

Advancing Timber for the Future Built Environment

DEVELOPMENT OF AN INTEGRATED SESMIC SIMULATION SYSTEM FOR TIMBER STRUCTURES

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ABSTRACT: In Japan, many full-scale shake table experiments have been conducted on wooden houses since the 1995 Southern Hyogo Prefecture Earthquake. There is an accumulation of data on the seismic performance of low-rise wooden houses and mid-rise wooden structures up to the point of collapse. On the other hand, numerical analysis tools that take into account strong nonlinearities have been developed, and the reproducibility of the experiments and their application to structural design methods in practice have been studied in the research field. This paper introduces the seismic simulation tool for the timber structures, the results of comparison with full-scale shaking table experiments, data linkage with CAD software and the development of the tool into structural design software.

KEYWORDS: Distinct Element Method, Wooden houses, Mid-rize timber structures, Time-history response analysis

1 – INTRODUCTION

Timber structures are characterised by a lighter weight than other structural types, and the lateral load level for checking the ultimate behaviors is relatively low. Consequently, many shaking table tests to investigate that ultimate behaviors using full-scale wooden houses have been conducted. Since 2005, a series of shaking table tests have been conducted utilising the E-Defense shaking table and other tables capable of inducing complete structural collapse. This has resulted in the accumulation of a substantial corpus of experimental data, which can be subjected to comparative analysis with numerical simulations. The experimental data has been used to verify and improve the accuracy of numerical analysis methods that can track a building until collapse.

This report will present a numerical analysis method developed for the purpose of reproducing the strongly nonlinear behaviour of wooden buildings in response to extremely large earthquake motions. It will also provide an example of the application of this method as software. In particular, it will introduce a method for visualising the seismic performance of low-rise wooden houses based on time history response analysis. It will then present an example of linking this method with CAD for wooden houses sold in Japan, and finally, it will demonstrate the application of this method as structural design software for mid-rise wooden structures.

2 – METHOD FOR ANALYSIS

2.1 ANALYTICAL THEORY

This analysis method employs a non-continuum analysis approach, specifically the distinct element method, to calculate the strongly nonlinear behaviour. In explicit methods, such as the distinct element method, the equations of motion are solved in a dynamic rather than a simultaneous manner in order to proceed with the calculation. A distinctive feature of this method is that the stress is calculated individually for each element, without the necessity of solving the overall stiffness matrix. As a consequence of the propagation of stress between elements over time, unbalanced forces and behaviour after collapse can be calculated without the need for special processing.

In order to accurately reproduce the collapse process of a wooden house, it is necessary to consider the destruction of joints and the increase in horizontal force due to the P- Δ effect. However, these cannot be fully reproduced by the response analysis of a mass system in which each floor is replaced by a shear spring or by a planar analysis using a pseudo-3D model. Therefore, a three-dimensional frame was used to model it in this sytem.

The general analysis models used in this method were depicted in Figure 1. The plan of this analysis model was based on the specimen used in the shake table test. The wood frames of numerical models were modelled by beam element as indicated in figure1 (a). The moment of beam elements starts to fall once the maximum bending moment has been exceeded, with transformation into a pinned state occurring at the point in time when 0 is reached, at which point the member is adjudged to have been broken. Vertical shear walls are modelled by the

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replacement of braces in truss elements as indicated in figure 2(a). Hysteric characteristics are expressed according to the bi-linear + slip-type models indicated in figure 2(c). Parameters designate bi-linear and slip skeleton curves. Bracing shear walls are modelled by the positioning of two compression and tensile truss elements for each brace, as indicated in figure 2(b). As with shear wall springs, bracing spring hysteric characteristics are expressed according to the bi-linear + slip-type I models.

As indicated in figure3, joints are modelled using the rotational spring + elasto-plastic spring (for strong shearing). Hysteric characteristics of the compression / tensile elasto-plastic spring are set as per the one side elastic + one side slip-type.



