Seismic Collapsing Behaviour of Three-story Wooden House under Strong Earthquake Ground Motion

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Abstract: In order to investigate the seismic behaviour of an old three-story wooden house, 3-D non-linear collapsing process analysis of this wooden house was conducted against a strong earthquake ground motion. A non-linear behaviour 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 theory of the Distinct Element method.
Keywords: seismic performance; 3-D collapsing process analysis; three-story wooden house

1. Introduction

In Japan, there has existed a serious problem on seismic retrofit for a lot of three-story wooden houses, which were built by a Japanese traditional framed-construction method. It is very important for structural engineers to accurately evaluate a seismic response of the three-story wooden house in the design process of seismic retrofit, because the seismic response of three-story wooden house can play a key role to propose an effective counter-measure in the design process of seismic retrofit for the wooden house. In order to investigate the seismic behaviour of an old three-story wooden house, 3-D non-linear collapsing process analysis [1] of this wooden house was conducted against a strong earthquake ground motion with the Japanese Metheological Agency (JMA) seismic intensity of "6 lower" level. A non-linear behaviour 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 software "Wallstat" [1] based on the Distinct Element Method proposed by Cundall and Strack [2]. Takatani [3], [4], Takatani and Nishikawa [5], [6] reported seismic collapsing analyses for various Japanese-style wooden structures with a low seismic performance to verify an appropriateness of each seismic retrofitting countermeasure against a strong earthquake ground motion.

In order to investigate not only the seismic response performance but also the effective seismic retrofit countermeasure of Japanese–style 3-story wooden house, 3-D seismic collapsing process analysis of an old 3-story wooden house without/ with seismic retrofit against a strong earthquake ground motion with the JMA seismic intensity of "6 lower" level was carried out in this paper.

2. Seismic collapsing analysis of 3-story wooden house

2.1. Outline of 3-story wooden house

Photo 1 shows an elevation view of 3-story wooden house, which was built in 1978 by a Japanese traditional wooden framework construction method. Figure 1 indicates a trapezoid-shape plan view of each floor of this 3-story wooden house, and the wider width in Y direction of this house is 5.56m, the narrower width of Y direction is 4.82m, and the width of X direction is 11.07m. The height of this 3-story wooden house is 11.44m. There is a larger space without wooden column in the first floor of this wooden house, because the half part of the first floor is a shop of hair salon.

Photo 1 Elevation view of 3-story wooden house

2.2 Seismic collapsing frame model

Fig.2 shows two wooden frame models for seismic collapsing analysis against a strong earth quake ground

