Streamlining Information Transfer between Construction and Structural Engineering
Edited by Shiau, J., Vimonsatit, V., Yazdani, S., and Singh, A.

ISBN: 978-0-9960437-7-9

STRUCTURAL ANALYSIS OF WOODEN FRAMES USED FOR MODERN WOODEN SCHOOL BUILDINGS

MITSUHIRO MIYAMOTO and MISAKI EBISUOKA

Dept of Safety Systems Construction Eng., Kagawa University, Takamatsu, Japan

Japanese school buildings have been changed from modern timber structures to reinforced concrete structures after the Building Standard Law was established in 1950. Therefore, only few modern wooden school buildings exist currently. Ensuring the seismic resilience of these wooden school buildings is essential for their preservation. The objective of this study is to develop an analysis model for the seismic performance evaluation of modern wooden school buildings. The fracture modes and the relationship between the lateral load and deformation of wooden frames were examined based on the results of full-scale static lateral loading tests performed in a previous study. The analysis models of these specimens were developed and compared with test results to examine their validity. Analysis results were in good agreement with test results.

Keywords: Single brace, Cross brace, Knee brace, Analysis model, Static pushover analysis, Static loading test.

1 INTRODUCTION

Japanese school buildings have been changed from modern timber structures to reinforced concrete structures after the Building Standard Law was established in 1950. Therefore, only few modern wooden school buildings exist currently. Ensuring the seismic resilience of these wooden school buildings is essential for their preservation.

A large number of studies in Japan focused on the seismic performance of wooden brace frames (Okamoto *et al.* 2010). However, only a few studies have focused on the large section brace used for modern wooden school buildings. In addition, a small number of studies have addressed wooden knee brace frames (Kamiya and Isoka 2012). Thus, almost no experimental data are available for evaluating the seismic performance of modern wooden school buildings.

The objective of this study is to develop an analysis model for the seismic performance evaluation of modern wooden school buildings. In a previous study, full-scale static lateral loading tests were conducted for wooden frame, single brace, cross brace, and knee brace specimens to examine the fracture modes and the relationship between the lateral load and deformation (Ebisuoka and Miyamoto 2018). These four specimens were designed based on the site investigation of existing modern wooden school buildings. In the present study, static pushover analysis was carried out for these specimens using a 2D frame model to simulate the relationship between lateral load and deformation. The analysis models were developed and compared with test results to examine their validity.

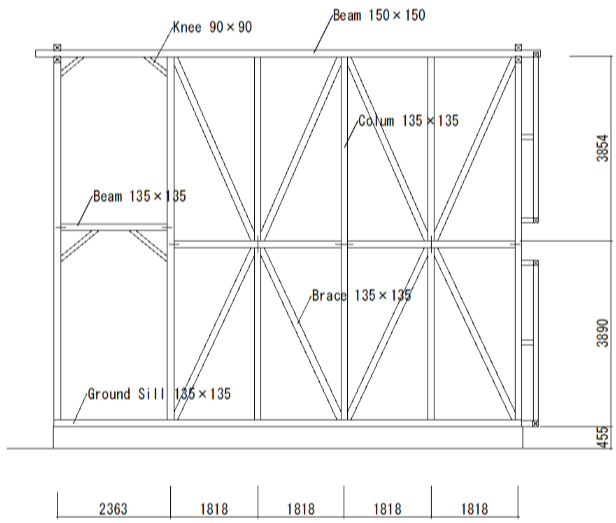
2 OUTLINE OF MODERN WOODEN SCHOOL BUILDINGS

The north and east school buildings of Yashiro Junior High School are wooden structures located in Ehime Prefecture. These buildings were built in 1960 and 1961. The buildings were dismantled recently; however, we were presented with an opportunity to investigate their structural characteristics before their dismantlement. Figure 1 shows the north school building. The main seismic elements are large section braces and knee braces (Figures 2 and 3). The dimensions of the column, groundsill, and brace are 135 × 135 mm, and those of the beam and knee brace are 135 × 135 mm or 150 × 150 mm and 90 × 90 mm, respectively. All braces and knee braces were fixed on the column using a bolt with a diameter of 12 mm. The column was connected to the beam or groundsill using metal connectors on each side of a connection.

