WORLD CONFERENCE ON TIMBER ENGINEERING 2025
BRISBANE, AUSTRALIA
Advancing Timber for the Future Built Environment

ANALYSIS OF THE PREDICTED COLLAPSE DIRECTION TENDENCIES OF HOUSES CAUSED BY THE 2024 NOTO PENINSULA EARTHQUAKE

Yuki Hashimoto[1], Takafumi Nakagawa[2], Hiroshi Isoda[3]

ABSTRACT: The study investigates the seismic performance of timber-framed houses in the Noto Peninsula, Ishikawa Prefecture, Japan, particularly focusing on buildings that collapsed during the M7.6 earthquake on January 1, 2024. The research analyzes a two-story timber-framed house (House-a), built after the 2000 revision of Japan's seismic codes, and explores the causes of its collapse. The building's shear wall distribution was found to be unbalanced, with a high eccentricity ratio in the Y-direction, contributing to its failure. A three-dimensional model of House-a was created for time-history response analysis, with multiple earthquake records applied to assess the collapse direction and damage. The analysis showed that House-a collapsed primarily due to significant damage to the first floor, with the second floor experiencing twisting deformation. Comparisons with another building, House-an, revealed that a lower eccentricity ratio resulted in less twisting deformation. Further analysis explored the impact of eccentricity in both X and Y directions, confirming that varying eccentricities influenced collapse direction. The study aims to improve seismic regulations by understanding how shear wall distribution affects building stability during earthquakes.

KEYWORDS: The 2024 Noto Peninsula Earthquake, Time-History Response Analysis, Parametric study, Wooden framed house

1 – INTRODUCTION

On January 1, 2024, at approximately 16:11, a large earthquake with a magnitude of M7.6 struck the Noto Peninsula, Ishikawa Prefecture, Japan. This earthquake caused significant damage, with 14.5% of timber-framed houses in the Noto Peninsula collapsing due to the seismic forces [1][2]. The Noto Peninsula has experienced strong seismic activity in recent years, with major earthquakes recorded in 2007 (M6.9) and 2023 (M6.5). However, the 2024 earthquake resulted in more widespread destruction compared to these previous events.

Japan's building codes were significantly revised in 1981 and 2000, and buildings constructed before 1981 lack the seismic resistance necessary to withstand earthquakes of this scale. Immediate retrofitting of older buildings is crucial. Buildings constructed after the 2000 revision are required to have seismic performance that can withstand large earthquakes without collapsing. However, it was observed that several buildings constructed after the 2000 revision in Wajima City, Ishikawa Prefecture, collapsed during the 2024 earthquake [1][2].

This study aims to assess the seismic performance of one of the collapsed buildings, identify the causes of the failure, and conduct an analytical reconstruction of the seismic damage to contribute to the improvement of seismic regulations. Furthermore, the study seeks to explore how strengthening building seismic performance can reduce the likelihood of collapse through time-history response analysis. By analyzing the trends of collapse direction when different seismic waveforms are applied, the study aims to develop a method for predicting building damage under various earthquake conditions.

2 – METHOD

2.1 DETERMINE TARGET BUILDING

Based on an analysis of construction periods derived from aerial photographs of Wajima City, Ishikawa Prefecture, it was confirmed that timber-framed houses constructed after 2000 collapsed during the 2024 Noto Peninsula Earthquake. The Building Standards Act of Japan underwent significant revisions in 1981 and 2000, resulting in three distinct seismic performance standards

1 Yuki Hashimoto, Master student, RISH, Kyoto University, Kyoto, Japan, MAIL: hashimoto.yuki.53k@st.kyoto-u.ac.jp

2 Takafumi Nakagawa, Associate Professor, RISH, Kyoto University, Kyoto, Japan, MAIL: nakagawa@rish.kyoto-u.ac.jp

3 Hiroshi Isoda, Professor, RISH, Kyoto University, Kyoto, Japan, MAIL: hisoda@rish.kyoto-u.ac.jp

https://doi.org/10.52202/080513-0483

for timber structures: the pre-1981 standard (Old Seismic Code), the 1981–2000 standard (New Seismic Code), and the post-2000 standard (2000 Seismic Code). Each revision introduced different seismic safety objectives, with the current 2000 Seismic Code primarily defining seismic performance based on the quantity and distribution of shear walls. This study aims to analyze the causes of collapse and examine the directional tendencies of structural failure under seismic excitation through a parametric study. The analysis is conducted by applying multiple earthquake ground motions to a computational model created based on architectural drawings obtained from Reference [1][2]. The subject of analysis is a two-story timber-framed house, designated as House-a. The floor plan of House-a is shown in Figure 1, while the arrangement of seismic-resistant elements is shown in Figures 2 and 3. The first floor features a large open-plan living room, with an absence of load-bearing walls directly beneath the shear walls of the upper floor.