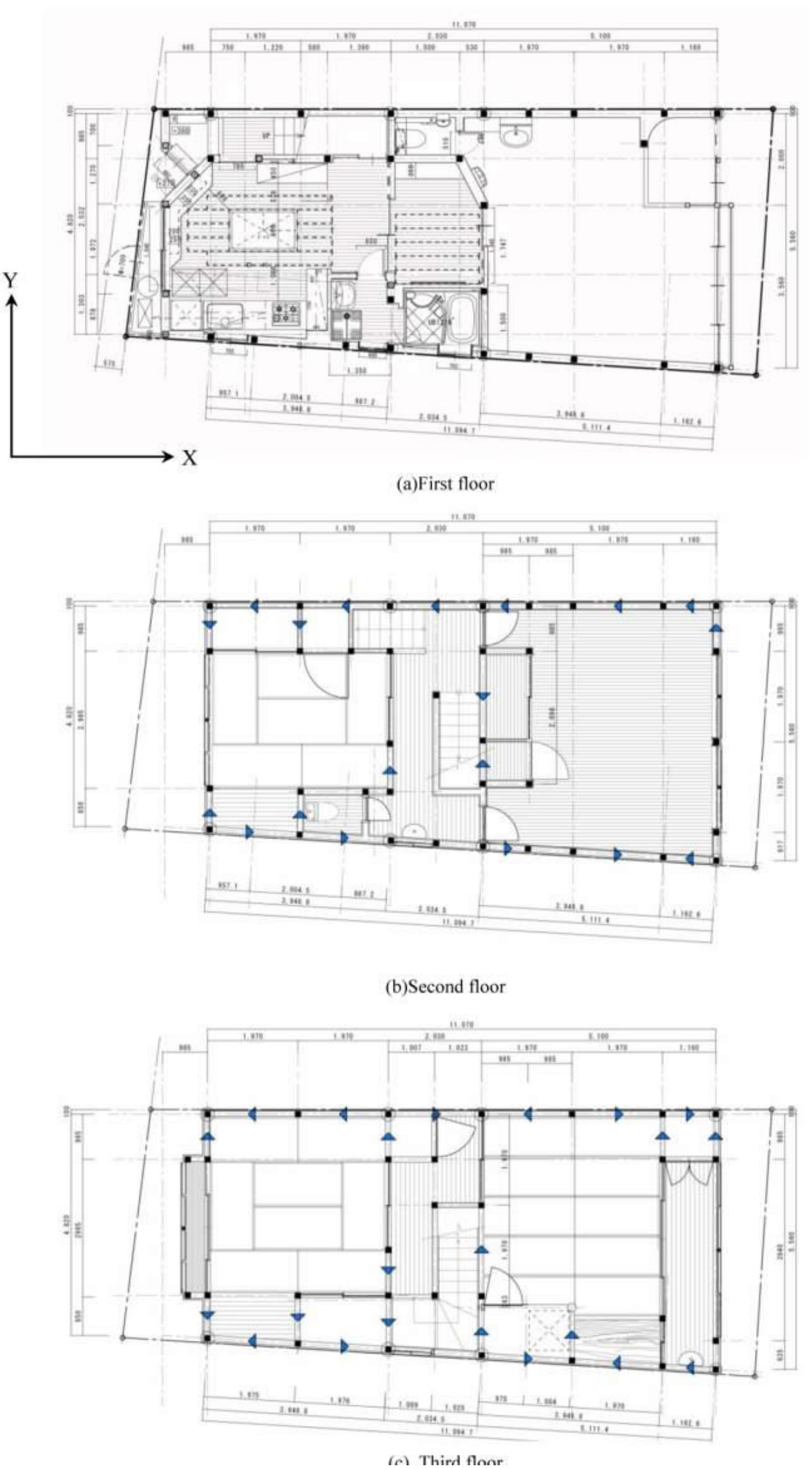
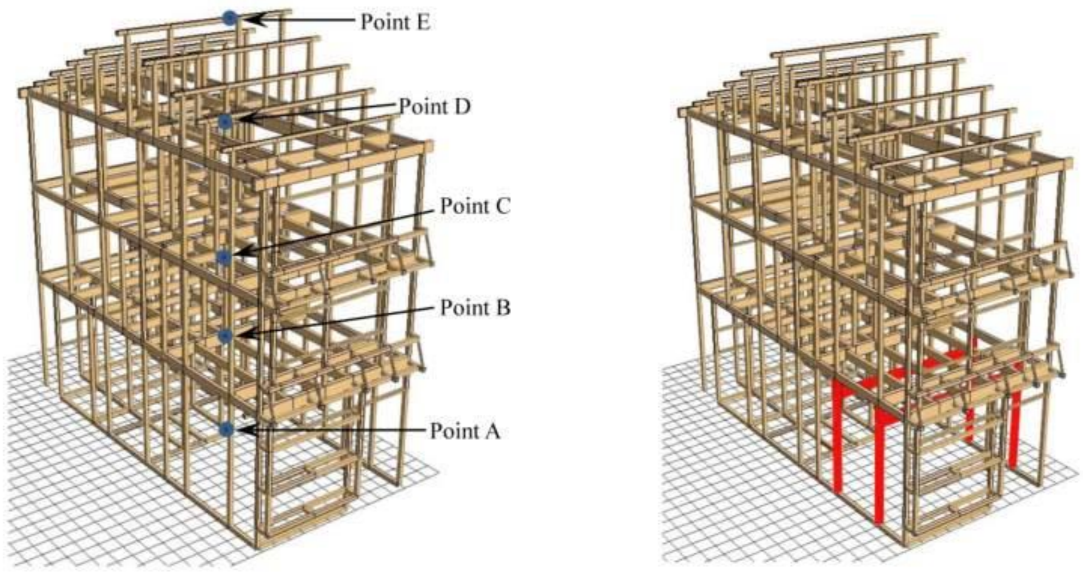


