TIME HISTORY RESPONSE ANALYSIS OF RC SCHOOL BUILDING USING SUPER-AND-SUB STRUCTURE MODEL

Tomofusa Akita[1] and Eiichi Inai[2]

1. Lecturer, Graduate School of Sciences and Technology for Innovation, Yamaguchi Univ. Dr. Eng.
2. Prof, Graduate School of Sciences and Technology for Innovation, Yamaguchi Univ. Dr. Eng.

Email:akita@yamaguchi-u.ac.jp, inai@yamaguchi-u.ac.jp

ABSTRACT

Many buildings were damaged in pile foundation in 2011 Tohoku-Chiho Taiheiyo-Oki Earthquake. In this study, a school building damaged in the pile foundation in 2011 Tohoku-Chiho Taiheiyo-Oki Earthquake was analyzed. The purpose of this study is to simulate the damage of pile foundation of the building. The time history response analysis using super-and-sub structure model was conducted. As a result, pile foundation was damaged in the analysis and it was corresponding with the actual damage. On the other hand, flexural failure of foundation beams occurred and shear failure of columns occurred in the analysis, it was different from the actual damage.

Keywords: 2011 Tohoku-Chiho Taiheiyo-Oki Earthquake, pile foundation, reinforced concrete

INTRODUCTION

Many buildings were damaged in pile foundation in 2011 Tohoku-Chiho Taiheiyo-Oki Earthquake as in the report (Architectural Institute of Japan, 2012). In the Building Standard Law of Japan, the superstructure is obliged to design for large earthquakes, whereas the substructure is not obliged to design for large earthquakes in the building standards law of Japan (The Building Center of Japan, 2016). Even if the substructure fails, people's lives are saved. However, when substructure is damaged, it is difficult to use a building continuously. In particular, buildings used as place of refuge have to work after large earthquakes. Therefore, the substructure must be obliged to design for large earthquakes in the future. In this study, a school building damaged in the pile foundation in 2011 Tohoku-Chiho Taiheiyo-Oki Earthquake was analyzed. In previous research by the authors (Yano, 2018), pushover analyses of the building were carried out using superstructure model, substructure model and super-and-sub structure model to clarify the damage factor of the building. Then, the purpose of this study is to simulate the damage of pile foundation of the building by dynamic analysis. The time history response analysis using super-and-sub structure model was conducted.

OVERVIEW OF THE BUILDING

Figure 1 shows a pile foundation plan and figure 2 shows the framing elevation. An analysis object is a 3-story RC building with pile foundation. The building do not have basement floor. The building has the frame structure in X direction and the frame structure with shear walls in Y direction. The most of walls of the building have openings. The pile is PHC pile (B type) 400 φ is used for the piles. The length of piles of the building are 13 m (Axis 1 to 4), 14 m (Axis 5 to 9) and 16 m (Axis 10 to 12). The ground are classified into 3 strength class, from level 1 to level 3 in Japan. The building stands on the level 2 ground. Level 2 ground is classified as intermediate strength ground. The damage of the building in 2011 Tohoku-Chiho Taiheiyo-Oki Earthquake are as follows. Slight cracks occurred in the columns and the walls at Axis 9-10 in the superstructure. On the other hand, compressive failure

