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# SEISMIC PERFORMANCE OF AN OLD JAPANESE-STYLE TWO-STORY WOODEN HOUSE UNDER A STRONG EARTHQUAKE GROUND MOTION

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In Japan, there is a serious and urgent issue on seismic retrofit for a lot of old Japanese-style two-story wooden houses built by a Japanese traditional framed-construction method. In order to investigate the seismic performance of an old Japanese-style two-story wooden house, 3-D non-linear collapsing process analysis of this wooden house was conducted against a strong earthquake ground motion with the Japan Meteorological Agency seismic intensity of “6 upper” level. The effect of post fixing condition under the floor of wooden house on the seismic response of an old Japanese-style two-story wooden house was numerically investigated in this paper. As a result, it was found that seismic collapsing behavior of the wooden house strongly depends on the post fixing condition under its first floor.

*Keywords*: Collapsing process analysis, Japanese traditional framed-construction method, Post fixing condition.

## 1 INTRODUCTION

In Japan, there is a serious and urgent issue on seismic retrofit for a lot of old Japanese-style two-story wooden houses, which were built by a Japanese traditional framed-construction method more than 80 years ago. It is very important for structural engineers to accurately evaluate a seismic response of the Japanese-style two-story wooden house in the design process of seismic retrofit, because the seismic response of two-story wooden house can play a key role to propose an effective countermeasure in the structural design process of seismic retrofit for the wooden house. In order to investigate the seismic performance of an old Japanese-style two-story wooden house, 3-D non-linear collapsing process analysis (Nakagawa and Ohta 2010) of timber structure was conducted against a strong earthquake ground motion with the Japan Meteorological Agency seismic intensity of “6 upper” level. A non-linear behavior of timber elements in the wooden structure during a strong earthquake ground motion can be simulated by this 3-D non-linear collapsing process analysis based on the Distinct Element Method (Cundall and Strack 1979). In general, the posts under the floor of an old Japanese-style wooden structure are erected on their foundation stones and are not fixed. Consequently, this system is likely to be a seismic base isolation. The effect of the post fixing condition under the floor of wooden structure on the seismic response of an old Japanese-style two-story wooden house was numerically investigated in this paper.

## 2 OUTLINE OF SEISMIC COLLAPSING PROCESS ANALYSIS

In this paper, a structural analysis software of "Wallstat" (Nakagawa and Ohta, 2010) is employed in order to investigate seismic response behavior and collapsing process of two-story wooden house during a strong earthquake ground motion. This software has an original analysis technique using the basic theory of the Distinct Element Method (Cundall and Strack, 1979), and can be taken into consideration the extremely non-linear properties of timber members breaking or being dispersed. In the collapsing process analytical calculation, two-story wooden house can be modeled by lumped mass and the weight of each floor in two-story wooden house model can be obtained from each structural element as illustrated in Figure 1. Timber characteristics of the compression and tensile elasto-plastic springs consist of an elastic part and slip-type part.

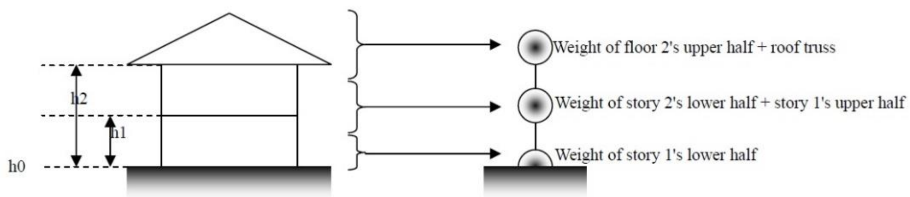



Figure 1. Weight of floor in the analytical model of wooden house.

### 2.1 Modeling of Structure Element (Nakagawa and Ohta, 2010)

#### *2.1.1 Modeling of Frame*

Timber frame is modelled by two elasto-plastic rotational springs (plastic hinge) and an elastic beam component as shown in the left-hand side of Figure 2. The spring can be defined by a relationship between bending moment $M$ and angle of rotation $\theta$ with the skeleton curve indicated in the right-hand side of Figure 2.