Figure 1 Plan view of 3-story wooden house

motion, which consist of wooden columns and beams and also are made according the framing plan of 3-story wooden house. In this paper, two seismic frame models are employed in order to seismic performance of this wooden house without/ with seismic retrofit. Figure 2(a) is a frame model without seismic retrofit and Figure 2(b) is a frame one with seismic retrofit. Wooden elements with red colour in shown Figure 2(b) are made an addition for seismic retrofit to the original frame model. Two beams are added and four columns are replaced with wooden column with larger cross section in order to assure the seismic resistance for a half space of the first floor of this 3-story wooden house.



(a) Frame model without seismic retrofit (b) Frame model with seismic retrofit

Figure 2 Seismic collapsing frame model

Table 1: Earthquake ground motion wave 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

2.3 Input earthquake ground motion

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 3-story wooden house. Figs. 3 – 5 illustrate the displacement waves and Fourier spectra of acceleration waves for JMA Kobe wave, JR Takatori one and Kariwa one, respectively.

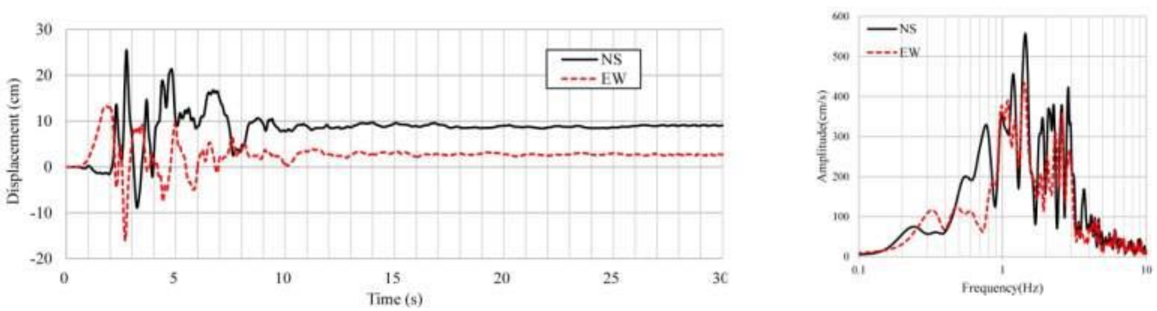


Fig. 3: Earthquake ground motion and its Fourier acceleration spectra (JMA Kobe, 1995)

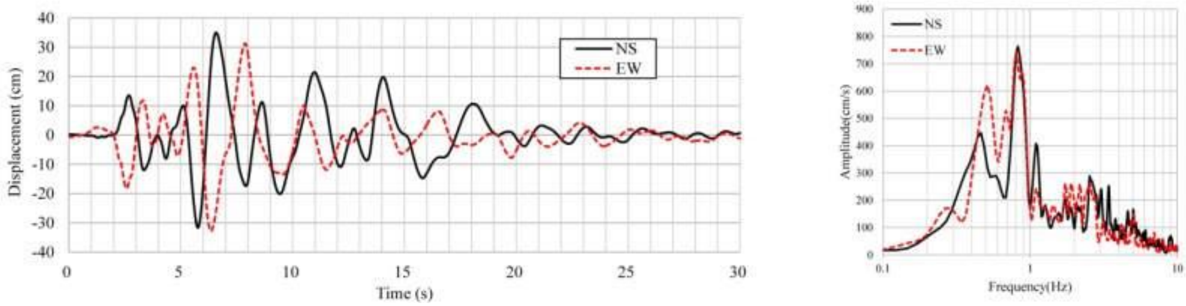


Fig. 4: Earthquake ground motion and its Fourier acceleration spectra (JR Takatori, 1995)