Table 1 presents the results of the wall quantity calculation, which assesses the total amount of shear walls, and the eccentricity ratio, which serves as an index of the balance of shear wall distribution. The results confirm that both the first and second floors meet the minimum wall quantity requirements stipulated by the current Building Standards Act. However, the eccentricity ratio in the Y-direction of the first floor exceeds the regulatory limit of 0.3, indicating that the shear wall arrangement is unbalanced. Consequently, it is confirmed that this building exhibits poor seismic balance in terms of wall distribution.

2.2 OVERVIEW OF ANALYSIS

In this study, a three-dimensional model was constructed and analyzed using the structural analysis software wallstat[3], which employs the extended discrete element method (EDEM). The analytical model developed for this study was based on the floor plan of House-A, with siding applied to the exterior walls and gypsum board used for the interior walls. Additionally, openings such as windows and doors were incorporated into the model.

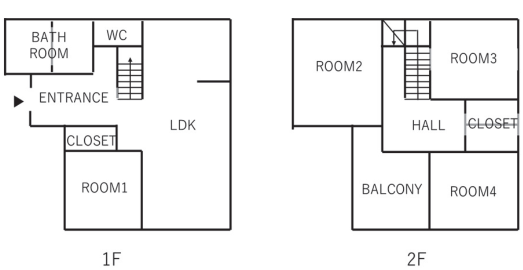


Figure 1. Floor plan of House-a

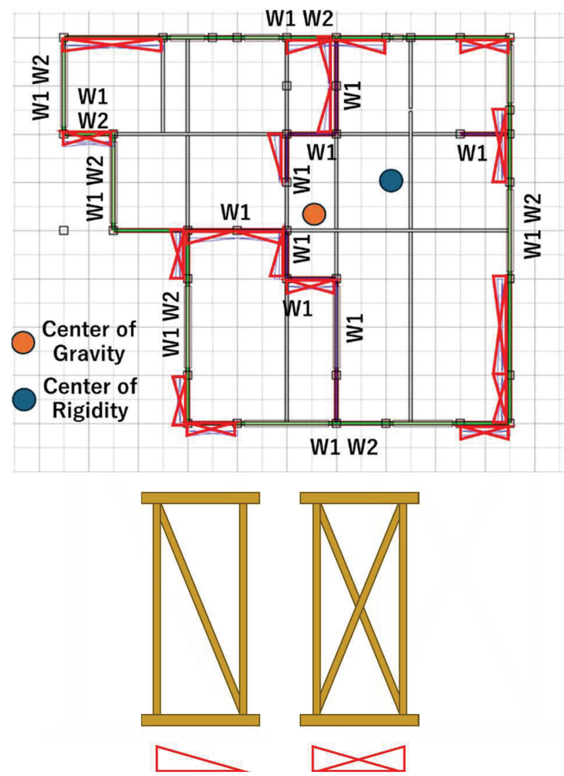


Figure 2. Seismic element layout on 1st floor of House-a

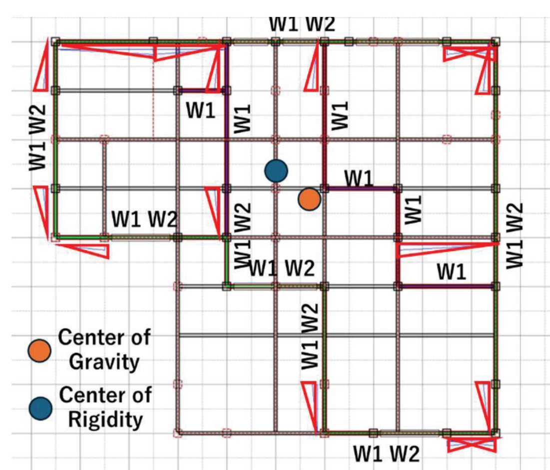


Figure 3. Seismic element layout on 2nd floor of House-a

Table 1. Seismic wall quantity and eccentricity ratio

House-a	Existing wall (m)	Required wall (m)	E/R	Modulus of eccentricity
1F-X	36.0	20.5	1.76	0.16
1F-Y	34.0	20.5	1.66	0.35
2F-X	21.0	10.9	1.92	0.12
2F-Y	16.0	10.9	1.47	0.15

https://doi.org/10.52202/080513-0483

Table 2. Material properties of structural elements

	Column	Beam	Connecting foundation	Brace
