Progressive Collapse Algorithm for OpenSeesPy

A progressive collapse algorithm is developed by Talaat, M and Mosalam, K.M. in [1-3] and is implemented in OpenSees with Tcl interpreter. The different applications of said algorithm are exemplified in references [4-7]. This algorithm is developed using element removal which relies on the dynamic equilibrium and the subsequent transient change in the system kinematics. The theoretical background of the routine is detailed in the references mentioned herein.

The progressive collapse algorithm is thus implemented within OpenSees Tcl for an automatic removal of elements which have "numerically" collapse during an ongoing dynamic simulation. Main elements of the progressive collapse routine are illustrated in Figures 1 and 2. The implementation is supported in Tcl as a relatively new OpenSees module. Following each converged step of the dynamic analysis, the algorithm is called to check each element respectively for possible violation given a user-defined removal criteria. The routine calls for the activation of the element removal sequence before accessing the main analysis module on the subsequent analysis step. Activation of the element removal algorithm includes updating nodal masses, checking if the removal of the collapsed element results in leaving behind dangling nodes or floating elements, which must be removed as well and removing all associated element and nodal forces, imposed displacements, and constraints.

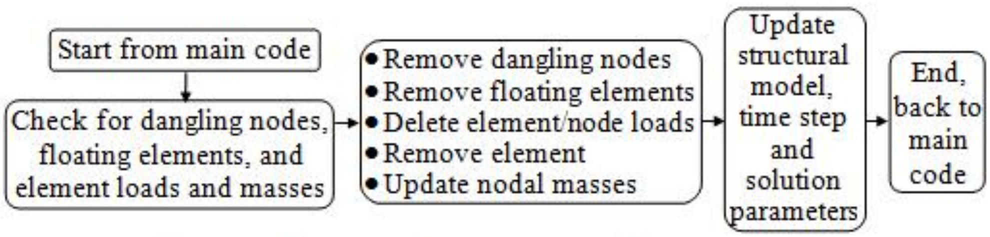

Figure 1: Flow chart for Element Removal Algorithm for Infill Walls. [Adapted from: *https://opensees.berkeley.edu/wiki/index.php/Infill_Wall_Model_and_Element_Removal#New_Command_in_OpenSees_Interpreter*]

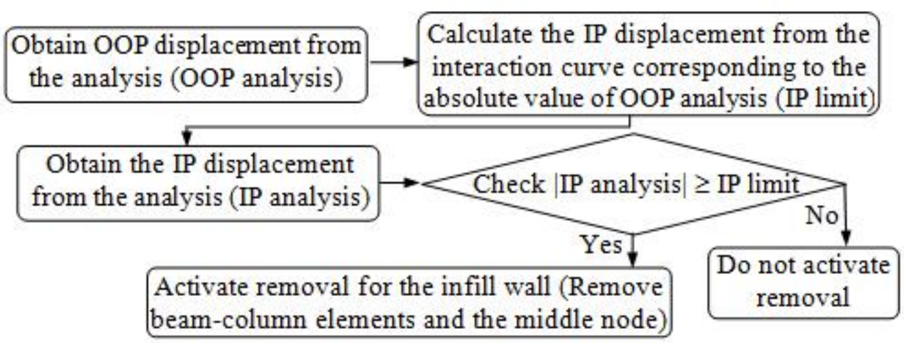

Figure 2: Element removal routine implemented in OpenSees Tcl. [Adapted from: *https://opensees.berkeley.edu/wiki/index.php/Infill_Wall_Model_and_Element_Removal#New_Command_in_OpenSees_Interpreter*]

Furthermore, the aforementioned infill wall element and its removal criteria are defined for force- and displacement-based distributed plasticity fiber elements and lumped plasticity beam–column elements with fiber-discretized plastic hinges. Current version of OpenSees Tcl considers only the removal of the infill wall model described in (*https://opensees.berkeley.edu/wiki/index.php/Infill_Wall_Model_and_Element_Removal#New_Command_in_OpenSees_Interpreter)*.

