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The Behaviour of Hinges in Buildings Over Various Monitored Displacement - Pushover Analysis

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***Abstract*- Before, most of the existing multi-storey building was designed only for gravity load. Later only linear analysis considering the design was adopted. But linear analysis results with reduced displacement and greater base force were obtained only up to the yield point. We must adopt nonlinear analysis, such as pushover analysis, to predict results beyond the yield point. In the case of pushover analysis, results beyond the yield point are also obtained. The nonlinear analysis gives a clear picture of different failure stages of the building before yield and also at collapse. The results of base force corresponding to displacement with hinges formed at various failure states such as A-B, B-IO, IO-LS, and LS-CP state is obtained. It also gives results of Demand. In the present problem, a 10 storey 5x5 bay structure is nominated. The building is subjected to pushover analysis and pushed for various monitored displacements starting from 0.1m to 4.0m. The formation of hinges at various failure states notes the variations occurring in the performance of the building. Observing the outcome gives an idea to adopt retrofitting technique or not.**

***Index Terms*— Linear analysis, Nonlinear Pushover analysis, Hinges.**

I. INTRODUCTION

Practically speaking, existing buildings resist force beyond the yield point also. However, this characteristic is not acknowledged in linear analysis. Further, if the building is subjected to lateral load, failure of the building takes place, which needs to be strengthened by providing LLRS or other techniques. Strengthening the building and analyzing the retrofitted building by linear analysis results in reduced displacement and greater base force up to the yield point only. To predict results beyond the yield point, nonlinear analysis such as pushover analysis should be performed where the results beyond the yield point are achieved. The pushover analysis gives a clear picture of different stages of the building before yield and at collapse (i.e., results of base force and displacement with failure states such as A-B, B-IO, IO-LS, and LS-CP state). Pushover analysis also gives results of the Demand and Capacity of the building. Observing the effect gives clarity to taking up retrofitting techniques or not.

The load distribution method to the building can be shown as uniform acceleration, which can be automatically applied. The results were obtained after analyzing the stochastic analysis. The following order of steps to perform nonlinear static pushover analysis is:

1. Generate a replica of the building
2. Name static load case
3. Describe the pushover load case
4. Outline hinge properties
5. Assign pivot properties to the frame element.(Columns and Beams)
6. Run the pushover analysis by selecting a static nonlinear load case.
7. Evaluate the pushover result.
8. If required, modify the replica of building and repeat steps 2 to 7.

The column and beam is checked for design before incorporation of nonlinear hinges. The reinforcement details of column which passes the design check for gravity load and the beam details with reinforcement which passes design check has to be performed first. The input required for pushover analysis is the assigned plastic hinges in case of columns as per ASCE 41-13, Table 10.8 for concrete.

Modeling parameters "a, b and c" are used to build analytical models of structure for seismic evaluation and acceptance criteria" IO, LS, CP" which provides a deformation limit below which member performance is acceptable.

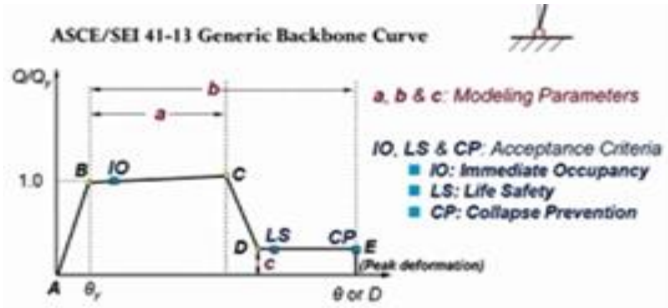

Figure 1: Load deformation backbone curve.

The curve (see Fig. 1) shows various states like elastic, yield, inelastic, and loss of lateral strength.
"a" End of life of the column is the axial collapse of the column.
" b" It is modelling parameter
" c" Residual strength ratio
The plastic rotation angle in the case of IO-LS, LS-CP and CP-C state with modelling parameters is as below.
Plastic rotation angle in radians

0.005 - a	IO - 0.002
0.005 -b	LS - 0.004
0.0 -c	CP - 0.005

Further modelling parameters in Reinforced concrete Beams can be referred to in standard ASCE 41-13 Table 10.7. In the present case, the analysis takes the modelling parameter as below. Plastic rotation angle in radians

0.025 -a	IO -0.010
0.05 -b	LS -0.025
0.2 -c	CP - 0.05

The following is the output obtained by performing a nonlinear analysis. We get to know the
Capacity: The structural capacity is known by the pushover curve. It shows the capacity of the structure to tolerate the lateral force. It denotes the ultimate strength of the structure in bending, shear and axial loading. The pushover curve is obtained by plotting base shear and roof displacement. It usually represents the first mode response of the structure. It is a process of pushing the building horizontally until it reaches a collapsed state. Each increment in loading is a separate analysis which starts from zero initial condition—continuing this increment until the structure deforms and reaches a condition where it cannot take gravity load. It shows the maximum load and displacement capacity of the building.