A(mm2)	105 × 105	105 × 210	105 × 105	45 × 90
E(N/mm2)	7500	12000	7500	-

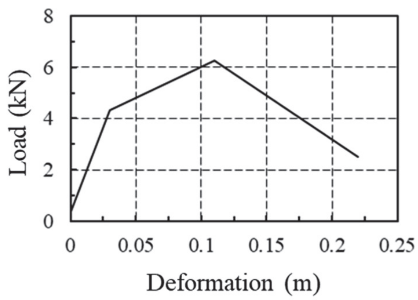


Figure 4. Restoring force behaviour of brace

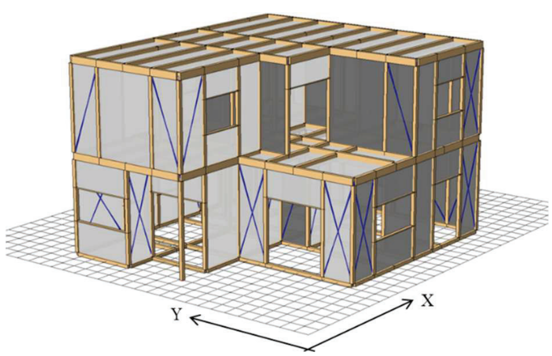


Figure 1. Analysis model

The columns, horizontal members, and braces were assigned dimensions and Young's modulus values commonly used in Japanese residential construction, with these details provided in Table 2. The restoring force characteristics of the seismic bracing elements are shown in Figure 4.

The building's weight was determined based on the simplified weight table for seismic diagnosis of wooden houses, considering the tiled roof. The roof weight was set at 1.3 kN/m², while the weights for the exterior walls, interior walls, and floors were each set at 1.2 kN/m², with an imposed load also set at 1.2 kN/m². An overview of the analytical model is shown in Figure 5.

The methodology began by inputting seismic ground motions recorded at the nearest observation point to the building into the analytical model, verifying the validity of the modeling approach by reproducing actual seismic damage. Subsequently, a parametric study was conducted by inputting multiple earthquake records from various monitoring stations across the Noto Peninsula into the

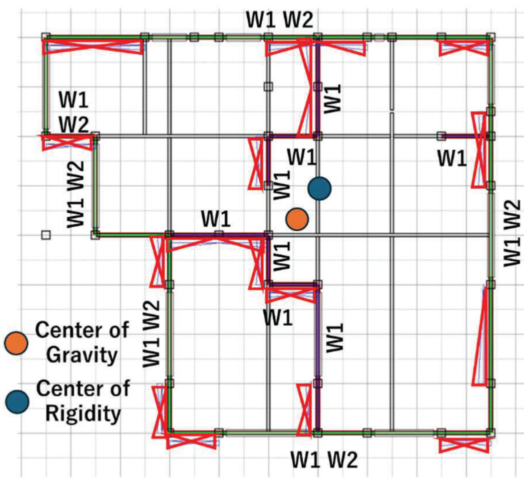


Figure 6. Seismic element layout on 1st floor of House-an

Table 3. Seismic wall quantity and eccentricity ratio

House-an	Existing wall (m)	Required wall (m)	E/R	Modulus of eccentricity
1F-X	36.0	20.5	1.76	0.17
1F-Y	34.0	20.5	1.66	0.14
2F-X	21.0	10.9	1.92	0.12
2F-Y	16.0	10.9	1.47	0.15

model with varying amplitudes, identifying the predominant collapse direction of the building.