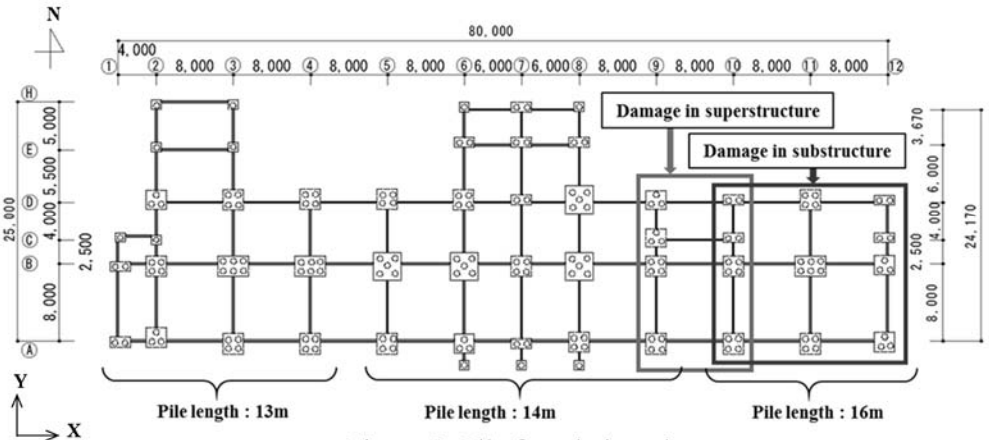
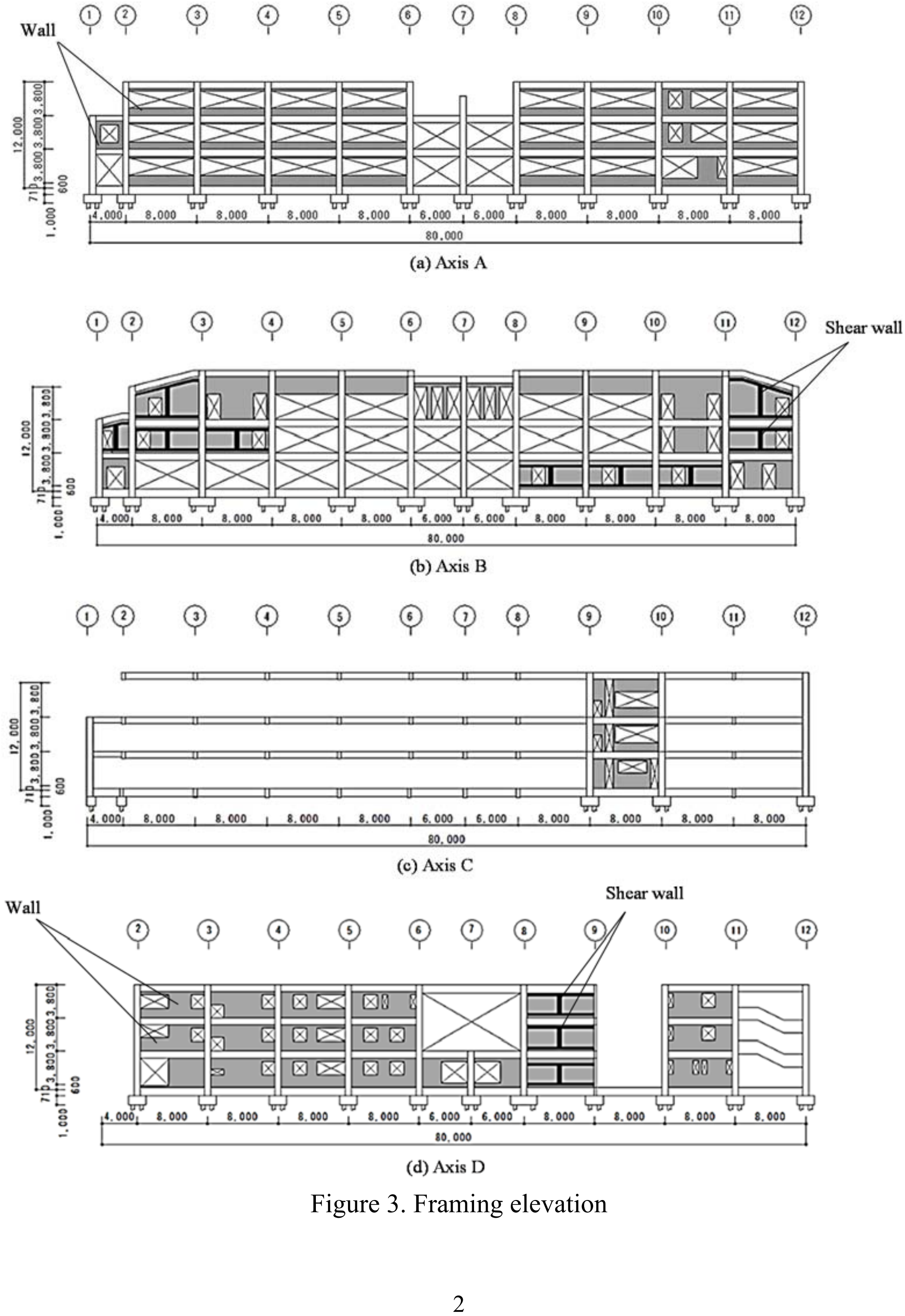


Figure 2. Pile foundation plan



(a) Axis A

(b) Axis B

(c) Axis C

(d) Axis D

Figure 3. Framing elevation

occurred in the pile head at Axis 10-12 in the substructure. Furthermore, the east side of the building (Axis 9 to 12) was sunk. Liquefaction was not observed.