Implementation of the removal of the elements representing the aforementioned infill wall analytical model in the progressive collapse algorithm is performed through defining a removal criterion for the beam-column elements of this model. This criterion is based on the interaction between the in-plane (IP) and out-of-plane (OOP) displacements. IP displacement is the relative horizontal displacement between the top and bottom nodes of the diagonal element. OOP displacement is that of the middle node (where the OOP mass is attached) with respect to the chord which connects the top and bottom nodes. The user is free to choose any interaction relationship between IP and OOP displacements. In the example highlighted above, the interaction between in-plane and out-of-plane is taken into consideration with regards to the displacement interaction between the two mechanisms, where the IP and OOP displacement capacities are obtained using the FEMA 356 formulation for collapse prevention level. During the nonlinear time history simulation, when the mentioned combination of displacements from the analysis exceeds the interaction curve, the two beam-column elements and the middle node, representing the unreinforced masonry infill wall, are removed.

For the example illustrated in Figure 3, the existing Tcl command and its arguments in the OpenSees interpreter with respect to the infill wall removal is described such that:

recorder Collapse -ele $ele1 -time -crit INFILLWALL -$file $filename -file_infill $filenameinf -global_gravaxis $globgrav -checknodes $nodebot $nodemid $nodetop

recorder Collapse -ele $ele2 -time -crit INFILLWALL -$file $filename -file_infill $filenameinf -global_gravaxis $globgrav -checknodes $nodebot $nodemid $nodetop

recorder Collapse -ele $ele1 $ele2 -node $nodemid

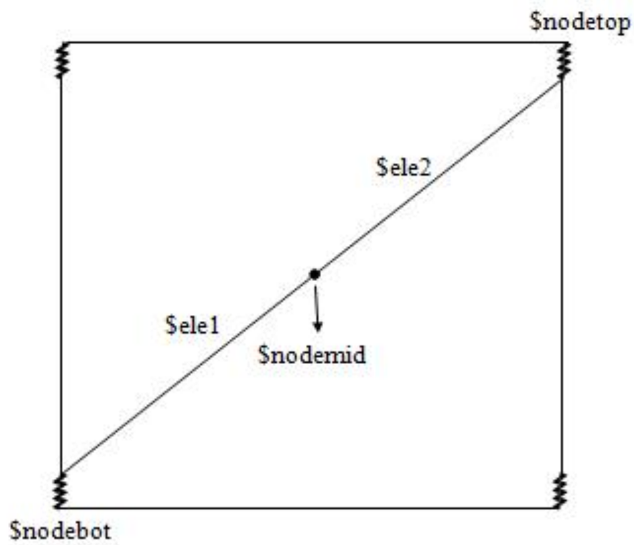

Figure 3: Description of the arguments needed for the Collapse recorder algorithm

Three collapse recorders whose syntax is mentioned above, are needed for the consideration of the removal of an infill wall. These collapse recorders should be defined individually for each infill wall that the user would like to be considered for removal. Figure 3 illustrates the modelled infill wall panel and the arguments for the element removal algorithm.

- **$ele1, $ele2, $nodebot, $nodemid, and $nodetop** are respectively the two beam-column elements, spanning from the bottom left panel node to the upper right panel node and joined by a midspan node. Element objects store the identities of their associated Node objects in the data structures of OpenSees.
- **$filename** is the file name for element removal log. Only one log file is constructed for all collapse recorder commands (i.e. for all removals). The first file name input to a collapse recorder command is used and any subsequent file names are ignored.
- **$filenameinf** is the file used to input the displacement interaction curve. Two columns of data are input in this file where only positive values are input. First column is the OOP displacement in ascending order and second column is the corresponding IP displacement. Full interaction should be defined. In other words, first value of OOP displacement and last value of IP displacement should be zero.
- **–crit INFILLWALL** is used to state that the removal is for the infill wall, because there will be options for removal of other elements in the next versions of OpenSees Tcl as stated by Mosalam et al.
- **$globgrav** is the global axis of the model in the direction of gravity. 1, 2 and 3 should be input for X, Y and Z axes, respectively.

<u>NOTE:</u> it might seem that node inputs are unnecessary. However, when there are shear springs in the model, $nodetop and $nodebot should be the nodes of the springs which connect to the beams, since the shear spring deformation contributes to the IP displacement of the infill wall. These nodes are not the nodes of the diagonal element. Therefore, it is necessary to input these nodes.

References

1. Talaat, M. and Mosalam, K.M. (2008), “Computational Modeling of Progressive Collapse in Reinforced Concrete Frame Structures”, *Pacific Earthquake Engineering Research Center*, PEER 2007/10.

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