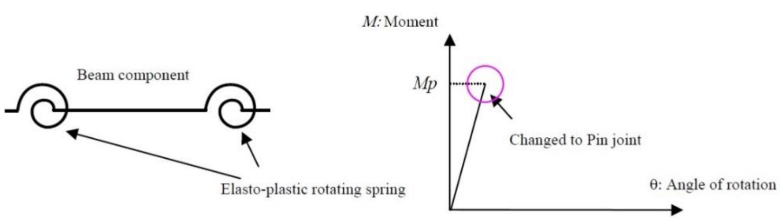


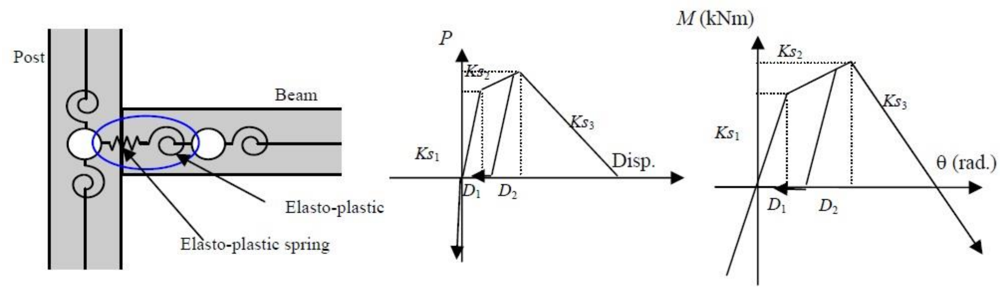

Figure 2. Schematic diagram and skeleton curve of frame spring.

#### *2.1.2 Modeling of Joint Spring*

Joint spring can be modelled by both an elasto-plastic spring and a rotational spring as shown in Figure 3(a). Timber characteristic of the compression and tensile elasto-plastic spring consist of an elastic part and slip-type part indicated in Figure 3(b), and also timber characteristics of the rotational spring is assumed to be a slip-type relationship between ending moment $M$ and angle of rotation $\theta$ shown in Figure 3(c).

### *2.1.3 Modeling of Shear Wall and Bracing*

Vertical shear wall indicated in Figure 4 can be modelled by the replacement of truss component with a load-displacement non-linear relationship shown in Figure 6. Also, bracing shear wall illustrated in Figure 5 can be modelled by the replacement of compression and tensile truss components defined by a set of bi-linear and slip skeleton curve shown in Figure 6, too.




(a) Schematic diagram of joint element
(b) Characteristic of elastoplastic spring
(c) Characteristic of rotational spring

Figure 3. Outline of joint modelling.

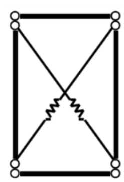


Figure 4. Shear wall spring.

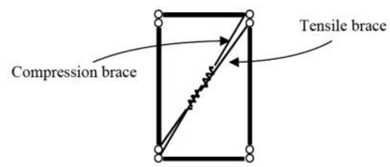



Figure 5. Outline of bracing shear wall.

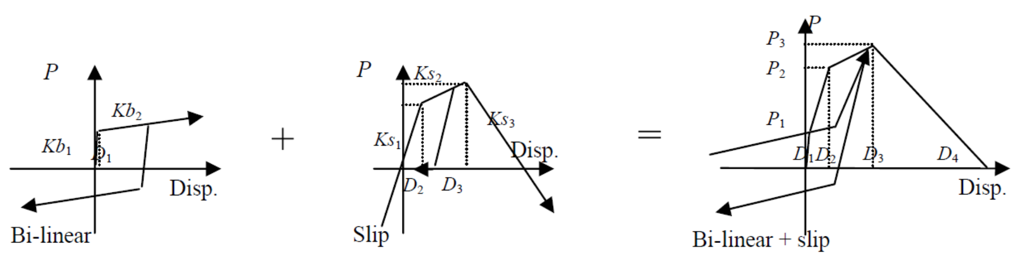



Figure 6. Hysteretic characteristics of shear wall and bracing.