2.3 LOW ECCENTRICITY MODEL

To examine how the damage characteristics change when the eccentricity ratio in the Y-direction of the first floor of House-a is reduced to comply with the Building Standards Act, the distribution of shear walls was adjusted in the structural layout shown in Figure 2 to ensure that the Y-direction eccentricity ratio remains below 0.3. This modified building is designated as House-an. The seismic element layout of the first floor is presented in Figure 6, while the wall quantity and eccentricity ratio are summarized in Table 3. The analysis follows the same methodology as for House-a, focusing on identifying the predominant collapse direction.

2.4 SEISMIC MOTION

The seismic motions used for the time-history response analysis were four earthquake records observed on January 1, 2024, at strong-motion observation stations of the National Research Institute for Earth Science and Disaster Resilience (NIED): K-NET Anamizu, Shoin, Togi, and Wajima. Figure 7 presents the acceleration response spectra of the input ground motions with 5% damping. The analysis was conducted by varying the amplitude from 100% in increments and decrements of

https://doi.org/10.52202/080513-0483

10% to determine the critical amplitude at which collapse occurs.

3 –ANALYSIS RESULTS

3.1 ANALYSIS RESULTS FOR HOUSE-A

The time-history response analysis was conducted by incrementally amplifying the observed ground motion from K-NET Wajima, the closest observation station to House-a, from 1.0 times the original amplitude in steps of 0.1. The results confirmed that the building collapsed at an amplitude of 1.2 times. Additionally, the collapse direction was found to be consistent with the actual observed failure. Figure 8 illustrates the collapse behavior of the analytical model at an input scaling factor of 1.2 for the K-NET Wajima record. The colors of the walls and horizontal structural elements indicate the degree of damage, with yellow representing minor damage and red indicating severe damage. Just before collapse, significant damage was concentrated in the first-floor walls, and the second floor exhibited a large twisting deformation as it failed. This behavior is attributed to the unbalanced distribution of seismic-resistant elements. Furthermore, Figure 9 presents the collapse direction of House-a for each ground motion and its corresponding input scaling factor (Ratio). The collapse direction was determined based on the movement of the first-floor center of mass, with angles (°) measured counterclockwise from the positive X-axis. While the center-of-mass movement varied depending on the ground motion, the collapse consistently showed a tendency toward the positive X-axis, with no cases of collapse occurring in the third quadrant. In all cases, the collapse was primarily induced by severe damage to the first floor.

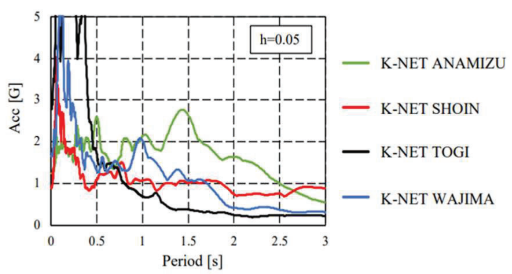


Figure 7. Acceleration response spectra

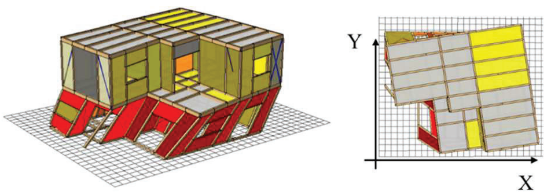


Figure 8. Collapse behaviour of House-a

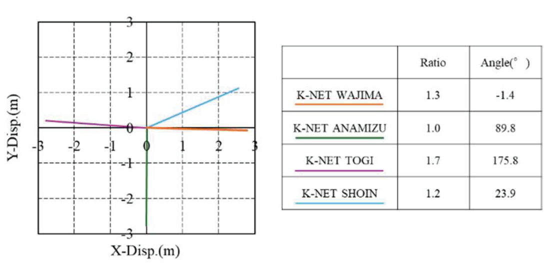


Figure 9. Collapse direction and input scaling factor of House-a

3.2 ANALYSIS RESULTS FOR HOUSE-AN

When the K-NET Wajima ground motion was applied to House-an, the structure collapsed at an input scaling factor of 1.3. The collapse behavior of the analytical model is shown in Figure 10. Similar to House-a, significant damage was concentrated in the first-floor walls, leading to structural failure. However, unlike

