ISCEAS-571
Damage Factors of Pile Foundation of School Building Due to Seismic Performance of the Building

Mitsuki Higashida
Graduate School of Science and Eng., Yamaguchi Univ., 2-16-1, Tokiwadai, Ube, Yamaguchi, Japan
v023vm@yamaguchi-u.ac.jp

Tomofusa Akita
Graduate School of Science and Eng., Yamaguchi Univ., 2-16-1, Tokiwadai, Ube, Yamaguchi, Japan
akita@yamaguchi-u.ac.jp

Eiichi Inai
Graduate School of Science and Eng., Yamaguchi Univ., 2-16-1, Tokiwadai, Ube, Yamaguchi, Japan
inai@yamaguchi-u.ac.jp

Tomohisa Mukai
Building Research Institute, 1 Tachihara, Tsukuba, Ibaraki, Japan
t_mukai@kenken.go.jp

Hisatoshi Kashiwa
Building Research Institute, 1 Tachihara, Tsukuba, Ibaraki, Japan
kashiwa@kenken.go.jp

Tsutomu Hirade
Building Research Institute, 1 Tachihara, Tsukuba, Ibaraki, Japan
hirade@kenken.go.jp

Osamu Kaneko
Toda Corporation 1-7-1 Kyobashi 1, Chuo-ku, Tokyo, Japan
osamu.kaneko2@toda.co.jp
The corresponding author: Tomofusa Akita

Abstract

There were many buildings that had severe damage at pile foundations under the 2011 off the Pacific coast of Tohoku Earthquake (As shown in the report [1]). In the building standard law of Japan (as shown in the book [2]), an upper structure is obliged to design for prevention of collapse against severe earthquakes, whereas a lower structure is not obliged to design against large earthquakes. However, a building loses the post-earthquake functional use when pile foundations suffered severe damage. Therefore, it is necessary to prevent damage of pile foundations of a building which is used as refuge facility, such as a school building. In this study, damage factors of the school building which was damaged in the pile foundations in the 2011 off the Pacific coast of Tohoku Earthquake were analyzed. If these damage factors become clear, the development of the preventive measures against the damage of the pile foundations will be promoted. An analysis object is 3-story Reinforced Concrete Construction school building with pile foundations. Slight cracks occurred at columns and walls due to the earthquake. On the other hand, the lower structure suffered serious damage at pile heads. A pushover analysis using an upper structure model was carried out. As a result, the following things were obtained as damage factors. The pile heads had large shear stress, since eccentric behavior of this building was excited due to the arrangement of shear walls. Since the eccentricity ratio of the building is relatively large, the horizontal displacement is increased in the one side of the building.

Keyword: Pushover Analysis, Reinforced Concrete Construction, The 2011 off the Pacific coast of Tohoku Earthquake, Upper Structure

1. Introduction

There were many buildings that had severe damage at pile foundations under the 2011 off the Pacific coast of Tohoku Earthquake (As shown in the report [1]). In the building standard law of Japan (As shown in the book [2]), an upper structure is obliged to design for prevention of collapse against severe earthquakes, whereas a lower structure is not obliged to design against large earthquakes. However, a building loses the post-earthquake functional use when pile foundations suffered severe damage. Therefore, it is necessary to prevent damage of pile foundations of a building which is used as refuge facility, such as a school building. The purpose of this study is to examine damage factors of the school building which was damaged in the pile foundations in the 2011 off the Pacific coast of Tohoku Earthquake. The piles with different length are using due to the inclinations of bearing ground. A characteristic of the damage is destruction of the pile heads at long pile. If these damage factors become clear, the development of preventive measures against the damage of the pile foundations will be promoted. The pushover analysis using the upper structure model was carried out to reveal that the large shear force and axial force acting on the damaged piles and to demonstrate the capacity of the upper structure.

2. Target Building

2.1 Outline of Building

The analysis object is 3-story Reinforced Concrete Construction school building with the pile foundations. Figure 1 shows the foundation plan and Fig.2 shows the framing elevation. There is no basement floor, and the longitudinal direction is framed structure with earthquake-resistant wall of 11 spans, the transverse direction is structure consist of earthquake-resistant wall of 5 spans. The longitudinal direction is called X direction and transverse direction is called Y direction. Most of the shear walls are located in the building has openings. Figure 3 shows the soil boring log. The foundation is independent footing. The piles are used pretension high concrete pile of 400φ (B type). The length of piles are 13m at Axis 1-4, 14m at Axis 5-9 and 16m at Axis 10-12. The ground is the soil type 2 (As shown in the book [2]).