Figure 1. School building of Yashiro Junior High School.

(a) Brace (b) Knee brace

Figure 2. Main seismic elements.



Unit: mm

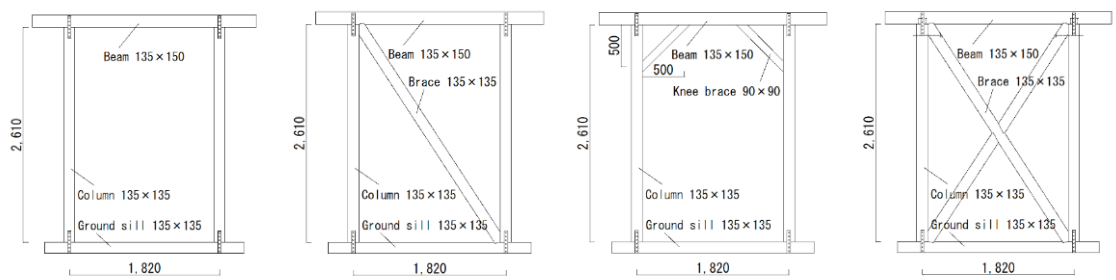
Figure 3. Cross section (transverse direction).

3 PROPOSED ANALYSIS MODEL

The simulation analysis was executed using a 2D frame model to estimate the relationship between the load and deformation angle of each specimen.

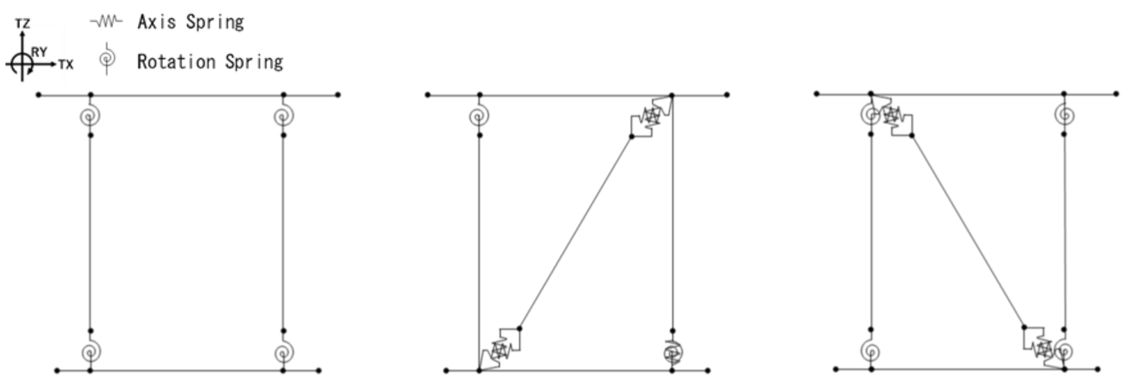
3.1 Outline of Specimen

Four specimens were used for the tests, as shown in Figure 4. In addition to a wooden frame specimen, single brace, cross brace, and knee brace specimens were used because they are the main seismic elements of wooden school buildings. One brace in a cross brace specimen was separated at the intersection. The height and width of each specimen were 2752.5 mm and 1820 mm, respectively. The dimensions of the column, groundsill, and brace were 135 × 135 mm and those of the beam and knee brace were 135 × 180 mm and 90 × 90 mm, respectively. The column and brace were made of cedar, the beam and knee brace were made of Douglas fir, and the groundsill was made of Japanese cypress. All connections were designed to be the same as those of actual wooden school buildings based on site investigation. In the column-to-brace connection, the brace was connected to the beam or groundsill with a depth of 15 mm. The column was connected to the beam or groundsill using a short tenon with a height, width, and thickness of 67.5 mm, 90 mm, and 30 mm, respectively. Similarly, in the column-to-knee brace connection, the knee brace was connected to the column with a depth of 15 mm. In addition, metal connectors were fixed on each side of the connection using six nails. The height, width, and thickness of the metal connectors were 270 mm, 40 mm, and 5 mm, respectively. The through brace, separate brace and knee brace were fixed on the column using a bolt with a diameter of 12 mm. These specimens were subjected to cyclic lateral loads, with the real shear deformation angle being gradually increased symmetrically from 1/450, 1/300, 1/200, 1/150, 1/100, 1/75, 1/50, 1/30, 1/20 to 1/15rad. Three cyclic loadings were applied. Finally, the specimen was loaded to 1/10rad at one end.