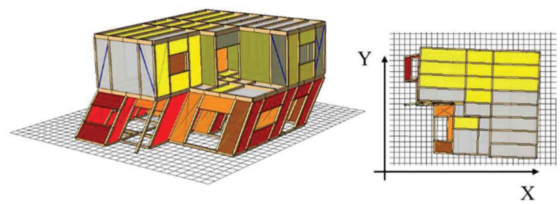


Figure 10. Collapse behaviour of House-an

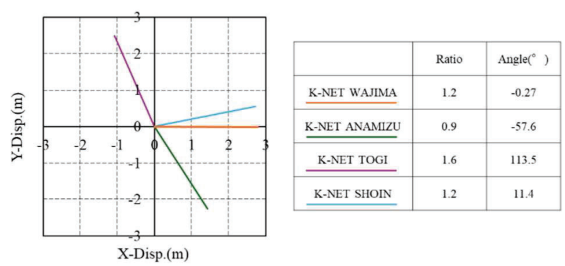


Figure 11. Collapse direction and input scaling factor of House-an

Table 2. Seismic wall quantity and eccentricity ratio

House-ax	Existing wall (m)	Required wall (m)	E/R	Modulus of eccentricity
1F-X	37.0	20.5	1.81	0.34
1F-Y	34.0	20.5	1.66	0.15
2F-X	21.0	10.9	1.92	0.12
2F-Y	16.0	10.9	1.47	0.15

House-axy	Existing wall (m)	Required wall (m)	E/R	Modulus of eccentricity
1F-X	37.0	20.5	1.81	0.34
1F-Y	36.0	20.5	1.76	0.36
2F-X	21.0	10.9	1.92	0.12
2F-Y	16.0	10.9	1.47	0.15

https://doi.org/10.52202/080513-0483

House-a, no noticeable twisting deformation of the second floor was observed at the point of collapse. This finding supports the conclusion that House-a's high eccentricity ratio contributed to the twisting of the second floor, ultimately leading to its failure.Furthermore, Figure 11 presents the collapse direction and input scaling factors (Ratio) for each ground motion applied to House-an. As with House-a, the analytical model collapsed in all cases due to severe damage to the first floor. However, the direction of center-of-mass movement varied significantly depending on the ground motion, with a tendency for collapse to occur in both the X and Y directions.

3.3. ANALYSIS WITH ECCENTRICITY IN X DIRECTION

Seventy percent of timber-framed houses in the Noto Peninsula were constructed under the pre-1981 seismic code, and many of these buildings likely exhibit higher eccentricity ratios compared to those built under the current standards. To further investigate general collapse tendencies, additional analytical models were developed with intentional eccentricity. The fundamental distribution of seismic-resistant elements was kept consistent with House-a and House-an. Two new models were introduced: House-ax, which has a high eccentricity ratio in the X-direction, and House-axy, which has high eccentricity ratios in both the X and Y directions. The arrangement of seismic elements is shown in Figures 12 and 13.

The input ground motion was taken from K-NET Wajima, and the analysis was conducted by gradually increasing the input scaling factor from 1.0, following the same methodology as in last studies. Figure 14 presents the collapse directions of House-a, House-an, House-ax, and House-axy. The results confirm that the collapse directions differed approximately by 90° depending on the wall configuration. Additionally, Figure 15 illustrates the movement of the second floor just before collapse. Except for House-a, which has a high eccentricity ratio in the Y-direction, all models collapsed without significant torsional deformation.

4 – CONCLUSION

This study analyzes the collapse of a timber-framed house (House-a) during the Noto Peninsula Earthquake on January 1, 2024, and investigates the causes of collapse and the directional tendencies of structural failure. The analysis revealed that the building had an unbalanced shear wall arrangement, particularly with an eccentricity ratio in the Y-direction exceeding regulatory limits. This imbalance contributed to the collapse. A 3D