Demand: It is the deformation or displacement which the building will be expected to undergo. Simply put, it is the shaking of the building due to ground motion caused by the earthquake. The shaking is observed due to the presence of damping in the building. In the Response spectrum method, the response of the building is mapped based on 5% damping for acceleration v/s time period, which is different for different types of soil as it mainly depends on the ground shaking.

Pushover Capacity curve: Nonlinear force deformation relationship for structural elements for static load nonlinear analysis in the form pushed to specified monitored displacement. Component behaviour is expressed in the form of line segments. The segments describe the linear response from A after E.
Yield Point: We can find the yield point by performing a pushover analysis. After the point of yielding or failure, the global structure starts experiencing inelastic deformation.

ATC 40 Capacity Demand: Performance point: It is the maximum allowable damage to the structural and nonstructural components within acceptable limits where the building shows performance (i.e., resistance and strength for the corresponding displacement) at a specified level of earthquake occurrence. If the structure tolerates the deformation, then capacity should meet Demand. The magnitude where Capacity and Demand meets is the performance point where the maximum base shear is obtained for the corresponding max—displacement at a specified period for the corresponding ground acceleration.

Acceptance criteria: It is the performance of the building within acceptable limits of deformation and rotation of hinges. There is a acceptable limit for each stage of failure (Immediate Occupancy, Life Safety, Collapse). This is obtained by the building's deformed shape, which shows hinge formation with different colours at the column and beam ends. The performance of the building is observed for various pushes applied on the building specifying the monitored displacement starting from 0.1m, 0.3m, 0.5m up to 1m. This is performed to notice the failure in the building and to observe whether the performance of the building is within the life safety stage.

II. METHODOLOGY

Column details: The Column chosen is of size 500x500mm with M25 grade of concrete and Fe 415 steel, with a cover of 40mm and 4 16 mm dia bars in X direction and 3 16 mm dia bars in Y direction.

Beam details: The Beam selected for analysis is a rectangular Beam of 600 x 300 mm dimension with M20 concrete and Fe 250 steel for the top 4 floors and M25 concrete and Fe 415 steel for the first to the sixth floor
In the beam case, plastic hinges are assigned as per ASCE 41-13, Table 10.7 for concrete beams with M3 degree of freedom, and transverse reinforcement as confining to deformation controlled hinge and load carrying capacity, which drops after point E.
Totally 1920 hinges are assigned on both sides of the Column and Beam at a distance of 0.05m and 0.95m. The beam and column are checked for design check and found to pass for gravity load. The hinge formation is checked for each monitored displacement given until it reaches all stages of failure as per the load deformation backbone curve shown in Fig.2.

Figure 2: Backbone curve.

III. RESULTS OBTAINED

Pushover Capacity curve- for the monitored displacement of 0.1m. As shown in Fig. 3, all the hinges (1920 number) lie in A-B, which is in range at the last step is 0.10m, and the base reaction is 13869.51kN.

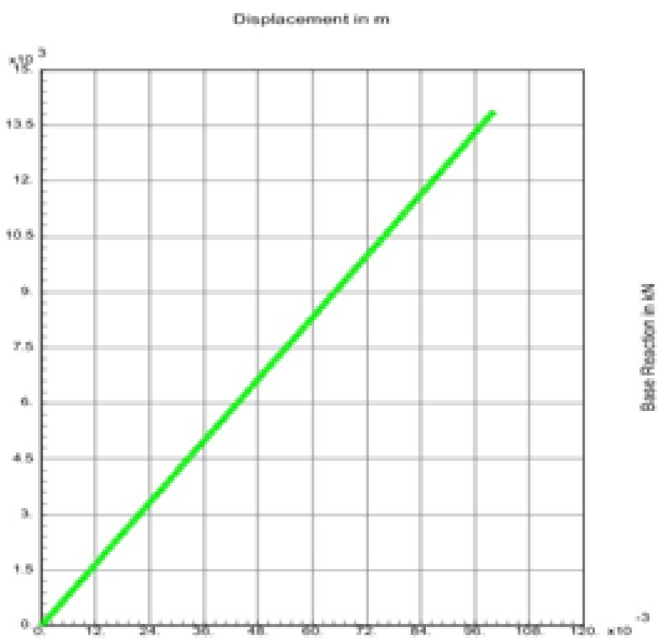

Figure 3: Block diagram of the project.