2.2 Damage of Building

According to the existing report (As shown in the report [3]), slight crack occurred at columns and walls in Axis 9-10 due to the earthquake, but there is a little exfoliation of the concrete, and reinforcement didn't exposed. The lower structure crushed at pile heads. Moreover prestressing steel have transformed and exposed. The building sunk at Axis 9-12 on the east side. In addition, liquefaction doesn't occur.

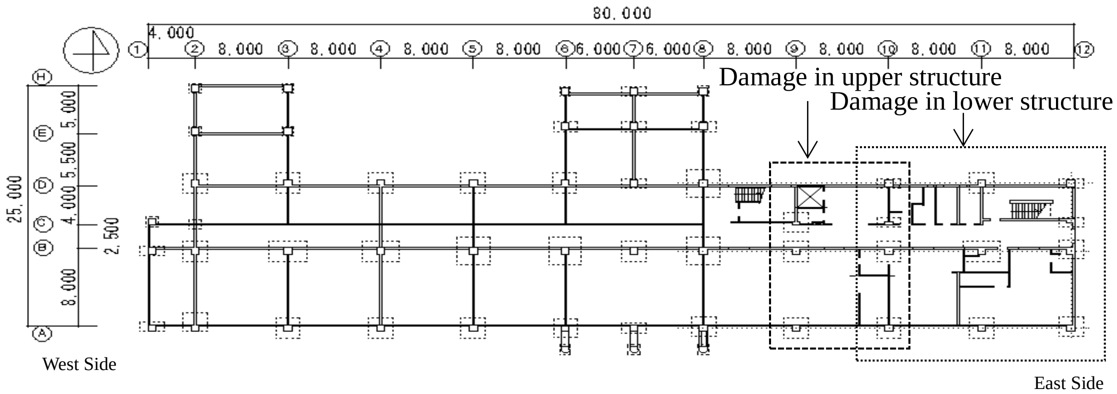
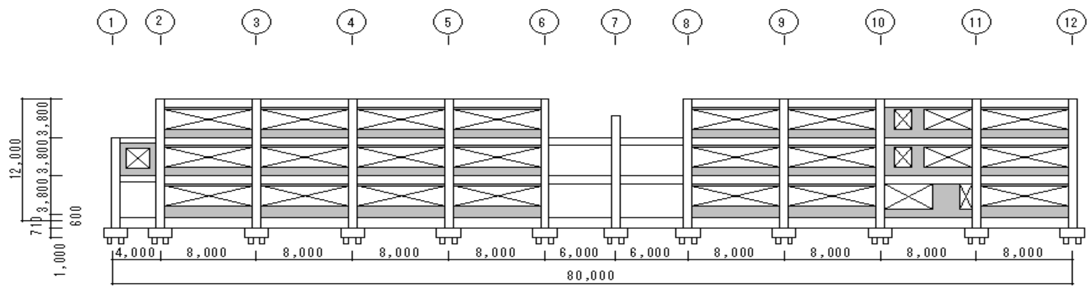
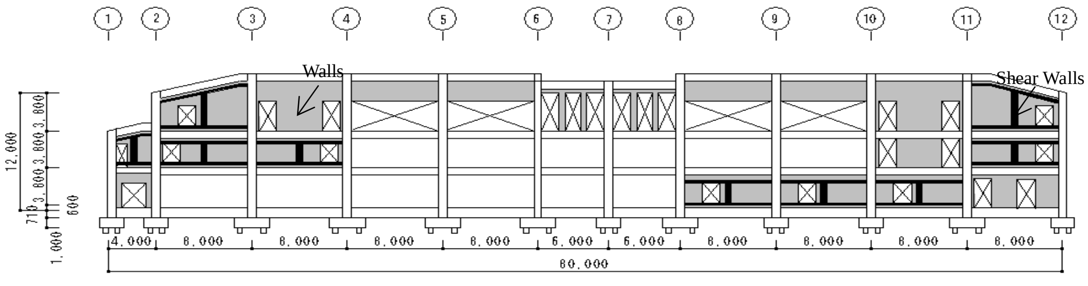