ANARYSIS PLAN

Analysis Model

The super-and-sub structure model is constructed by combining the substructure model with the superstructure model. Figure 3 shows the outline of the super-and-sub structure model. Frame model is used for the superstructure. Frame model has the line member of columns and beams. The end spring model is applied to the beam members. The end spring model has the tri-linear skeleton curve which consider flexural cracking point and flexural yield point. The multi-spring model is applied to the column members. The shear walls are replaced with the line members and the end spring model is applied. Nonstructural walls are considered only their own weight. The other walls are replaced with the spandrel wall of the side beam and the hanging wall of the side beam, and the wing wall of the side columns. And they are considered as stiffness and strength of side beams and side columns. And the stiffness and strength of spandrel wall, hanging wall and wing wall are add to the stiffness and strength of beam and column. Since the slab is the dirt floor concrete structure, the second floor and the third floor are supposed to be rigid. A single pile model is used for the substructure. It is divided into longitudinal elements of 100 cm length each. The fiber model is applied to the pile cross section and the pile cross section was divided into 36 elements. Horizontal soil springs with tri-linear skeleton curve are attached to the node of the longitudinal element of the pile, and the pile end supported by pin. In this model, the pile length is defined as the length from the ground surface to the tip of the pile. The details of the single pile model are described in the previous research by the authors (Yano, 2018).

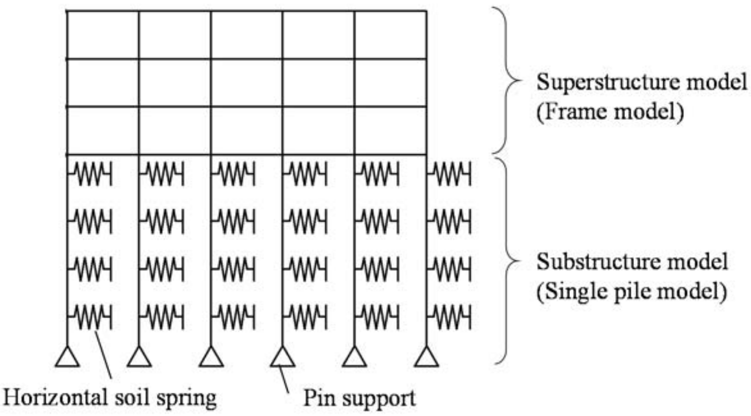


Figure 3. Outline of the Super-and-Sub structure model

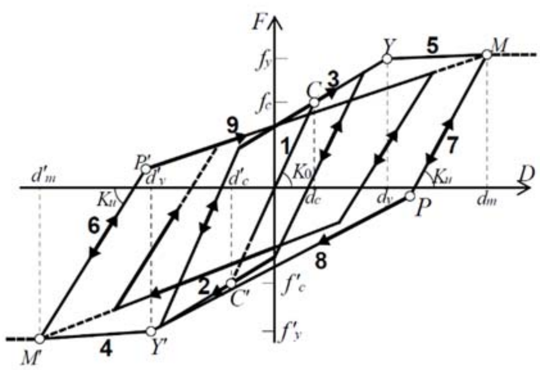


Figure 4. Hysteresis model of horizontal soil spring

Takeda-Model is used for beam bending hysteresis loop and elastic model for shear hysteresis loop. Since the fiber model is used for the single pile model, general material properties are used for the concrete and steel hysteresis loops. The hysteresis model shown in Figure 4 were used for the hysteresis loop of the horizontal soil spring. In addition, the damping constant is set to an instantaneous stiffness proportional type, and the value is 3% with respect to the first natural period.

Analysis Case

Two models, “Io model” and “Is model”, are used in this analysis. “Io model” is the standard model just combined superstructure model and substructure model. In “Is model”, the stiffness of the horizontal soil spring at ground surface is set to almost zero to consider that N value of the ground surface is fairly small. Furthermore, the stiffness and reaction force of the horizontal soil spring is set to half to consider the evaluation accuracy of the horizontal soil spring. The horizontal ground springs of “Io model” and “Is model” are the stiffness reduction type hysteresis models as shown in Figure 4, but only the horizontal ground springs of the nodes below the pile head in the Is model are elastic hysteresis models.

Input Wave

The seismic motion of the engineering bedrock estimated from the surface ground motion observed at the nearest observation point of the building is used for the input ground motion. Seismic records in the EW and NS directions observed at the nearest K-NET station (NIED, 2019) of the building during the 2011 Tohoku earthquake are selected in this analysis. Figure 5 shows the time history of acceleration of the seismic motions and Figure 6 shows the acceleration response spectrum of the seismic motion of engineering bedrock compared with the earthquake motion of the observation point. The X direction (long side direction of the building) corresponds to EW, and the Y direction (short side direction of the building) corresponds to NS. In both X and Y directions, seismic motion of the engineering bedrock are inputted to the pile tip at a magnification of 1.0. The duration time is 170 seconds, from 0 seconds to 170 seconds. The maximum acceleration in the EW direction of the seismic motion of engineering bedrock is 492.4 cm/s^2, and the maximum acceleration in the NS direction of that is 553.3 cm/s^2.