## 3 SEISMIC RESPONSE RESULTS

### 3.1 Seismic Collapsing Frame Model and Input Earthquake Ground Motion

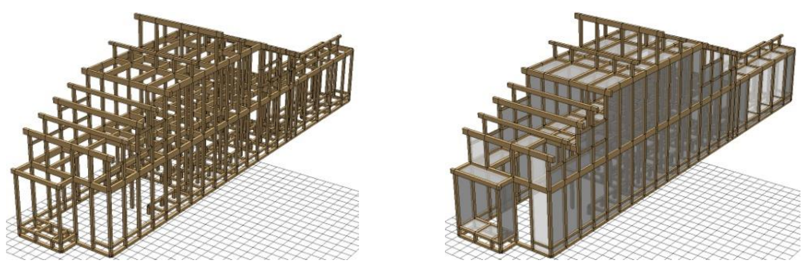
Figure 7 shows two wooden frame models without and with wall for seismic collapsing analysis against a strong earthquake ground motion, which consist of wooden columns and beams and also are made according the framing plan of two-story wooden house.

Table 1 shows three earthquake ground motion measured in the past earthquakes, and the JMA seismic intensity, peak acceleration, peak velocity, peak frequency and duration in each earthquake motion are indicated in this table. In this paper, three earthquake ground motion with the JMA seismic intensity of "6 upper" level are employed in seismic collapsing analysis of two-story wooden house. Figures 8 – 10 illustrate the displacement waves and the Fourier spectra of their acceleration waves for JMA Kobe wave, JR Takatori one and Kariwa one, respectively.

### 3.2 Seismic Collapsing Results

In this section, the effect of post fixed condition on the seismic performance during a strong earthquake ground motion is numerically investigated.

Figure 11(a) and 11(b) show final states after seismic collapsing simulation against JMA Kobe wave under both post fixed condition and unfixed one, respectively. In this paper, a dynamic friction coefficient, $\mu_d = 0.3$, between the base of wooden house and the ground is employed for post unfixed condition. Because JMA Kobe wave has a peak velocity of 91 kine, the roof truss on the second floor of two-story wooden house collapses under post fixed condition shown in Figure 11(a). While, there are few damages in two-story wooden house collapsing behavior under post unfixed condition shown in Figure 11(b). This is because this post unfixed condition is likely to simulate a seismic base isolation.



(a) Without wall (b) With wall

Figure 7. Frame model of two-story wooden house for seismic collapsing analysis.

Table 1. Earthquake ground motion records.

| Earthquake Motion Name | $I_{JMA}$ | Peak Acceleration ($cm/s^2$) | Peak Velocity (cm/s) | Peak Frequency (Hz) | Duration (s) |
|---|---|---|---|---|---|
| JMA Kobe (1995) | 6.4 | 818 | 91 | 1.43 | 30 |
| JR Takatori (1995) | 6.4 | 657 | 126 | 0.81 | 30 |
| Kariwa (2004) | 6.0 | 465 | 122 | 0.38 | 45 |

Final states after seismic collapsing simulation against JR Takatori wave under both post fixed condition and unfixed one are indicated in Figure 12(a) and 12(b), respectively. The second floor of two-story wooden house collapses under post fixed condition shown in Figure 12(a). While, there are few damages in the two-story wooden house collapsing behavior under post unfixed condition shown in Figure 12(b).

Figure 13(a) and 13(b) illustrate final states after seismic collapsing simulation against Kariwa wave under both post fixed condition and unfixed one, respectively. Two-story wooden house completely collapses under post fixed condition shown in Figure 13(a). While, there are few damages in the two-story wooden house collapsing behavior under post unfixed condition shown in Figure 13(b), and this final state is the same as Figures 11(b) and 12(b). The effect of the post unfixed condition on the seismic performance is analytically confirmed through some simulations.