At the performance point, the values obtained are shown below for Base reaction, Demand, effective period and damping in Fig. 3.

$$\text{Global Stiffness} - \frac{\text{Base shear } (3695.52)}{\text{Displacement } (0.027)} = 136851.852$$

$$\text{Safety ratio} = \frac{\text{Base shear } (13869.214)}{\text{Base shear (ESLM) } (9183.241)} = 1.51 > 1 \text{ Safe}$$

$$\text{Ductility ratio} = \frac{\text{Yield Displacement } (0.000153)}{\text{Max Displacement } (0.10003)}$$

Acceptance Criteria: - 0.1m monitored displacement

Hinge result in Beam: Below Fig. 4, displays Beam number 361 details subjected to M3 Degree of freedom. It is observed that there is no hinge formation in the structure, and no hinge rotation is observed.

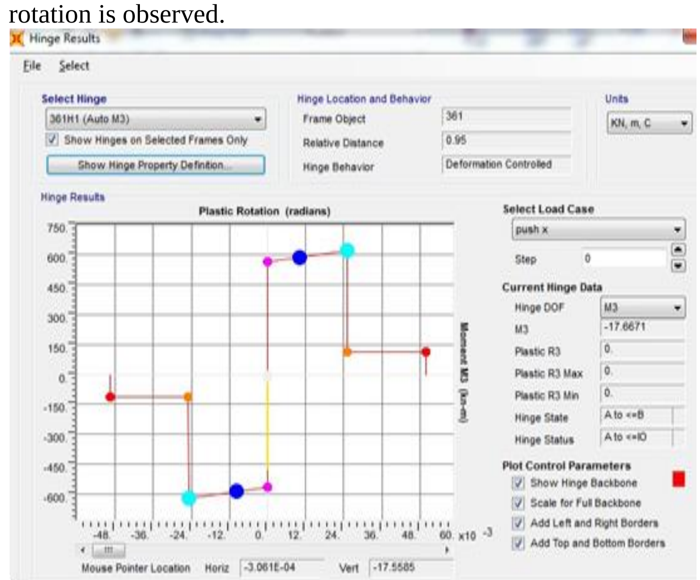

Figure 4: Block diagram of the frame.

Hinge result in Column: Fig. 5 shows the results of Column no.1, which is subjected to PM2M3 degree of freedom. It's observed that as there is no hinge formation in the structure, hence there is no rotation of hinges observed.

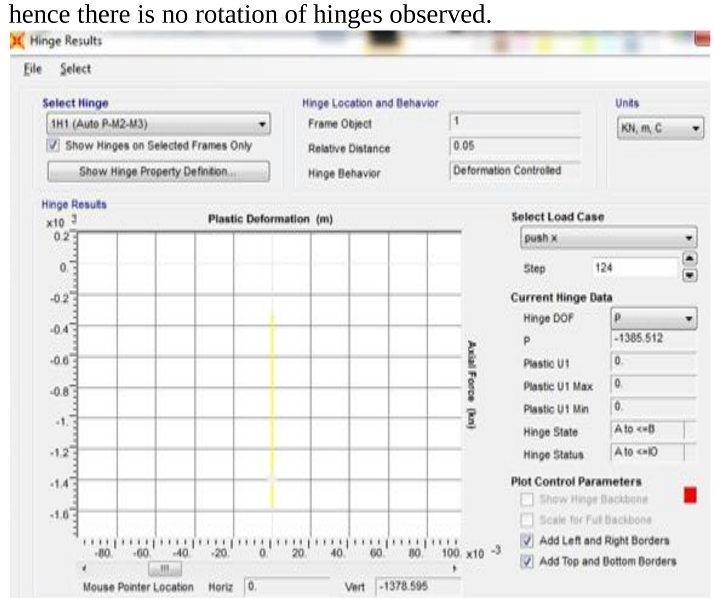

Figure 5: Arduino board.