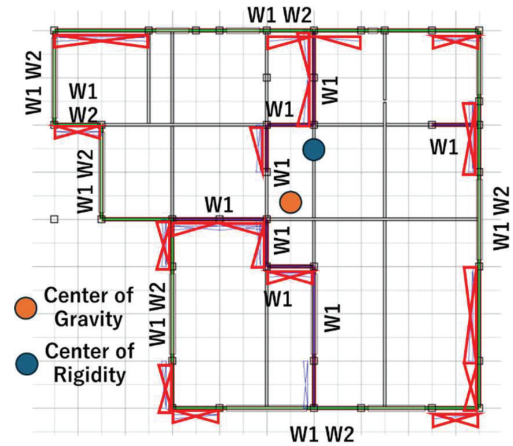


Figure 5. Seismic element layout on 1st floor of House-ax

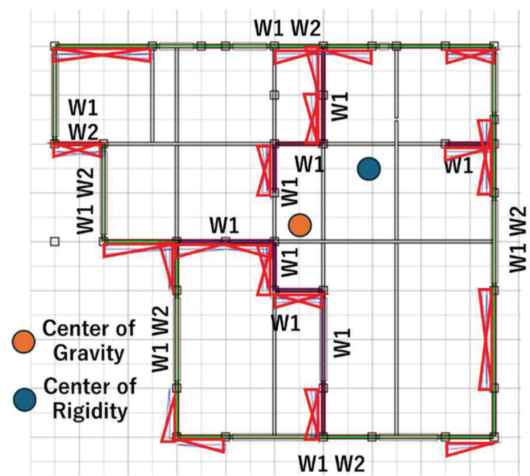
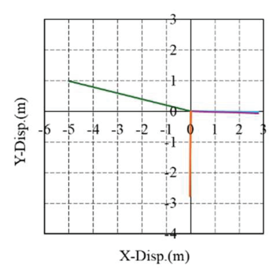


Figure 53. Seismic element layout on 1st floor of House-axy



	Ratio	Angle(°)
House-a	1.3	-0.27
House-an	1.0	-1.36
House-ax	1.7	-89.5
House-axy	1.2	168.8

Figure 54. Collapse direction and input scaling factor of all House

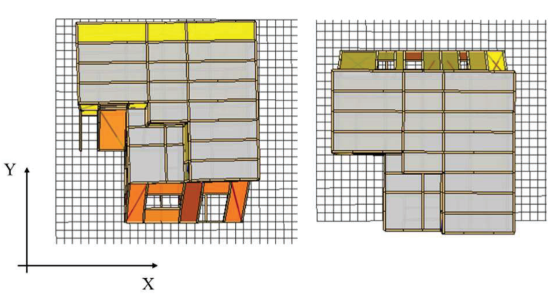


Figure 55. Collapse behaviour of House-ax and House-axy

https://doi.org/10.52202/080513-0483

model was used for time-history response analysis, with input from K-NET Wajima ground motion records. The results showed that House-a collapsed at an input amplitude of 1.2 times the original ground motion, with significant damage concentrated in the first-floor walls and a twisting deformation observed in the second floor. The collapse direction consistently tended towards the positive X-axis. Further analysis with a modified model (House-an) with improved wall distribution showed that the collapse occurred in both the X and Y directions, confirming that House-a's high eccentricity in the Y-direction contributed to the twisting deformation. The study emphasizes the importance of balanced shear wall distribution to enhance seismic performance.

5 – ACKNOWLEDGMENT

In this study, we used strong-motion records from K-NET, provided by the National Research Institute for Earth Science and Disaster Resilience. We sincerely appreciate their support.

6 – REFERENCES

[1] National Institute for Land and Infrastructure Management Ministry of Land, Infrastructure, Transport and Tourism, Japan: Quick Report of the Field Survey on the Building Damage by The 2024 Noto Peninsula Earthquake, TECHNICAL NOTE of National Institute for Land and Infrastructure Management, No.1296, 2024.10 (in Japanese)

[2] Building Research Institute National Research and Development Agency, Japan: Quick Report of the Field Survey on the Building Damage by The 2024 Noto Peninsula Earthquake, Building Research Data, No.212, 2024.10 (in Japanese)

[3] Takafumi Nakagawa: Development of Analysis for Collapsing Behaviour of Wooden Post-and-beam Houses during Earthquake, Building Research Data, No.128,2010.11 (in Japanese)

https://doi.org/10.52202/080513-0483