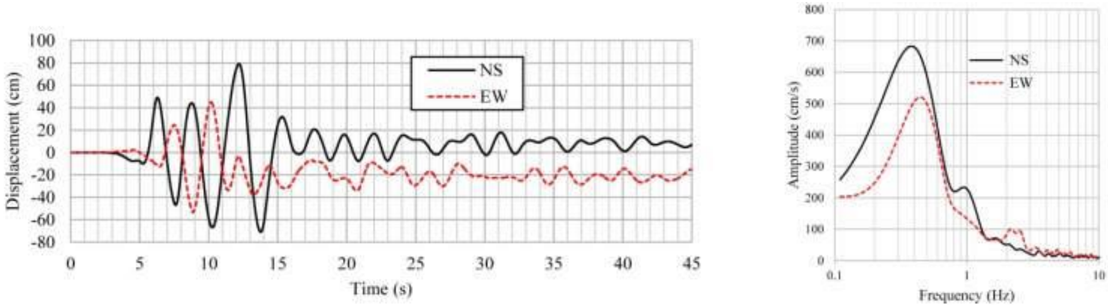
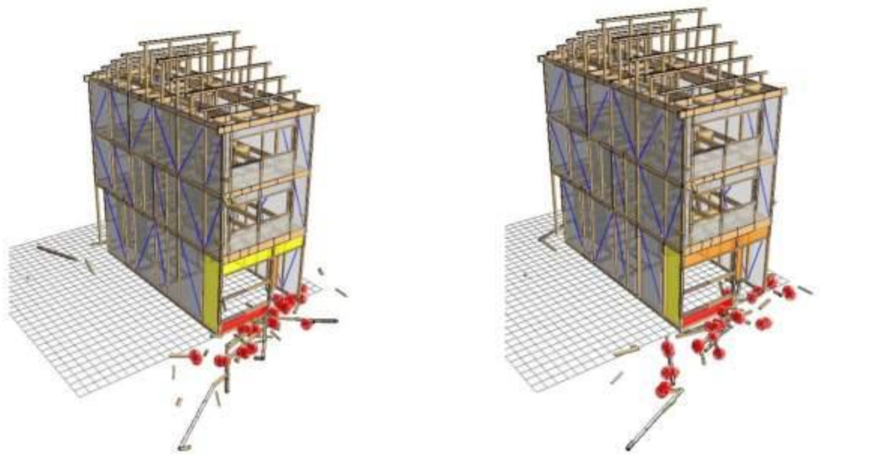
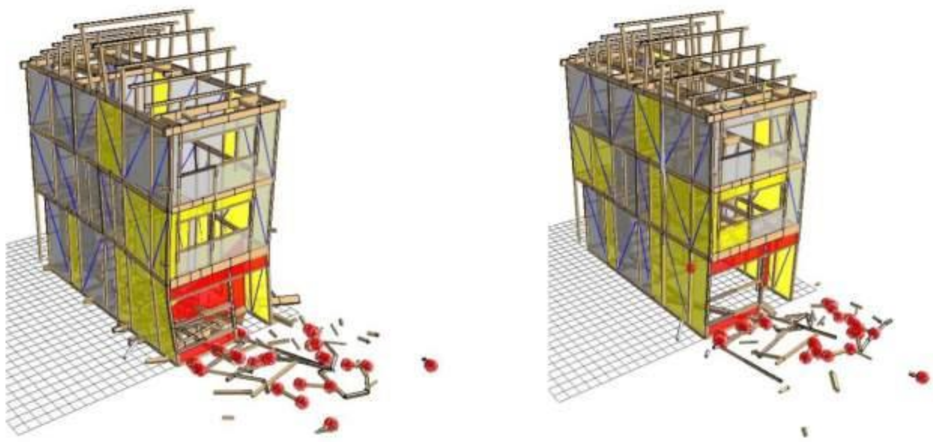


Fig. 5: Earthquake ground motion and its Fourier acceleration spectra (Kariwa, 2004)