It shows details of the Pushover Capacity Curve- for the monitored displacement of 0.3m. It is observed that from step o to step 308, the hinges lie in A-B (elastic limit state). At Step 71, the curve shows the performance point where the displacement is 0.27m and the Base reaction is 3692.758kN. (In this case, also zero hinge formation is observed) The performance point is achieved within the Elastic limit. The hinge formation is observed in the B-IO failure state with 4 hinges at step 309 and step 441. Hinge formation is noticed in the IO-LS failure state.

Further, 4 hinges are observed in LS-CP state at step 501 and zero hinges at step 524 CP-C state. Later, 6 hinges are observed in C-D state at step 525. Finally, 94 hinges occur at step 800 in C-D state where the displacement noticed is 0.3m and the Base reaction is 23019.527kN. There is also a sudden decrease in Base reaction at step 717 with 74 hinges in the C-D state. It can be said that the hinges lie in the linear state of A-B up to step 308. In between, there is a change in the magnitude of axial hinges from compression to tension state. At step 414 the hinges change to B-C state, i.e., from immediate occupancy to life safety state. Further, at step 525, the hinge shifts to C-D, reaching a state greater than collapse se Fig. 6.

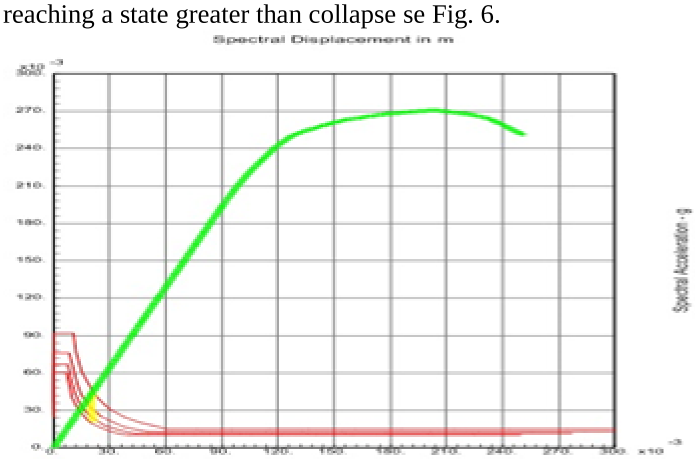

Figure 6: Demand - Capacity curve.

At step 71 the capacity is equal to Demand, and at this point, the performance point is obtained where the magnitude of Capacity and Demand of the building is the same. Further, at step 794 the Spectral acceleration capacity suddenly decreases. The result shows that damping increases, and there is a gradual change in spectral acceleration as the period increases.

Column no 1 with the assigned degree of freedom (PM2M3) or the hinges shows no rotation in the case of axial load 'P', whereas the rotation is seen in the case of moments (M2 and M3). The hinges reach beyond the acceptable limit, and the rotation reaches a failure state of collapse in case of the moment 'M3 '. As per Table 10.8 of ACSE 41-13, the acceptable limit in case of collapse is 0.0252. Whereas in the present problem for a monitored displacement of 0.3m 'M3'reaches beyond 0.252, the curve crosses beyond the backbone curve see Fig. 7.

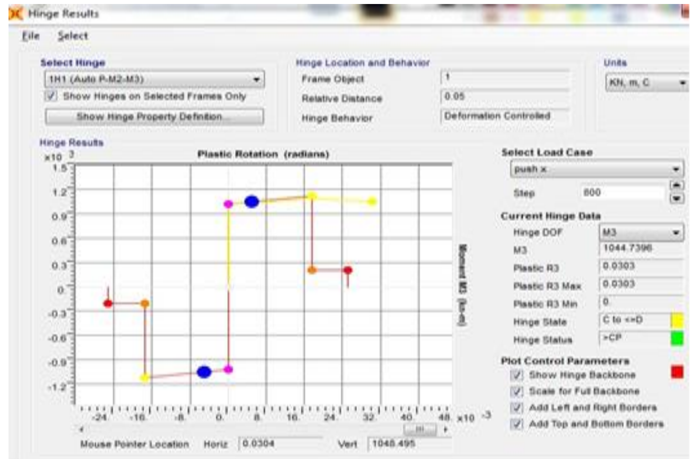

Figure 7: M3 hinge in Column 1.

The same is the case of the moment 'M2' see Fig. 8. The rotation of the hinges lies within the acceptable limit as given in ASCE 41-13 standards. It's observed that there is no hinge formation in the case of axial load' P.'