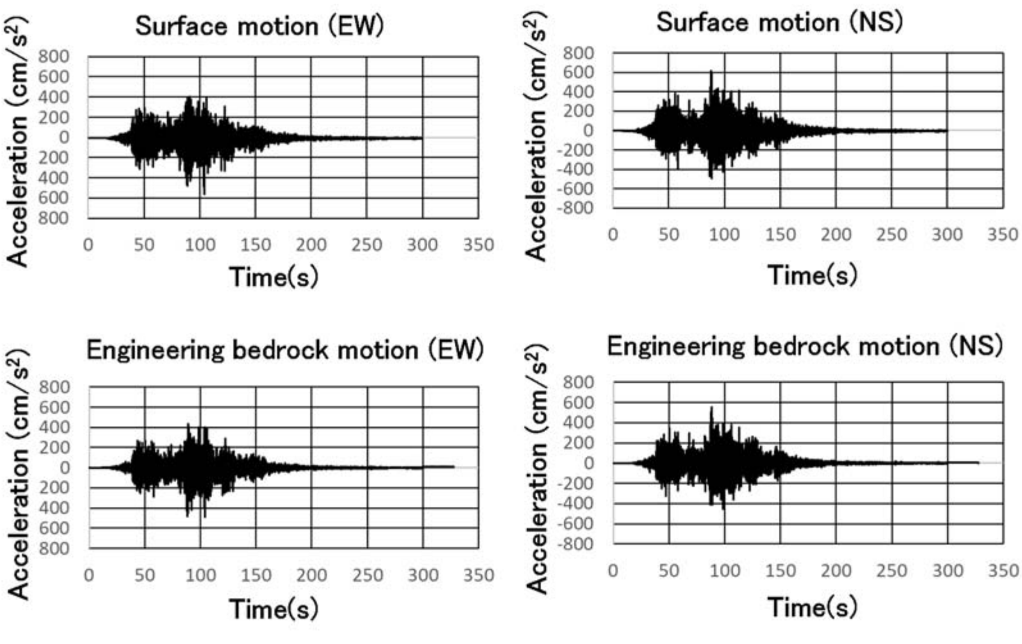


Figure 5. Time history of acceleration of seismic motions

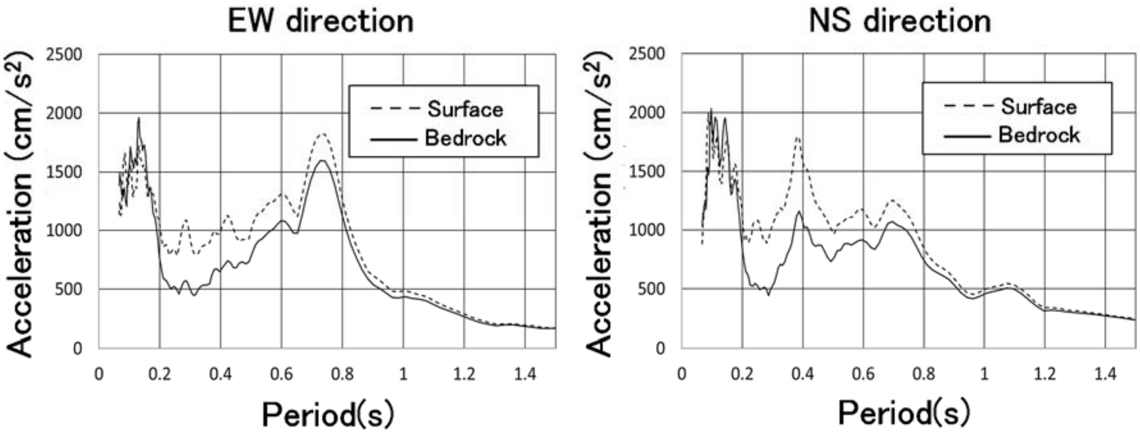


Figure 6. Acceleration response spectrum of seismic motions

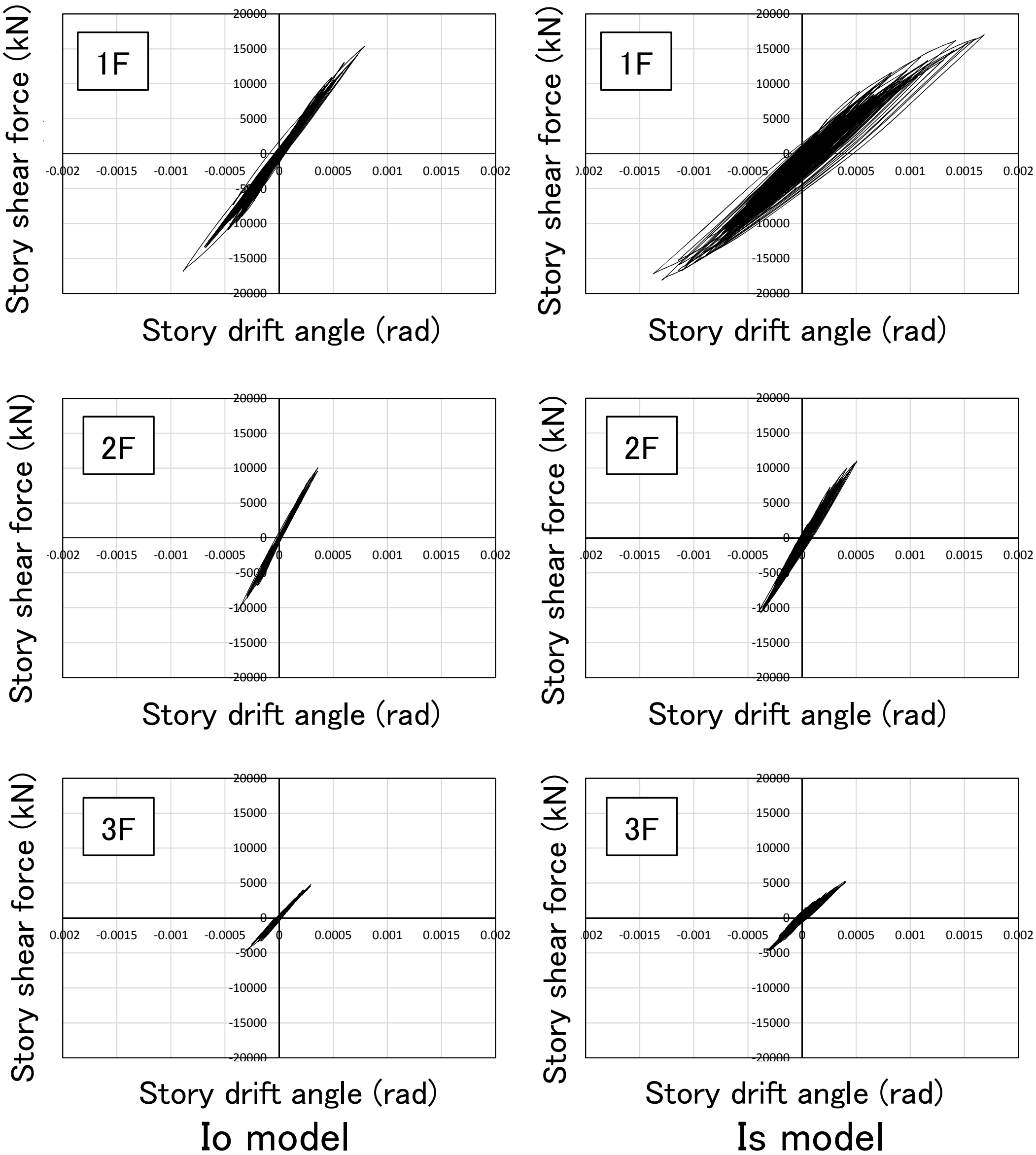


Figure 7. Hysteresis loop of Io model and Is model in X direction

ANARYSIS RESULT

Hysteresis loop

Figure 7 shows the story shear force – story drift angle relationship of Io model and Is model in X direction. The maximum base shear of Io model was 1.7×10^4kN, and the maximum base shear of the Is model was 1.8×10^4kN. The maximum base shear of Io model was almost equal to the maximum base shear of Is model. The base shear coefficient at the maximum story shear force of Io model was 0.46, and the base shear coefficient at the maximum story shear force of Is model was 0.50. The story drift angle of first story at the maximum base shear of Io model was 0.89×10^{-3}rad, and the story drift angle of first story at the maximum base shear of the Is model was 1.3×10^{-3}rad. The story drift angle of Is model was about 1.5 times larger than that of Io model. Figure 8 shows the story shear force – story drift angle relationship of Io model and Is model in Y direction. The maximum base shear of Io model was 2.8×10^4kN, and the maximum base shear of the Is model was 2.2×10^4kN. The maximum base shear of Io model was about 1.2 times larger than that of Is model. The base shear coefficient at the maximum story shear force of Io model was 0.76, and the base shear coefficient at the maximum