(a) Without seismic retrofit (b) With seismic retrofit

Fig. 6: Seismic collapsing state of 3-story wooden house after JMA Kobe wave



(a) Without seismic retrofit (b) With seismic retrofit

Figure 7 Seismic collapsing state of 3-story wooden house after JR Takatori wave

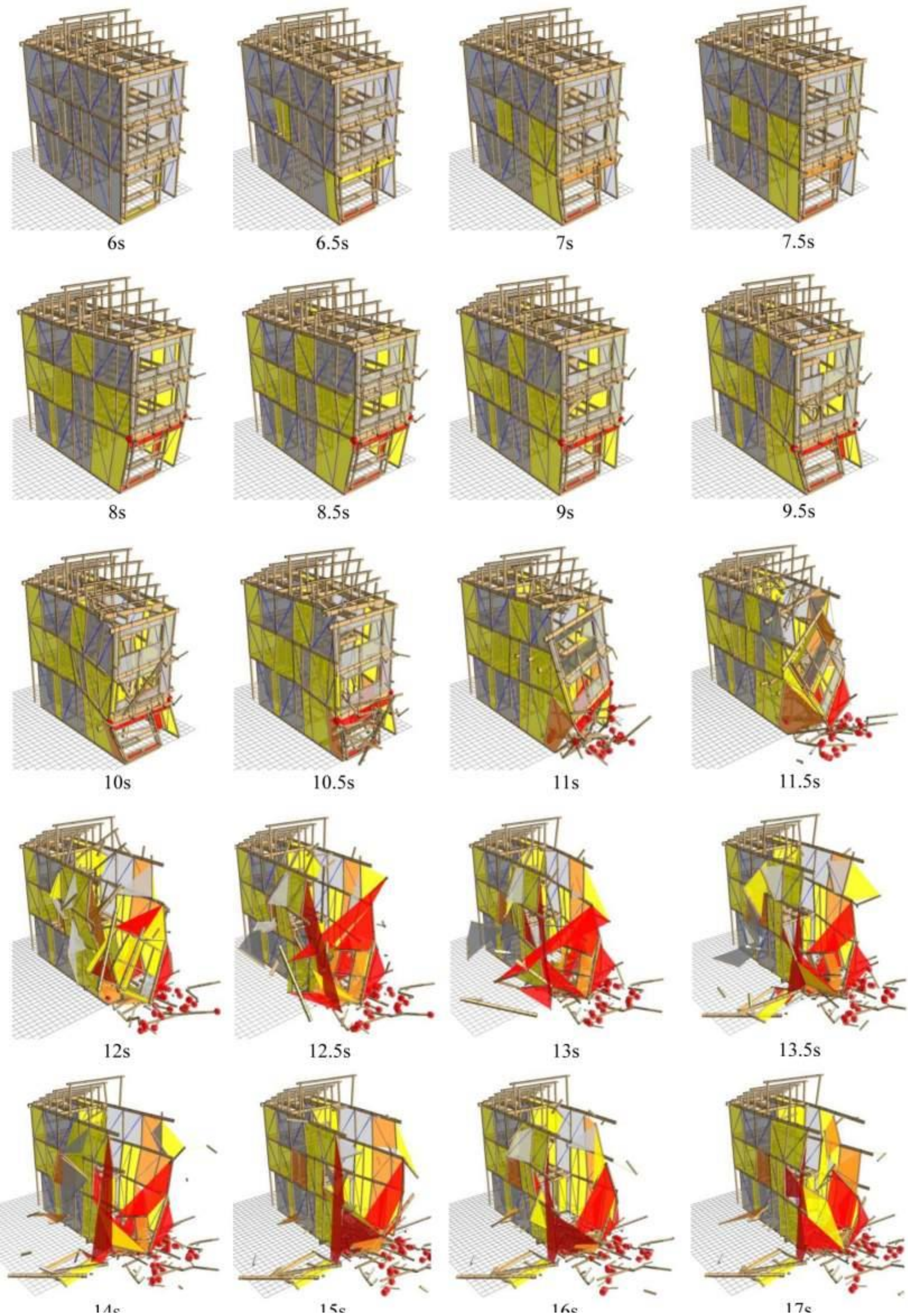


Figure 8 Seismic collapsing behaviour of 3-story wooden house without seismic retrofit (Kariwa wave)