Fig.1 Foundation plan

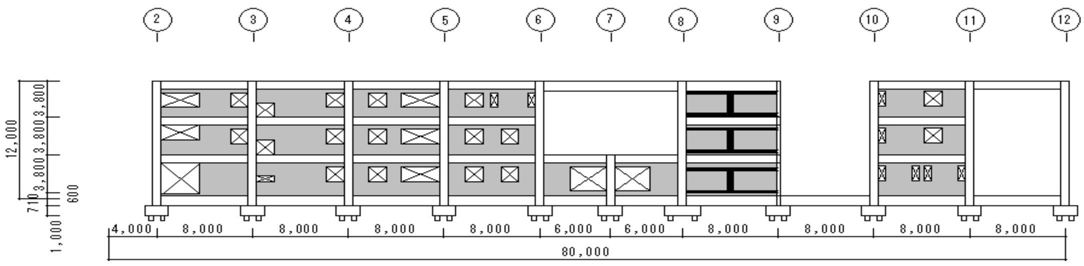


(a) Axis A

West Side East Side



(b) Axis B



(c) Axis D

Fig.2 Framing elevation (工 indicates shear wall, colored indicates wall)

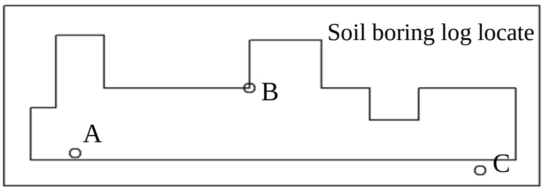


Fig.3 Soil boring log

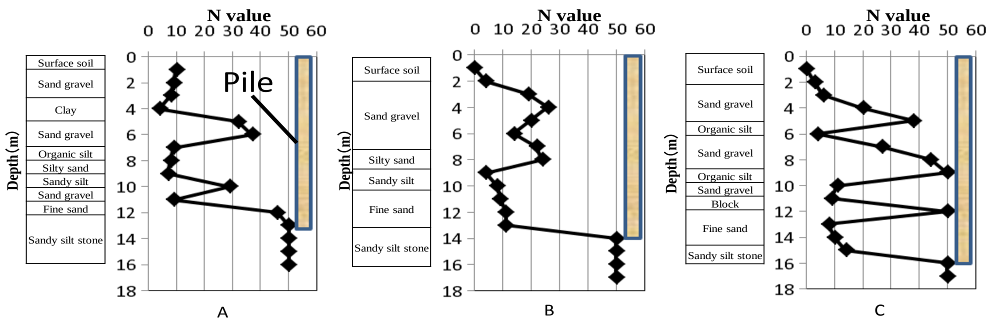


Fig.3 Soil boring log

3. Analysis Plan

3.1 Analysis Method

The analysis model is space frame that the upper structure modeled. The columns and beams replaced with a linear element. An end spring model with a tri-linear skeleton curve is used to the beam and a multi-spring model is used to the column. An end spring model is used to the wall. The horizontal force distribution used in the pushover analysis is based on Ai distribution (As shown in the book [2]). The analysis is stopped when a maximum drift angle reached 0.02 rad.

3.2 Analysis Case

Two types of models are constructed in this analysis. One is that just modeled on the target building and the other is that modeled on the building in which removed all walls from the target building. The former is called “O model” and the latter is called “F model”. Table 1 shows building weight and modulus of eccentricity and Tab.2 shows natural first period. The O model has a bigger modulus of eccentricity than that of the F model. In addition, the difference of the natural first period of the both directions is small in each model. For each model, the positive and negative loading are applied in X and Y direction so 8 cases analyses are carried out in total. The positive loading stands for the loading from South to North and from West to East. Comparing the positive and negative results, there is no almost difference. Therefore, this paper shows only the result of the positive loading in chapter 4 and chapter 5.

Tab.1 Building weight and modulus of eccentricity

	O model(X direction)	O model(Y direction)	F model(X direction)	F model(Y direction)
Weight(kN)	48356		41554	
Mass center of gravity(mm)	37654	9073	37287	8781
Center of rigidity(mm)	36014	10738	38471	8932
Modulus of eccentricity	0.078	0.127	0.037	0.016

Tab.2 Natural first period (sec.)

	O model	F model
X direction	0.142	0.352
Y direction	0.119	0.363
Torsional	0.103	0.323

4. Analysis Result

4.1 Shear Force (Q) – Story Drift Angle (R) Relationship

Figure 4 shows story shear force (Q)-story drift angle(R) relationship of the O model and the F model. In X direction, the base shear of the O model is about 2.6 times larger that of the F model at the story drift angle 0.02rad. The cause is presence of many walls with openings in X direction. In Y direction, the base shear of the O model is about 3.5 times larger that of the F model at the story drift angle 0.02rad.