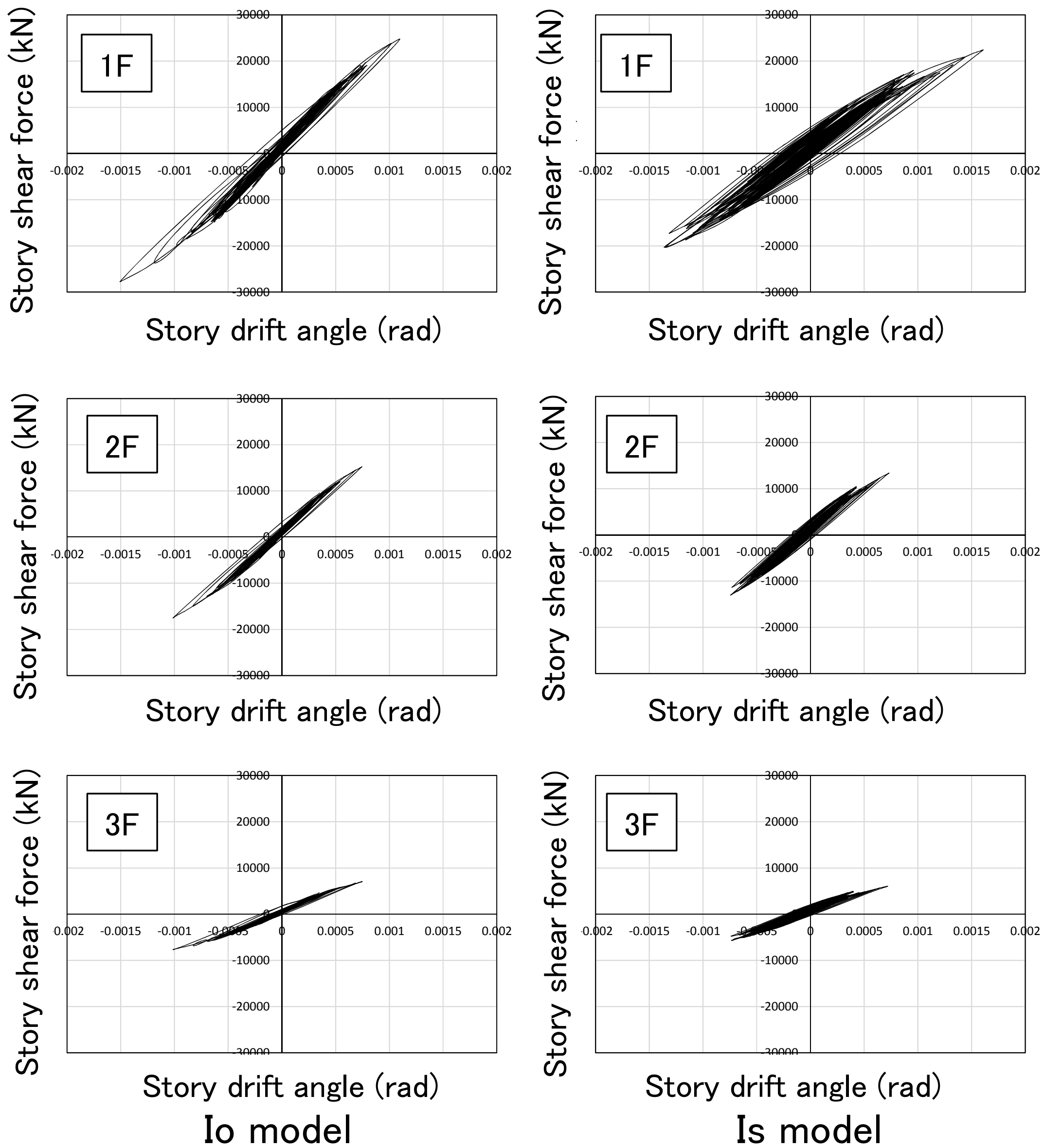


Figure 8. Hysteresis loop of Io model and Is model in Y direction

story shear force of Is model was 0.62. The story drift angle of first story at the maximum base shear of Io model was 1.5×10^{-3}rad, and the story drift angle of first story at the maximum base shear of the Is model was 1.6×10^{-3}rad. The story drift angle of first story at the maximum base shear of Io model was almost equal to that of Is model.