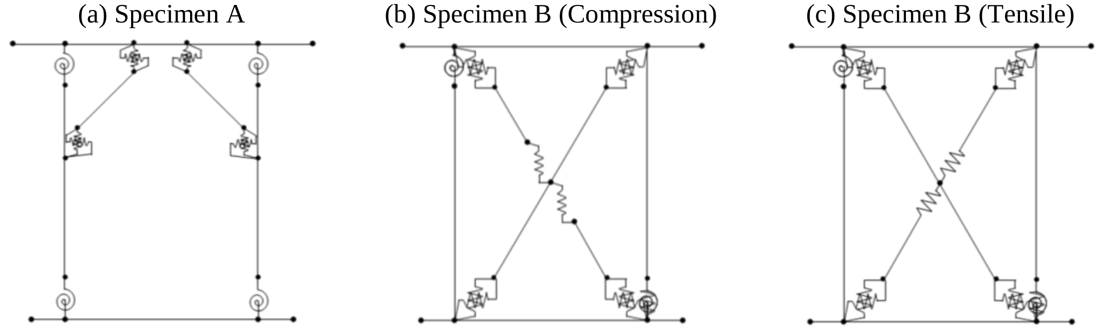


(a) Specimen A (b) Specimen B (c) Specimen C (d) Specimen D

Figure 4. Outline of specimens (Unit: mm).



(a) Specimen A (b) Specimen B (Compression) (c) Specimen B (Tensile)



(d) Specimen C (e) Specimen D (Compression) (f) Specimen D (Tensile)

Figure 5. Model of each specimen.

Table 1. Resistance elements and direction.

Resistance element	Specimen	A	B (Com)	B (Ten)	C	D (Com)	D (Ten)
Metal connector	Bending strength	RY	RY	RY	RY	RY	RY
Short tenon	Bending strength	RY	RY	RY	RY	RY	RY
	Embedment to beam	*	TX	*	*	TX	TX
	Embedment from groundsill	*	TX	*	*	TX	TX
Bolt	Shear	—	—	TZ	TX, TZ	TZ	TZ, Axis
	Tensile	—	—	TX	TX, TZ	TX	TX
Brace	Embedment to column	—	TX	—	—	TX	TX
	Embedment to beam	—	TZ	—	—	TZ	TZ
	Embedment to groundsill	—	TZ	—	—	TZ	TZ
	Embedment to brace	—	—	—	—	—	Axis
Knee brace	Embedment to column	—	—	—	TX	—	—
	Embedment to beam	—	—	—	TZ	—	—
	Embedment from lack of column	—	—	—	TZ	—	—
	Embedment from lack of beam	—	—	—	TX	—	—
Column	Up lift of column bottom	—	TZ	—	—	TZ	TZ

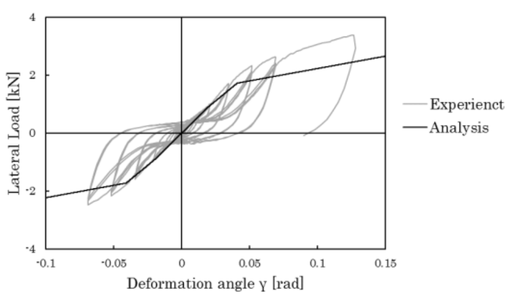
* Included in bending strengh of short tenon

