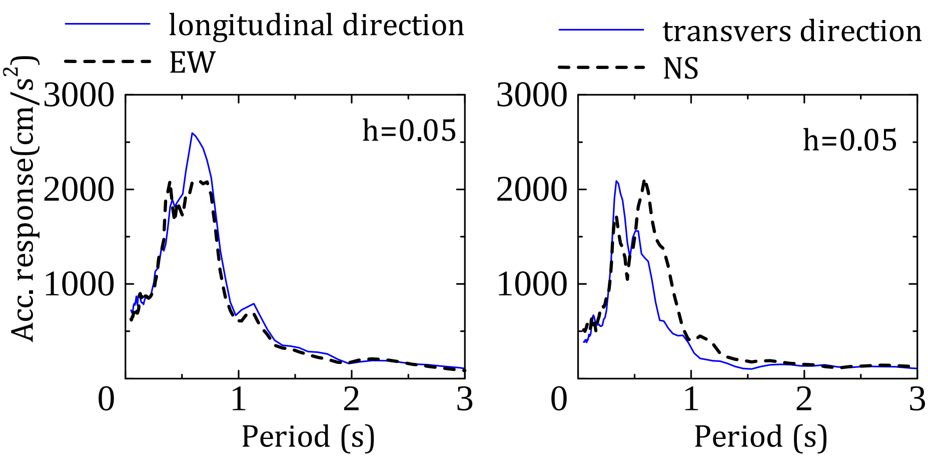
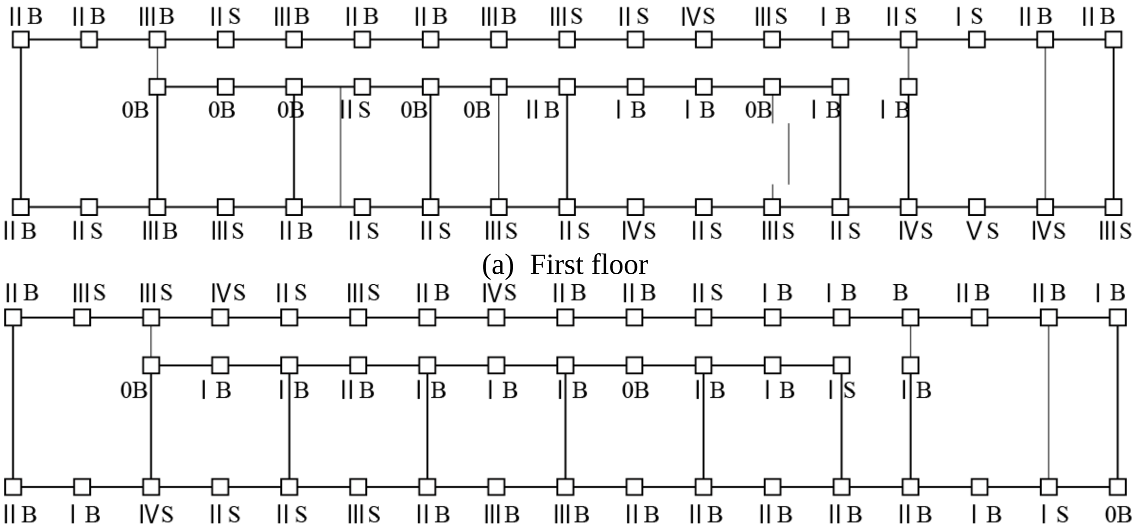


Figure 2 Acceleration response spectra

S-building is a three-story reinforced-concrete framed structure with piles containing classrooms. The building is shown in Figure 3. The building consists of 16 bay frames in the longitudinal direction and two bay frames in the transverse direction. The typical bay length in the longitudinal direction is 4.1 m. The bay lengths in the transverse direction are 7 and 2.8 m. Figure 4 shows the floor plan with the damage class of each vertical member. The damage classes are defined by Post-earthquake Damage Evaluation and Rehabilitation (JBDPA, 2001); there are five damage classes, I (visible narrow cracks on a concrete surface) through V (buckling of reinforcing bars, cracks in core concrete, visible vertical and/or lateral deformation of columns and/or walls, and visible settlement and/or leaning of the building). In the figure, “B” denotes a ductile member in flexure failure and “S” a brittle member in shear failure. The residual seismic capacity ratio index R calculated from the observed damage class in a simplified procedure was 63.1 percent on the first floor, 71.96 percent on the second floor and 95.7 percent on the third floor. Therefore, the damage levels of the Guideline for Post-earthquake Damage Evaluation and Rehabilitation are moderate damage on the first and second floors and light damage on the third floor.

Figure 3 Wide view of S-building



(a) First floor

(b) Second floor

Figure 4 Floor plan with the damage class of each vertical member

RESPONSE ANALYSES

Response analysis was conducted using STERA-3D software (Saito). Properties of sections of columns and walls for structural analyses were obtained from on-site investigation and data of beam sections were obtained from design documents. Six structural models with various conditions of cutoff bars and spandrel walls and material strength were used in response analysis. Main variables were the presence of cutoff bars, live load, snow load and material strength. Table 1 gives the material strengths. Strengths recorded in material tests were higher than the design strengths (Kato et al., 2013). Oguni receives heavy snow and a load of 240 cm of snow is considered in this study. However, the earthquake occurred on a summer's weekend, and therefore, there were no students at school and there was no snow at that time. The response analysis is conducted with and without a snow load.
Table 2 presents properties of the structural models used in the earthquake response analyses.