Comparison of pile head yield

Figure 9 shows the pile head yield place of Io model and Is model in X direction. The circle mark indicates pile head yield place and the value of the yield place indicates the base shear coefficient when the yield occurred. It was assumed that the pile head yielded when the outermost reinforcement bar of the pile head yielded. No pile head yield occurred in Io model. Five pile heads yielded at almost the same time. The base shear coefficient are about 0.48 when the pile heads yielded. Although the pile head yield occurred in the actual damage place, the pile head yield also occurred in other places. Bending yield of foundation beams and shear failure of columns occurred in both Io model and Is model. Figure 10 shows the pile head yield place of Io model and Is model in Y direction. The pile head yield occurred at four places in the Io model. Only one yield place of the pile head corresponded with the actual damage place. The pile head yield first occurred at a place where no actual damage occurred. The pile head yield occurred at eighteen places in the Is model. Four yield places of the pile heads corresponded with the actual damage places. The pile head yield first occurred at a place where no actual damage occurred. Bending yield of foundation beams and shear failure of columns occurred in both Io model and Is model.

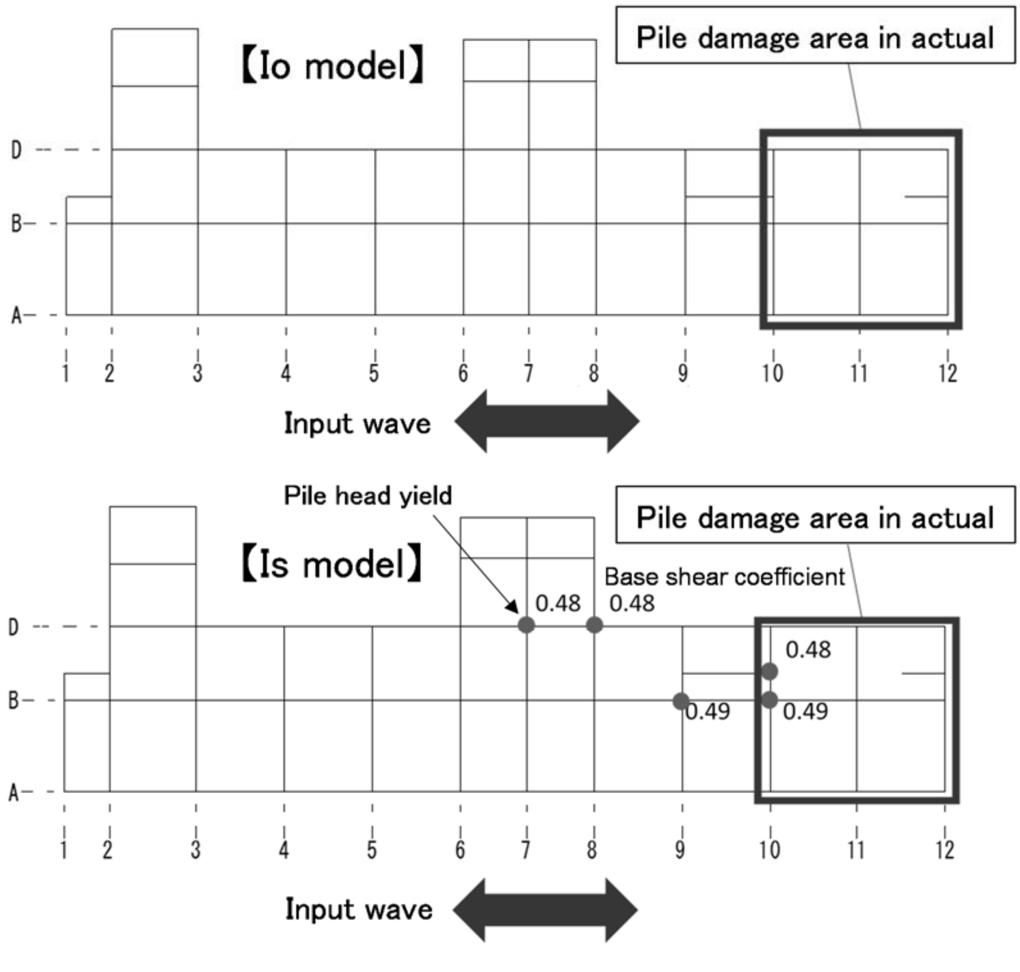