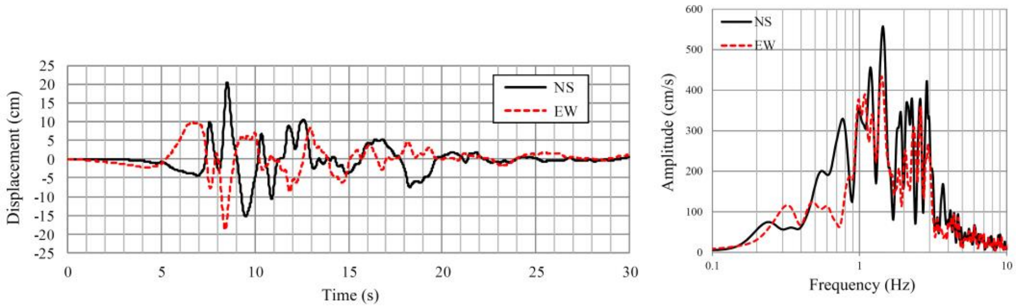



Figure 8. Earthquake motion and its Fourier acceleration spectrum (JMA Kobe).

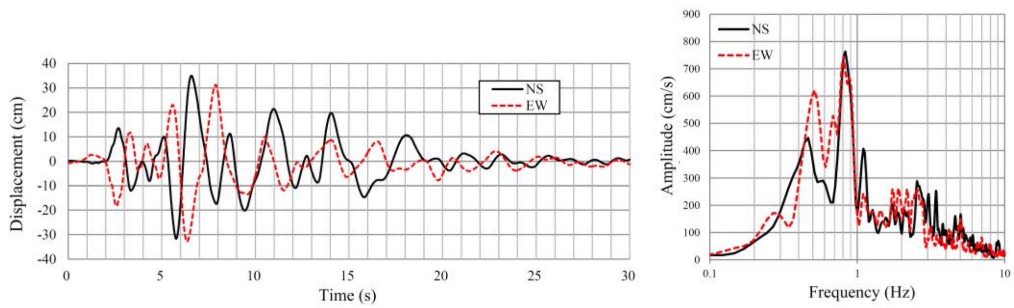



Figure 9. Earthquake motion and its Fourier acceleration spectrum (JR Takataori).

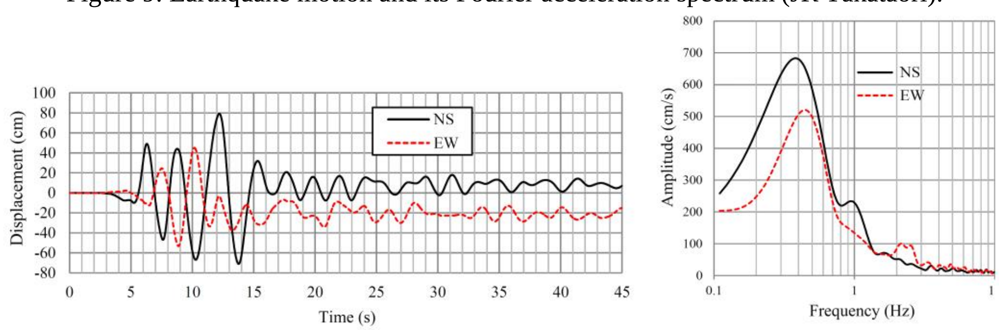
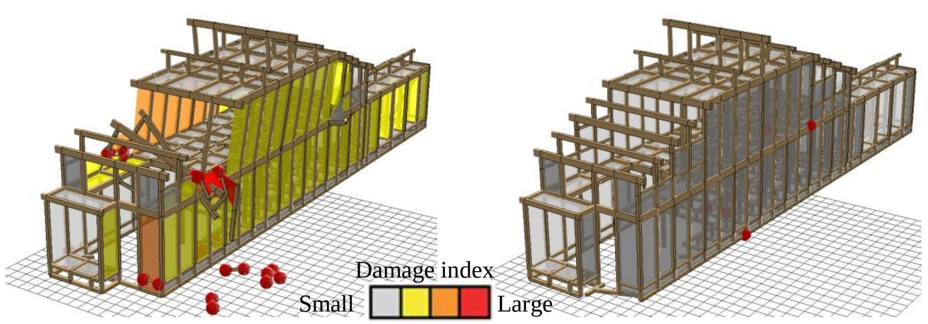
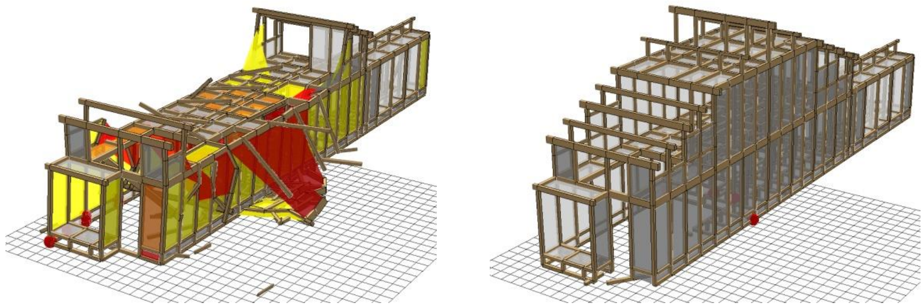