Table 1 Material strengths

	main bar	hoop	concrete
design strength	294 (N/mm^2)	294 (N/mm^2)	18 (N/mm^2)
material test	355 (N/mm^2) (1st floor)	339 (N/mm^2)	32.7 (N/mm^2)

Table 2 Properties of structural models

	strength		snow and movable load		cutoff bar	
model No.	design strength	strength from material test	considered	unconsiderd	considerd	unconsiderd
1	o		o			o
2	o			o		o
3		o	o			o
4		o		o		o
5		o	o		o	
6		o		o	o	

The residual seismic capacity ratio index (R) is defined as the ratio of the post-disaster seismic capacity to the pre-earthquake seismic capacity (JBDPA, 2001). R is calculated according to each commensurate residual seismic capacity reduction factor of the damage category and the failure modes of vertical members. There is total collapse when R = 0%, heavy damage when R < 60%, moderate damage when 60% < R < 80%, light damage when 80% < R < 95%, slight damage when 95% < R < 100%, and no damage when R = 100%.

In this study, the residual seismic capacity reduction factor of vertical members was assumed from the correspondence of damage classes and maximum drift angle of members. Figure 5 shows the assumed relationship between R and the damage class.

Kato et al. (2012) revealed that the deformation capacity of a column with cutoff bars and spandrel walls was small under certain conditions. The deformation capacity of a brittle column was assumed a third factor of the deformation capacity of a ductile column. R was calculated in the response analyses of the six models listed in Table 2. The earthquake acceleration observed at Oguni Town Hall was used as input motion. R values of the six models are given in Table 3.

Damage classes obtained with the models that did not consider the snow and live loads and used material strengths obtained in material tests suggested less damage than what was observed. In these cases, the failure type of some columns was flexure whereas the actual failure mode was shearing. R values of models 2, 4 and 6 were recalculated in consideration of the observed failure type. The resulting damage levels were lower but still different from the levels of real damage.

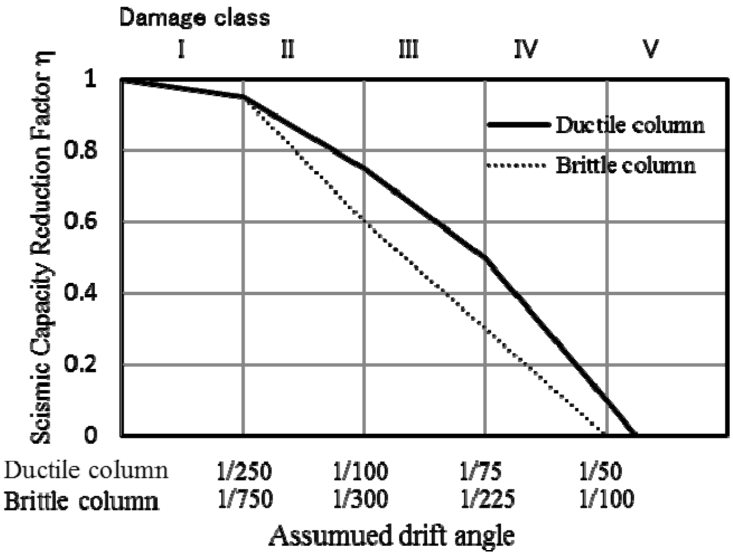


Figure 5 Assumed relationship between the seismic capacity reduction factor and the damage class

Table 3 R values and damage categories for different models

	analyitical failure type	
Model No.	Residual Seismic Capacity Ratio Index R (%)	Damage
1	46	Heavey
2	97.9	Slight
3	39.2	Heavey
4	98.8	Slight
5	91.2	Slight
6	96.9	Slight
	Observed failure type	
	Residual Seismic Capacity Ratio Index R (%)	Damage
2	94.1	Light
4	97.8	Slight
6	97.6	Slight

CONCLUSIONS

This study modelled the damage to S-building in the 2007 Chuetsu-oki Earthquake. Most column failure modes of the building cannot be explained by the Standard for Seismic Evaluation of Existing Reinforced Concrete Buildings. Six structural models of S-building with different conditions of cutoff bars and spandrel walls and material strengths were used in earthquake response analysis, and the residual seismic capacity ratios of these models were examined. The damage levels estimated from residual seismic capacity ratios of the models that do not consider snow and live loads and use material strengths obtained in material tests suggest less damage than what was observed. When the observed failure type was considered for these models, the level of damage decreased.

REFERENCES

Daisuke Kato and Yukiko Nakamura(2011) "Effects of Loading Conditions and Hoop Details on Residual Axial Load Capacity of R/C Columns Failing in Shear", *Journal of Asian Architecture and Building Engineering* Vol.10(2011), No.2, November 15, pp.399-405

Daisuke Kato, Katsushi Yoshizawa, Tetsuo Nagahashi, Yukiko Nakamura (2012) "Failure Mechanism of Columns of Existing R/C Building Damaged during the 2007 Niigata Chuetsu-Oki Earthquake", *The fifteenth World Conference of Earthquake Engineering*, Lisbon, 2012

Daisuke Kato, Katsushi Yoshizawa, Tetsuo Nagahashi, Yukiko Nakamura (2013) " Strength and deformation capacity of R/C columns with cut off bars –Effects of yielding hinge location and existence of spandrel wall-", *Journal of Structural Engineering, Architectural Institute of Japan*, Vol.78, No.683, 139-145, Jan., 2013

Nagahashi T., Kokubo T., Nakamura Y. and Kato D. (2009) "Seismic Performance of a R/C School Building Suffered during the Chuetsu and Chuetsu Oki earthquake", *Journal of Structural Engineering, Architectural Institute of Japan and Japan Society of Civil Engineering*, Vol 55B, pp. 459-468.(in Japanese)

The Japan Building Disaster Prevention Association (2001) Standard for Seismic Evaluation of Existing Reinforced Concrete Buildings

The Japan Building Disaster Prevention Association (JBDPA) (1991 revised 2001), Guideline for Post-earthquake Damage Evaluation and Rehabilitation.