Figure 9. Pile head yield place of Io model and Is model in X direction

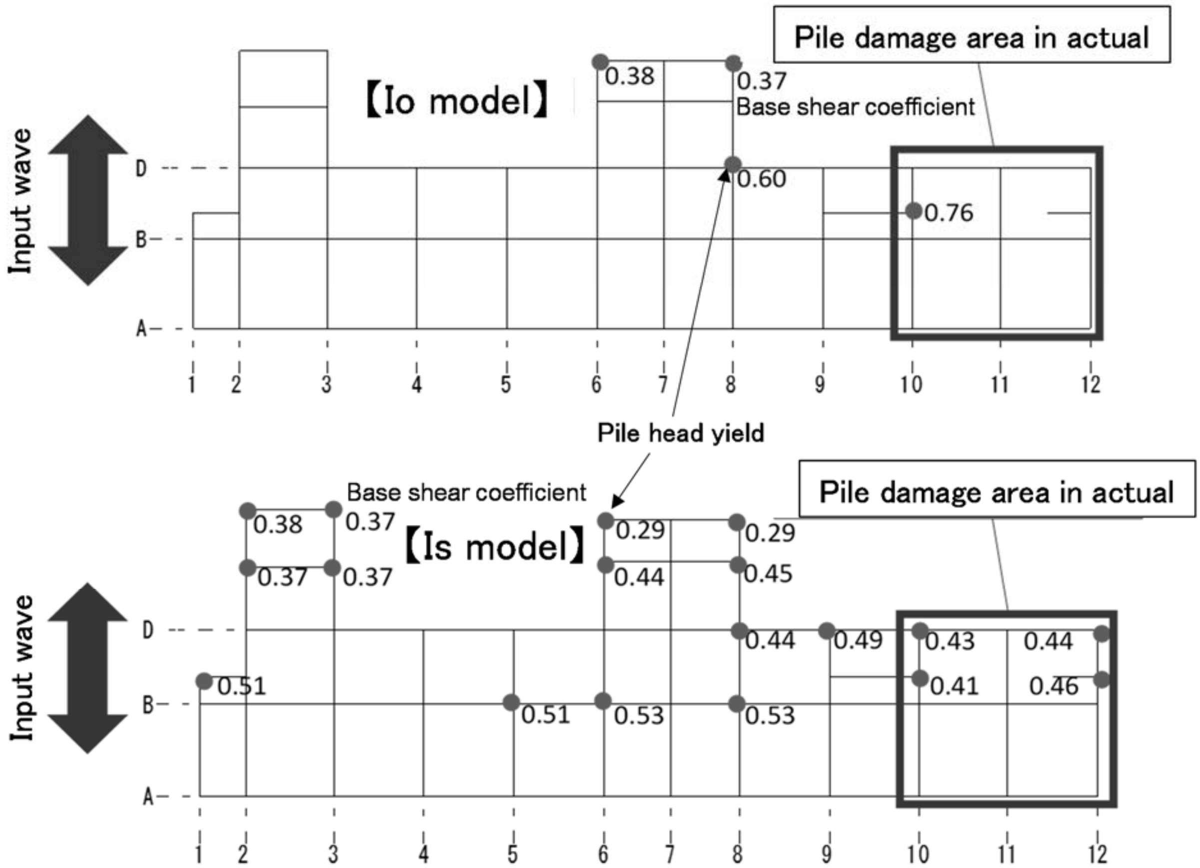


Figure 10. Pile head yield place of Io model and Is model in Y direction

CONCLUSIONS

The time history response analysis using super-and-sub structure model was conducted to simulate the damage of the pile foundation of the 3 story RC school building. As a result, the pile heads were damaged as well as the actual damage. On the other hand, the pile head yields occurred in the analysis even at undamaged places in actual. In addition, bending yield of foundation beams and shear failure of columns occurred. That was different from the actual damage situation of the superstructure. It is necessary to further study the modeling method and the input earthquake motions.

REFERENCES

Architectural Institute of Japan, (2012). *Preliminary Reconnaissance Report of the 2011 Tohoku-Chiho Taiheiyo-Oki Earthquake*.

National Research Institute for Earth Science and Disaster Resilience (NIED), (2019). *NIED K-NET, KiK-net, National Research Institute for Earth Science and Disaster Resilience*, doi:10.17598/NIED.0004.

The Building Center of Japan, (2016). *The Building Standard Law of Japan on CD-ROM May 2016*.

Yano, N., Akita, T. and Inai, E. (2018). “Damage Factor of the School Building which Suffered the Damage on Pile Foundation,” *Proceedings of the 7th Asia Conference on Earthquake Engineering*, Paper ID ACEE0057