Simulation of Collapsing Process of Wooden Frame Models under Dynamic Loading

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Introduction

During Kobe earthquake, over five thousand peoples were killed and most of causalities occurred due to collapse of wooden houses. Many of the collapsed houses were constructed using beam and post method before or just after the Second World War and these houses lacked presence of adequate braces or bearing walls. However, new houses, in the same locality, with brace elements suffered little or no damage[1]. Therefore it is necessary to know the reaction of the wooden frames with and without braces under dynamic loadings. In this paper, the collapsing process of wooden frames is simulated using the Distinct Element Method (DEM). The effect of the brace elements on the stability of the model frames is evaluated by comparing the response of wooden frames with and without brace elements.

Theoretical background

The simulation of the collapse process is done using the 3D distinct element method. The distinct element method was originally developed for the granular materials by Cundall in 1971. In DEM, a material is considered an assembly of individual particles and contact between particles is represented by the spring-dash pot assembly. Later Meguro, et al.[2] added elastic springs and dashpot to give continuity to the numerical model. The model behaves as continuous medium before the fracture of the springs but after the fracture, this model will only encounter the contact between the members. By using DEM, it is possible to follow the track of the elements that have separated from the whole assembly.

Since the breakage of the frame members is seen rarely in past earthquakes so the frame members are considered to be rigid elements for the analysis purposes. The joint model represents the connection between the elements. During collapse process, the contact between the falling elements is represented by contact model that represents the normal and shear stiffness by spring dashpot assembly in direction normal to contact surface and shear spring-dash pot assembly in the plane perpendicular to the normal axis as shown in figure1. Where as joint model contains a group of spring and dashpot assemblies like contact model but normal spring can resist both tension and compression. This joint is considered broken when fracture criteria is met. The calculations are performed under the following theoretical concept[3]

$$m\frac{d^2u}{dt^2}+c\frac{du}{dt}+F_i=0 \qquad \ldots..(1)$$

$$I_\xi\frac{d\omega_\xi}{dt}(I_\eta-I_\varsigma)\omega_\eta\omega_\zeta=(\sum_i r_iF_i) \qquad \ldots..(2)$$

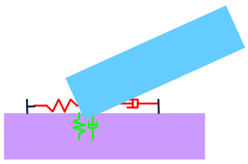

Fig 1. Configuration of Contact Model

The time history of displacement and rotation of members can be obtained step by step in the time domain by the numerical integration of equation(1) and equation(2) respectively. At each step of calculation, the state of the joint model is checked against the fracture criteria, which limits the maximum strain of joint springs. Once joint is broken, the contact between the elements is evaluated using the contact model. Then the normal and shear forces acting on the element are calculated from the strain of the respective springs.

Keyword: Distinct Element Method, Simulation, Kobe earthquake, Braces, Drift
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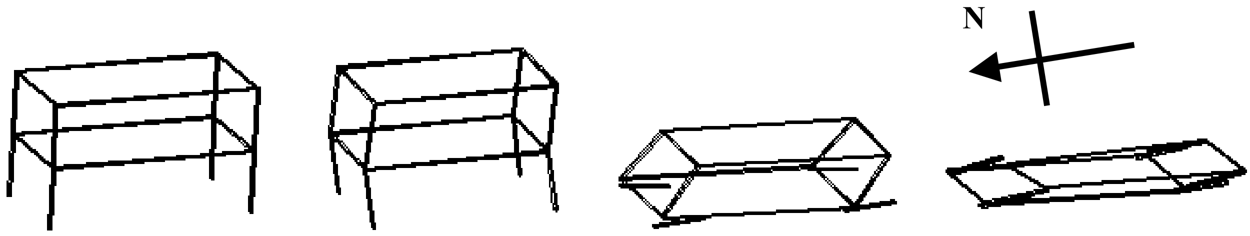
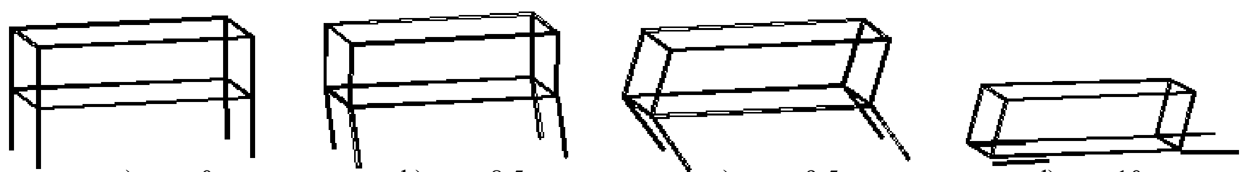
Modeling and Results

The simulated model frames are shown in the following sections. The frame A represents an old house with weak joints between the members. Frame B represents newly constructed house and Frame C represents new construction with the brace elements. The frames A and B consist of 16 members each (8 beams, 8 columns) where as frame C consists of 18 members including 2 brace elements. The brace elements are used in the first story East and West sides. The cross section of the columns is 10 mm x 20 mm and length is 290 mm. The cross section of the beam is 10 mm x 10 mm and length is 490 mm. The cross section of the braces is 10 mm x 20 mm. Kobe earthquake is used for the dynamic loading on the structure. The main earthquake direction is along the NS-direction of frames. The time period Δt , used for calculations, was 0.00001 second.



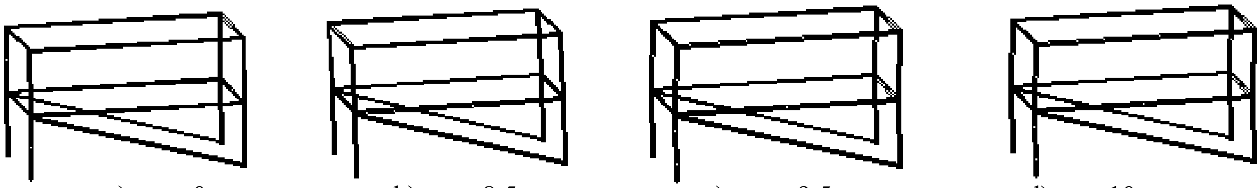
a) at t=0 sec b) at t=8.5 sec c) at t=9.5 sec d) at t=10 sec

Figure 2. Collapsing process of model frame A



a) at t=0 sec b) at t=8.5 sec c) at t=9.5 sec d) at t=10 sec

Figure 3. Collapsing process of model frame B



a) at t=0 sec b) at t=8.5 sec c) at t=9.5 sec d) at t=10 sec

Figure 4. Collapsing process of model frame C

Figure 2 represents the frame A. Frame A started leaning due to failure of joint between beams and columns of first story, which leads to complete collapse of the frame. For the frame B, rather strong joint connection is considered, to represent new construction, and the values of stiffness coefficients are increased. Due to inertia second story delays movement causing leaning of the first story, which leads to the collapse of first story but second story did not collapsed. In case of frame C, additional brace reduced the lateral movement of first story and it withstand earthquake safely.

Conclusions

The results shows that the presence of the braces reduce the drift of the first story and provided stability to frame with the same joint conditions. Using this method, the seismic behavior of wooden frames can be quantitatively simulated. This simulation method will be applied to real timber houses in the line of this research.

References

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