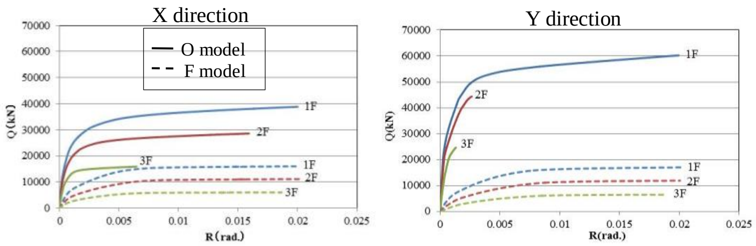


Fig.4 Shear force – story drift angle relationship

4.2 Base Shear Coefficient-Representative Drift Angle Relations

Figure 5 shows base shear coefficient (CB) - representative drift angle (RT) relations of the O model and the F model. The representative drift angle RT is calculated by δ/h (where, δ: 3rd floor deformation, h: 3rd floor height). In X direction, the base shear coefficient of the O model is about 2.3 times larger that of the F model at the representative drift angle 0.01rad. In Y direction, the base shear coefficient of the O model is about 3.5 times larger that of the F model at the representative angle 0.01rad.

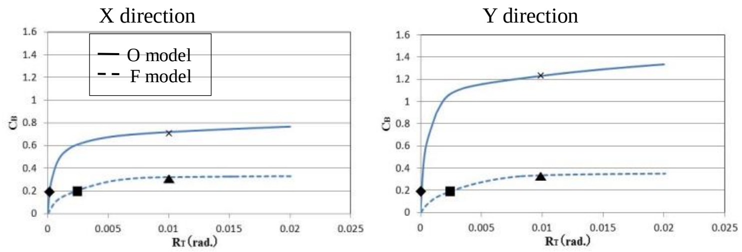


Fig.5 Base shear coefficient-representative drift angle relationship

5. Damage Factor Examination

5.1 Capacity of Upper Structure

Figure 6 shows the base shear in X direction of each axis. In addition, Tab.3 shows the base shear of each axis divided by the base shear of all axes in X direction. In this chapter, it is shown the result of CB=0.2 and RT=1/100. CB=0.2 means the situation of the allowable stress design (As shown in the book [2]). RT=1/100 means the situation when the building capacity generally reaches the horizontal load-carrying. The O model of CB=0.2 (mark ◆), RT=1/100 (× mark), and the F model of CB=0.2 (■ mark), RT=1/100 (▲ mark), are indicated in Fig.5. The result of CB=0.2 time of the O model is the state where cracks are occurred in the building. Therefore, the result of the O model corresponds to the situation of the building after the earthquake. From Tab.3, the ratios of the bear story shear force in the F model are not a big difference among Axis A, B, D. On the other hand, the ratio of the bear story shear force of Axis D in the O model is 0.47 at CB=0.2, and that is 0.37 at RT=1/100. These values are large compared to the values of the other axis. Look at Fig.2, there are many openings to Axis A on the south side, so it is thought that the wall quantity of the Axis D on the north side is relatively large.

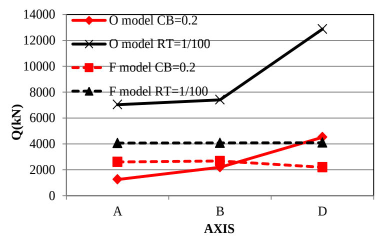


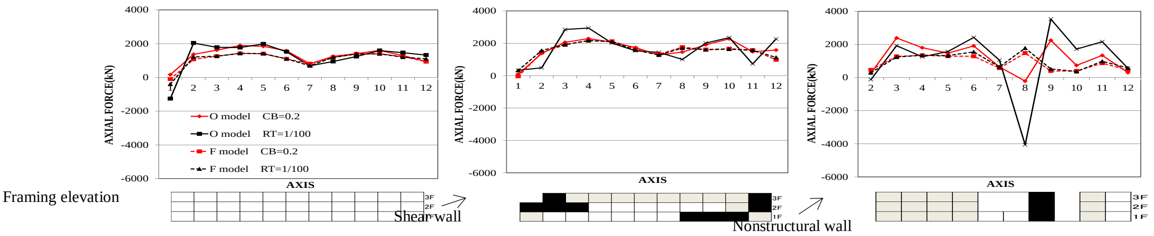
Fig.6 Base shear of each axis

Tab.3 Ratio of base shear

		A	B	D	C,E,H
O model	CB=0.2	0.13	0.23	0.47	0.17
	RT=1/100	0.2	0.21	0.37	0.22
F model	CB=0.2	0.27	0.28	0.23	0.22
	RT=1/100	0.26	0.26	0.26	0.22