3.2 Outline of Analysis Model

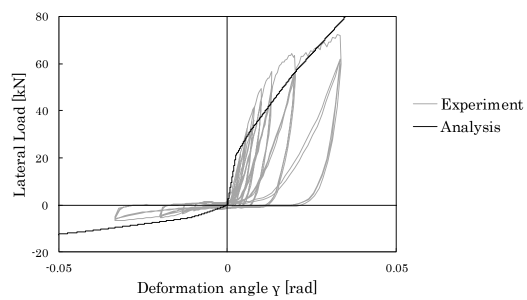
Figure 5 shows the analysis model used for the static pushover analysis. The analysis models of specimens B and D were assumed to be different because the resistance element of a through brace was different for tensile and compressive braces. The bending resistance at the connection of the metal connector and short tenon was expressed as a rotation spring. The rotation springs of these connections with a through brace on specimens B (compression) and D were excluded because there was a brace to prevent the connection from rotating. The uplift behavior at one side of the column-to-groundsill connection on specimens B (compression) and D was expressed as an axis spring (Appendix A). The embedment resistance at the connection of the through brace, separate brace, or knee brace and the beam, groundsill, or column was expressed as an axis spring. The shear and tensile resistance of a bolt were expressed as an axis spring. A bilinear hysteresis model was used for each rotation spring and axis spring. The initial stiffness and yield moment or strength were calculated based on a previous study (Architectural Institute of Japan 2006, Architectural Institute of Japan 2009, Sakata *et al.* 2012). The material property was estimated through the results of destructive tests for each wooden member and based on a previous study (Architectural Institute of Japan 2006, Architectural Institute of Japan 2009). Table 1 summarizes the type and direction of each resistance element. The direction "TX", "TZ" and "RY" are defined in Figure 5.

3.3 Comparison of Test and Analysis Results

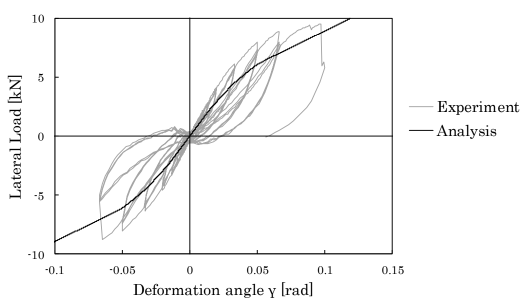
The static pushover analysis was performed using general purpose analysis software, *i.e.*, SNAP (Ver. 7). Figure 6 shows the comparison of the relationship between the load and deformation angle of each specimen as obtained from the test and analysis results. The analysis results are in good agreement with the test results for each specimen. The load to the range of large deformation angle on almost all specimens obtained through the analysis is smaller than that obtained in the tests because the design equations were used for calculation.



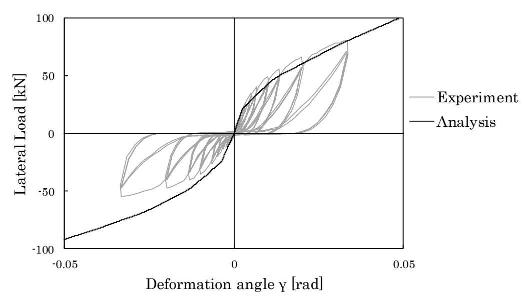
(a) Specimen A



(b) Specimen B



(c) Specimen C



(d) Specimen D

Figure 6. Comparison of experimental and analysis results.

4 CONCLUSIONS

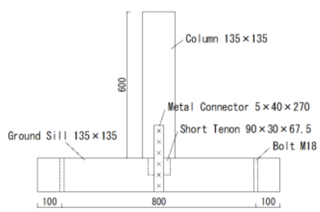
In this study, an analysis model was developed for the seismic performance evaluation of modern wooden school buildings. The results obtained using the model were compared with test results to examine the validity of the model. Four specimens were used for the tests, *i.e.*, wooden frame, single brace, cross brace, and knee brace specimens. This was because they are the main seismic elements of wooden school buildings. Analysis results exhibited good agreement with the test results.

Acknowledgments

This research was partially supported by the Asahi Glass Foundation. We gratefully acknowledge this support.

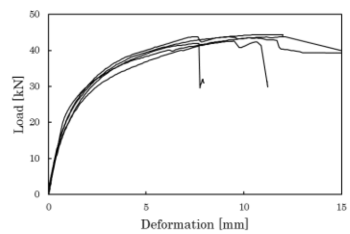
Appendix A. Tensile Test Results of Column-to-Groundsill Connection

The tensile test for column-to-groundsill connection was conducted as shown in Appendix figures 1–3. The specimen size was the same as that for the full-scale static lateral loading tests. The number of specimens was five.



Appendix Figure 1. Outline of specimen.

Appendix Figure 2. Loading instrument.



Appendix Figure 3. Relationship between load and deformation.

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