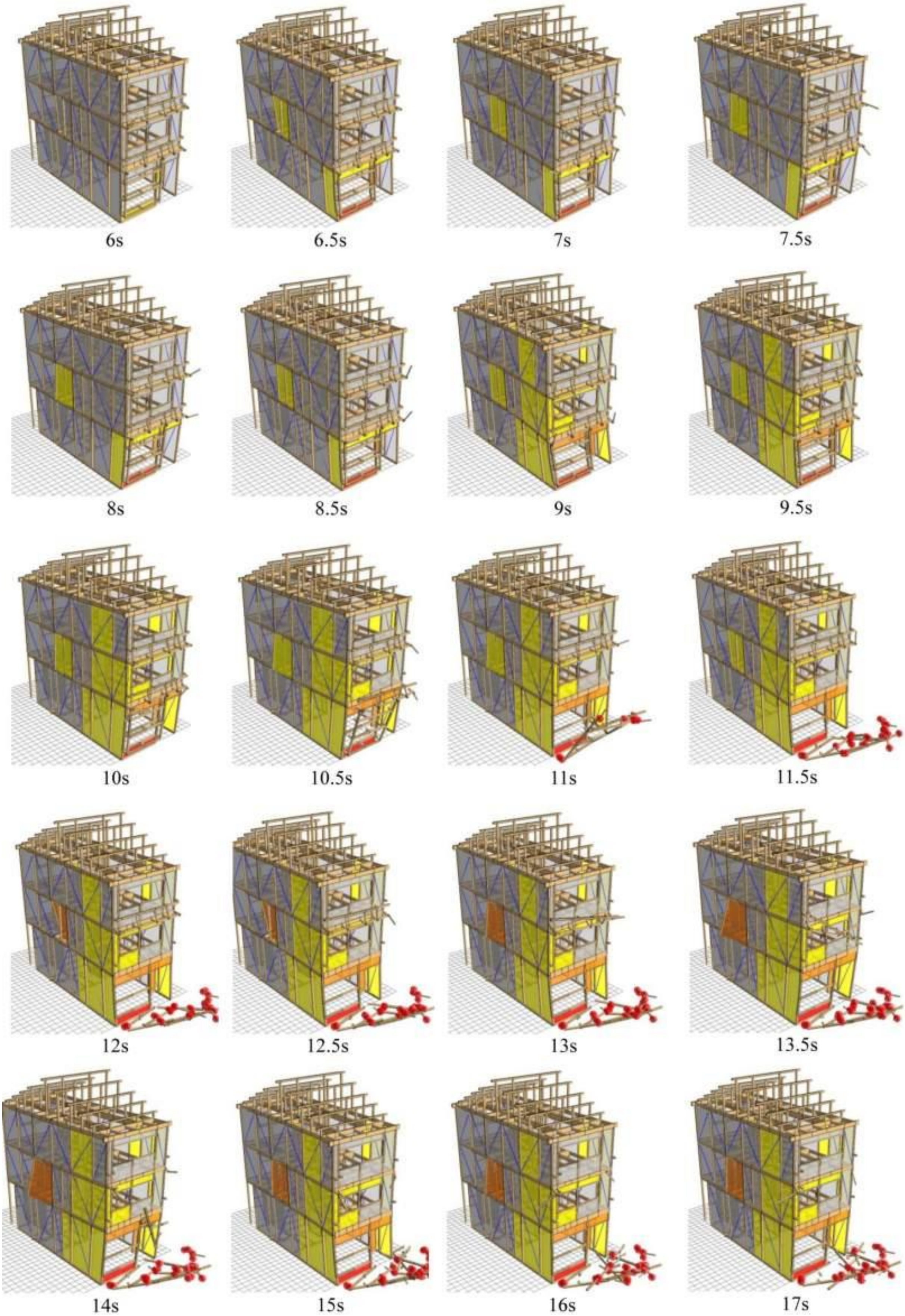