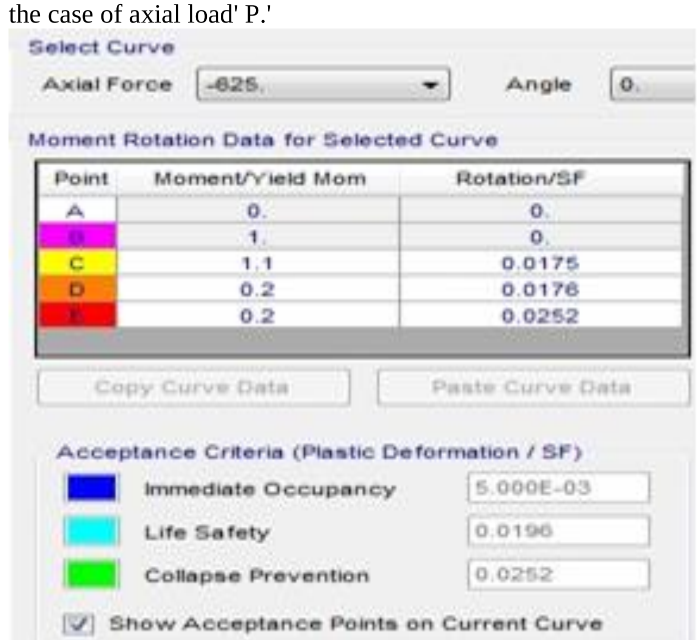

Figure 8: Acceptance limit of Column1 (PM2M3).

Moment (M3) in BEAM 361

In the case of Beam no. 361, Fig. 8 shows that the beam lies within the acceptable limit in the IO-LS state (i.e., 0.025 as per ASCE41-13). Also, as observed, the hinges are in A-B state up to step 312. From step 313 the hinges change to IO to LS state. The rotation of hinges is noticed from step 796, which is noticed from the result that the rotation lies within the acceptable limit.

Deformed shape of structure: As seen in Fig. 9 the structure is deformed as there is hinge formation at base of the building at step 795 indicated by blue color which shows that the building has reached C-D state. Also the pushover curve is not linear.

The behaviour of hinges in frames for - 0.5m monitored displacement.

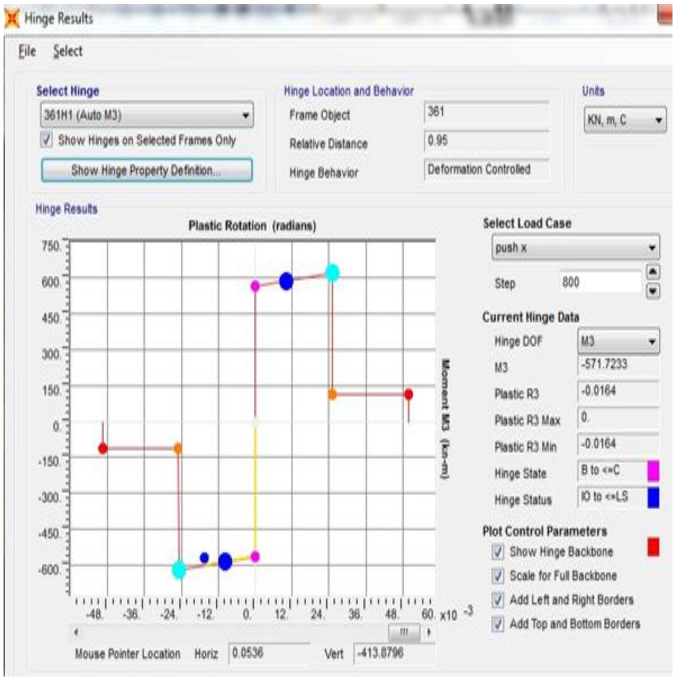

Figure 9: Acceptance limit of Beam 361 (M3).