Figure 2: Springs for metal connecter



Figure 4: Hysteretic rule of shear wall spring



(a)Wood frames

(b)Shear walls and floor diaphragms

Figure 1: Outline of numerical models

(c)Whole image of numerical model

3 – COMPARISON WITH SHAKING TABLE TESTS

The methodology developed in this study was evaluated in comparison with a series of full-scale shaking table experiments in which the structure was subjected to a controlled excitation until it reached a state of collapse. It is inherently challenging to accurately predict the response prior to an experiment, particularly in the context of strongly nonlinear deformation. The findings revealed that the experiment could be reproduced with high precision through the process of repeated parameter identification, thereby enabling the reproduction of the experiment.

3.1 ANAYSIS FOR 3 STORY WOODEN HOUSES

No.1 and No.2 is the target specimens for our numerical analysis. Figure 1 shows the picture of specimens No.1 and No.2. The both specimens are real-size three story wood house by post-and-beam construction. The main seismic element is bracing shear walls, gypsum board wall, and siding panel sheathed wall. The shake table tests were carried out at the E-Defence (National institute of earth science and disaster prevention) in Kobe prefecture. The two of the specimens (No.1 and No.2) have the same amount of shear walls, but the specification of the column end joints was different. The specimen No.2 didn't have sufficient tensile capacity of column end joint and No.1 have enough tensile capacity.

Figure 7 shows the movie snapshot for analytical results of one of the analytical model. The rocking behaviour of No.2 was simulated in calculation. The numerical analysis uses Model C agreed well with shake table result in terms of the collapsing behaviour of No.1 and rocking behaviour of No.2. The numerical analysis uses one of these spring parameters agreed well with shake table result in terms of the collapsing behaviour of No.1 and rocking behaviour of No.2.



Figure 5: Target specimens



Figure 6: Comparison between shaking table results and analytical result on load-displacement curce



Figure 7: Comparison between shaking table results and analytical result

3.2 ANAYSIS FOR JAPANESE TRADITIONAL WOODEN HOUSES

Figure 1 shows the photograph of the specimens. The tests were executed on four specimens, but we focused on the specimen No.4 in this paper. The main seismic components of the specimen were mud plastered walls. The size of the specimen was 10.92x7.28m.

Figure 3 shows the maximum deformation of analytical and experimental results at BCJ-L2 X-direction, Ydirection and JMA kobe input. Figure 4 shows the time history of displacement of sliding of the corner column end (L1-S1) at BCJ-L2 Y-direction input. Figure 5 shows the aspects of deformation of column ends at the maximum sliding deformation at BCJ-L2 Y-direction input. Calculated column end displacements of analysis model were fairly agreed with experimental results.





(a) Specimen No.4

(b) Column end and stone

Figure 8: Target specimens







Figure 10: The maximum deformation of analytical and experimental results at BCJ-L2 X-direction input



Figure 11: The maximum deformation of analytical and experimental results at BCJ-L2 Y-direction input

4 – APPLICATION AS THE VISUAL SIMULATION TOOL AND DATA LINKAGE WITH CAD SOFTWARES

The software is available for free on the Kyoto University website under the name "wallstat" and is designed as a seismic simulation tool for low-rise wooden houses constructed using frame construction. The english version is also available. The creation of analytical models and other forms of pre- and post-processing can be accomplished through the utilisation of a GUI, which facilitates straightforward operations. An increasing number of housing companies in Japan are employing wallstat for the analysis of all wooden houses they build. The software popularization is due to the establishment of data linkage through the use of "CEDXM," a prevalent computer-aided design (CAD) format for wooden houses in Japan. In recent years, "CEDXM" has also become compatible with the IFC format, paving the way for future integration with CAD systems across the globe







Figure 13: Collaboration between CAD software



Figure 14: Outline of seismic simulation software "wallstat"

5 – CONCLUSION

This report introduces a strongly nonlinear analysis method for wooden houses and its applications. At the conference, we will present an analysis method and example of a shaking table experiment, including video, and an enhanced tool for structural design.

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