Figure 10. Earthquake motion and its Fourier acceleration spectrum (Kariwa).



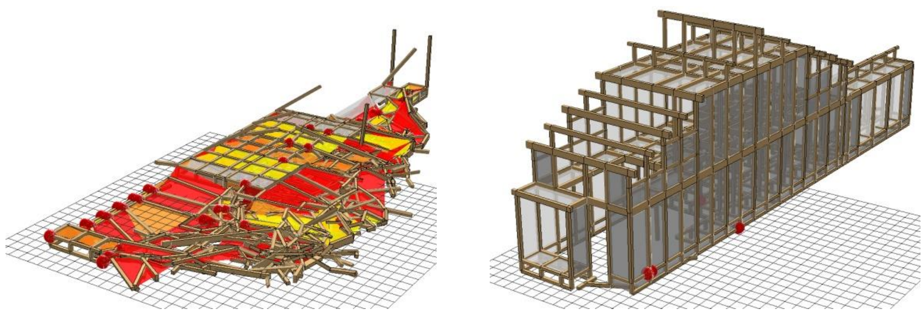

(a) Post fixed condition (b) Post unfixed condition ( $\mu_d = 0.3$ )

Figure 11. Seismic collapsing result after earthquake motion (JMA Kobe).



(a) Post fixed condition (b) Post unfixed condition ( $\mu_d = 0.3$ )

Figure 12. Seismic collapsing result after earthquake motion (JR Takatori).



(a) Post fixed condition (b) Post unfixed condition ( $\mu_d = 0.3$ )

Figure 13. Seismic collapsing result after earthquake motion (Kariwa).

## 4 CONCLUTIONS

Investigation of the seismic performance of Japanese-style, two-story wooden houses was done using 3-D non-linear collapsing process analysis with simulated seisic activity. The effect of post fixing condition under the floors of wooden houses was also numerically investigated.

A summary of the results obtained by this study is as follows:

(1) Seismic behavior of old Japanese-style, two-story wooden houses can be numerically simulated by 3-D collapsing process analysis.

(2) The application of 3-D collapsing analysis to this style of wooden houses may play a key role in the seismic retrofit design process for these two-story wooden houses.

(3) Two-story wooden structure may be collapsed by a strong earthquake ground motion with the JMA seismic intensity of “6 upper” level.

(4) Seismic collapsing behavior strongly depends on the post fixing condition under the floor of an old Japanese-style two-story wooden house.

## References

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