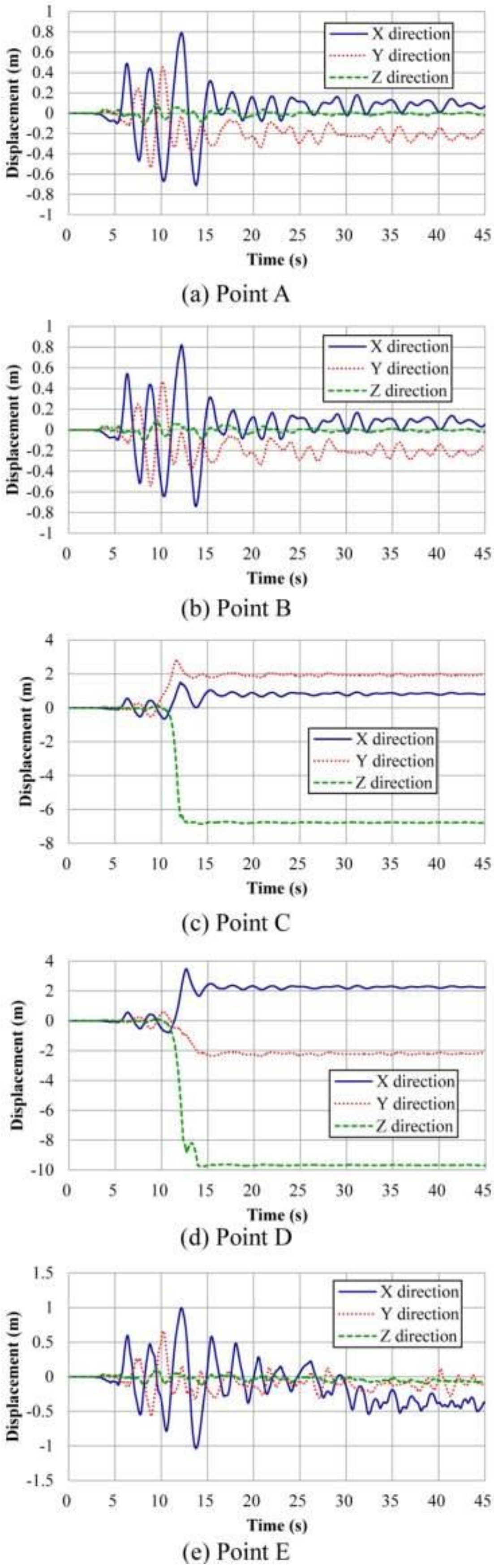