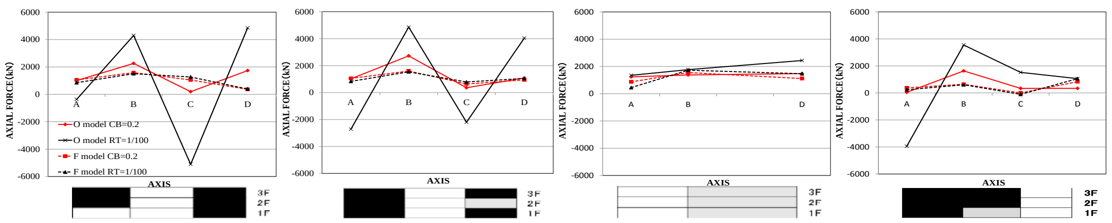
5.2 Axial Force Acting on Pile Head

Figure 7 shows axial force acting on the pile heads. The axial force acting on the pile heads is the vertical supporting point reaction force of the upper structure. It shows the Axis A, B and D that have plenty of walls, and also shows the Axis 9-12 that suffered the damage. The black coating of framing elevation in Fig.7 expresses a part that considered as a shear wall in the analysis model. According to the comparison of the axial force of CB=0.2 of the O model in X direction between the damaged pile heads at Axis 10-12 and undamaged the pile heads at Axis 1-9, the axial forces at the damaged piles are not so large. Compressive and tensile the axial forces occur in the O model of CB=0.2 in Y direction. In addition, looking at both models of CB=0.2 and RT=1/100, it was found that the axial forces at the place with the shear wall become large when deformation become large.



Axis A **Axis B** **Axis D**

(a)X direction



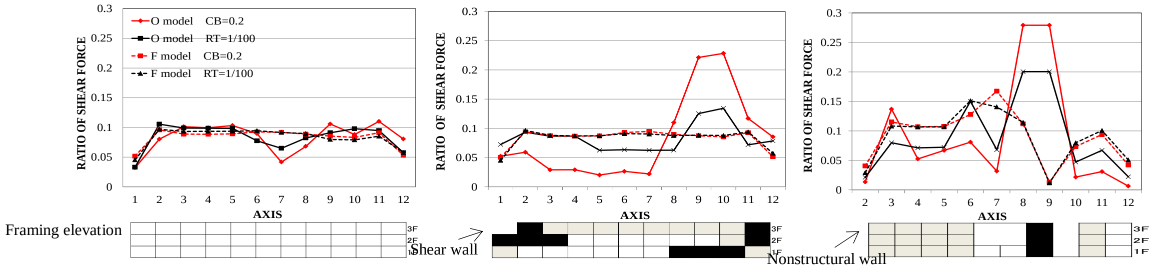
Axis 9 **Axis 10** **Axis 11** **Axis 12**

(b)Y direction

Fig.7 Axial force acting on pile head

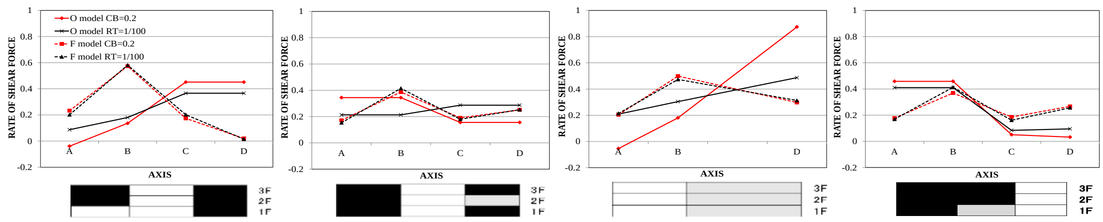
5.3 Shear Force Acting on Pile Head

Figure 8 shows the ratio of shear force of each axes acting on the pile heads. The ratio of shear force is derived from the shear force on each pile heads divided by the total shear force in the axis. The shear force acting on the pile heads is the lateral supporting point reaction force of the upper structure, and the inertial forces acting on the base portion are not included. Similar to Fig.7, it shows the Axis A, B and D that have plenty of walls, and also shows the Axis 9-12 that suffered the damage. Looking at the O model of CB=0.2 in X direction, it was found that burden of the shear force increase at the place where has the shear wall. The burden of the shear force is large on the east side (Axis 8-11), it is supposed that it becomes a cause that the damage occurred in the east side (Axis 9-12).