Figure 9 Seismic collapsing behaviour of 3-story wooden house with seismic retrofit (Kariwa wave)



(a) Point A

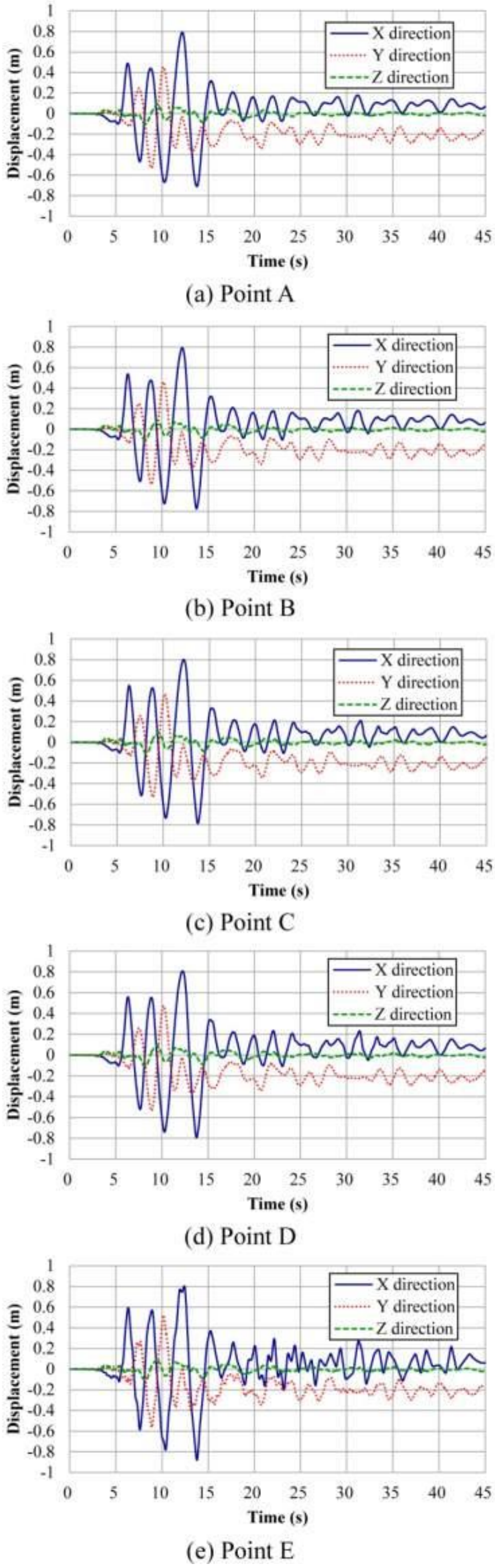
(b) Point B

(c) Point C

(d) Point D

(e) Point E

Figure 10 Seismic response behaviour at nodal point of 3-story wooden house without seismic retrofit



(a) Point A

(b) Point B

(c) Point C

(d) Point D

(e) Point E

Figure 11 Seismic response behaviour at nodal point of 3-story wooden house with seismic retrofit

2.4 Seismic collapsing results

Figure 6 shows seismic collapsing state of 3-story wooden house without/with seismic retrofit after a strong earthquake ground motion of JMA Kobe with the maximum acceleration in three earthquake ground motions. Seismic collapsing state of 3-story wooden house without/with seismic retrofit does not collapse regardless of quite damage.

Figure 7 indicates seismic collapsing state of 3-story wooden house without/with seismic retrofit after a strong earthquake ground motion of JR Takatori with the maximum velocity in three earthquake motions. Seismic collapsing state of 3-story wooden house without/with seismic retrofit does not collapse regardless of severe damage in comparison with JMA Kobe.

Figure 8 illustrates seismic collapsing behaviour of 3-story wooden house without seismic retrofit during a strong earthquake ground motion of Kariwa with the lowest peak frequency in three earthquake motions. 3-story wooden house without seismic retrofit starts to collapse after 10 seconds, and the half of this wooden house collapses after 17 seconds because the seismic resistance of half part of the first floor of this wooden house is lower.

Figur 9 shows seismic collapsing behaviour of 3-story wooden house with seismic retrofit during a strong earthquake ground motion of Kariwa. 3-story wooden house with seismic retrofit shown in Figure 2(b) does not collapse. This implies that seismic retrofit in the half part of the first floor of 3-story wooden house may be more effective.

Seismic collapsing behaviours during Kariwa wave at five point shown in Figure 2(a) for 3-story wooden house without seismic retrofit are indicated in Figure 10. Although seismic response behaviours at Points A, B, and E implies uncollapsing, seismic response behaviours at Points B and C express a seismic collapse of the falling phenomenon of wooden elements.

While, seismic collapsing behaviours during Kariwa wave at five point for 3-story wooden house with seismic retrofit are illustrated in Figure 11. These seismic response behaviours at five points imply the uncollapsing of 3-story wooden house with seismic retrofit. It should be noted that 3-D seismic collapsing analysis may be a significant evaluation tool to numerically investigate whether the seismic retrofitting countermeasure for an old wooden house is definitely effective or not.

3.Conclutions

In order to investigate the seismic behaviour of an old three-story wooden house, 3-D non-linear seismic collapsing process analysis of this wooden house was conducted against a strong earthquake ground motion with the JMA seismic intensity of “6 upper” level. In this paper, the effect of seismic retrofit for 3-story wooden house on seismic response behaviour during a strong earthquake ground motion can be simulated by this 3-D non-linear collapsing process analysis. The summary obtained in this paper is as follows.

(1) Seismic behaviour of an old 3-story wooden house under a strong earthquake ground motion can be numerically simulated by 3-D seismic collapsing process analysis.

(2) The application of 3-D collapsing analysis to an old 3-story wooden house with low seismic performance against a strong earthquake ground motion may may play an important key role in seismic retrofit design process of this wooden house.

This collapsing process analysis has a significant potential to find when and where begin to break first in an old 3-story wooden house during a strong earthquake ground motion. An optimum seismic retrofit of 3-story wooden house can be made by using the collapsing analysis. In addition, further investigation may be needed to simulate the collapsing process phenomenon of a 3-story wooden house without or with seismic retrofit and make some concrete conclusions.

4. References

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