Axis A Axis B Axis D

(a)X direction



Axis 9 Axis 10 Axis 11 Axis 12

(b)Y direction

Fig.8 Shear force acting on pile head

5.4 Horizontal Displacement

Figure 9 shows the horizontal displacement at 2 floor position in Y direction loading and Fig.10 shows the displacement diagram of the O model at RT=1/100. In Fig.10, the dotted line means the original position of the building and the solid line means the position of the building after deformation in expansion ratio of 10 times. According to Fig.9 and Fig.10, displacement of east side is large at the place where damaged pile heads. It is supposed that the large displacement on east side cause the damage concentrated on the piles at Axis 10-12. The displacement of the O model at RT=1/100 is larger than that of the F model because the deformation concentrates on the first story in the O model from Fig. 5. The eccentricity of the building is relatively large, so it is guessed that the displacement of the east side of the building is large.

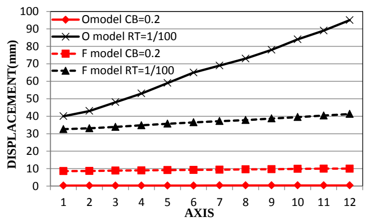


Fig.9 Horizontal displacement

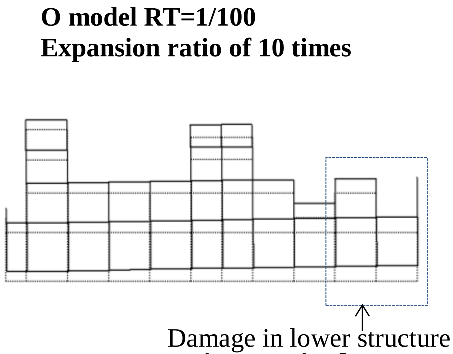


Fig.10 Displacement diagram

6. Conclusions

In this paper, the pushover analysis of the upper structure model was carried out in order to examine the damage of the building. The main purposes are to examine the large shear force and axial force acting on the damaged piles and to reveal the capacity of the upper structure. The findings obtained in this study may be summarized as follows.

(1)The capacity of the upper structure is relatively large because many shear walls and nonstructural walls are present.

(2)Most of the walls located in this building has openings. When the walls are regarded as the shear walls in the analysis model by the opening situation, the shear force and the axial force of the piles under the shear walls are increased.

(3) The pile heads had large shear stress, since eccentric behavior of this building was excited due to the arrangement of shear walls.

(4)Since eccentricity ratio of the building is relatively large, the horizontal displacement is increased in the east side of the building.

In this paper, the examination by the analysis of the upper structure model was only conducted. The effect of the coupling of the lower structure and upper structure is not considered. From now on, the analysis using the lower structure model and upper-and-lower structure model will be carried out.

Acknowledgments

This research was supported by JSPS KAKENHI Grant Number 26242035 which is entitled "Development of advanced technology to improve seismic performance for Disaster Prevention Center with Post-EQ functional use". Moreover, a part of the damage investigation was conducted in the following two projects. One is the maintenance promotion project of building standard organized by Ministry of Land, Infrastructure and Tourism in 2012 and 2013 which is entitled “Study on safety measure for pile foundation against earthquake”. The other is the important research issue in Building research institute which is entitled “Development on performance based seismic design for buildings with Post-EQ functional use". The latter project was conducted by Building Research Institute, Chiba University, Shibaura Institute of Technology, Yamaguchi University and Toda Corporation. We would like to express the deepest appreciation to collaborators.

References

[1] Architectural Institute of Japan (2011), Preliminary Reconnaissance Report of the 2011 Tohoku-Chiho Taiheiyo-Oki Earthquake (in Japanese), 577pp.

[2] The Building Center of Japan (2011), The Building Standard Law of Japan (CD-ROM)

[3] Osamu Kaneko, Shoichi Nakai (2014), Evaluation of Seismic Performance of Pile Foundations Damaged During the 2011 Great East Japan Earthquake (in Japanese), Architectural Institute of Japan, Vo.695, pp.83-91