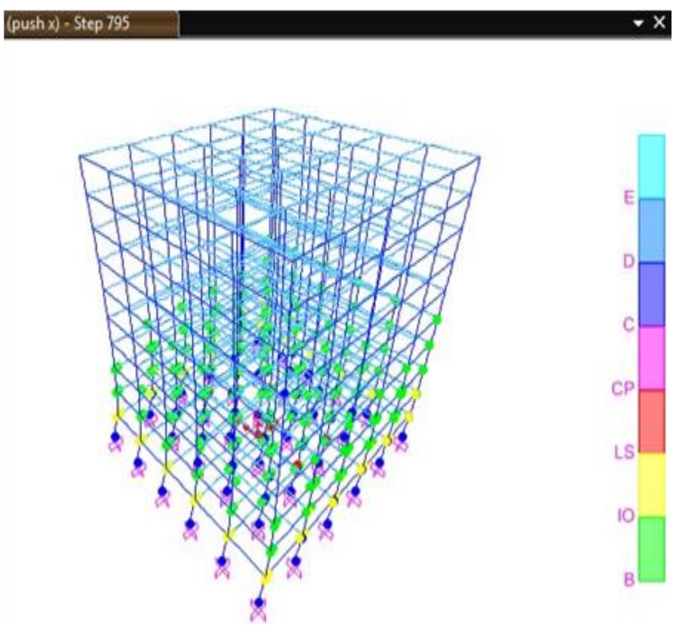

Figure 9: Deformed Shape.

Column acceptance criteria: Column no 1 with an assigned degree of freedom (PM2M3) or the hinges shows the Axial load 'P' with no rotation. At the same time, the process is seen in moments (M2 and M3). The M3 hinges reach beyond the acceptable limit 0.0252 (see Fig. 9), and the rotation of the hinges reaches a failure stage of collapse. This might be the reason why the curve crosses beyond the Backbone curve.

In the case of M2 the rotation of hinges lies within the acceptable limit (see Fig. 10); hence there is no hinge formation in the case of axial load 'P'.

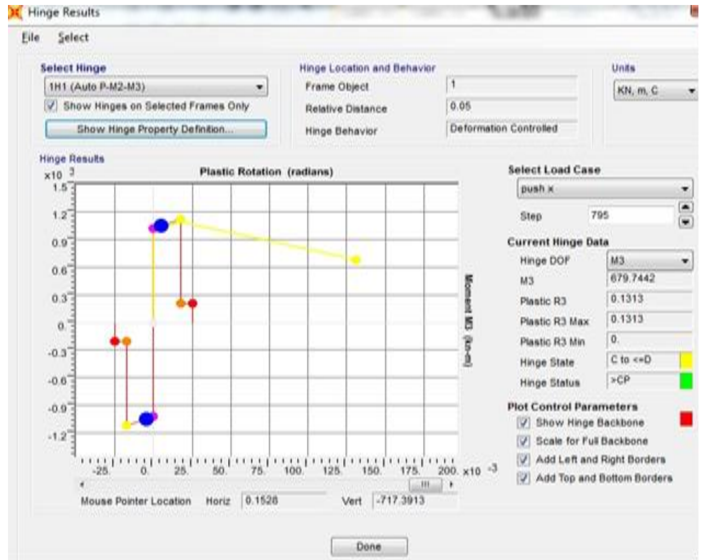

Figure 10: Acceptance criteria for Column (M3).

Beam acceptance criteria: Moment (M3): The Beam lies within the acceptable limit in the IO-LS state (0.025 as per ASCE 41-13). The hinges are in the state of A-B up to step 187. From step 188 the hinges change to IO-LS state. The rotation of hinges starts from step 340, which lies within acceptable limits see Fig. 11.

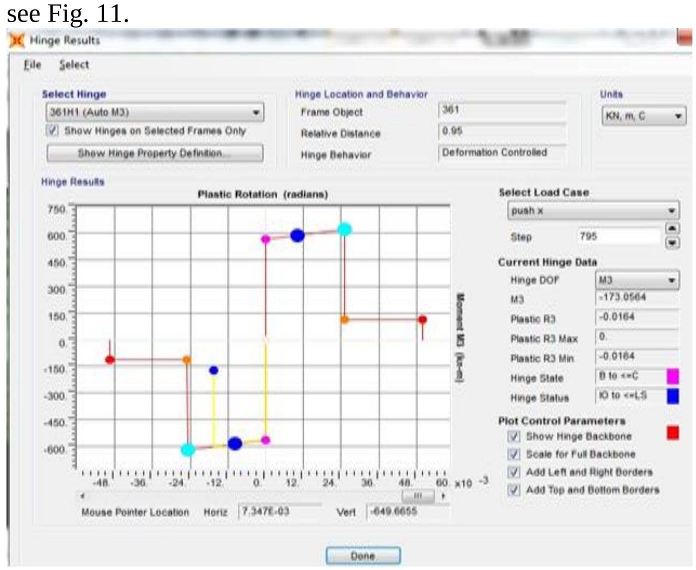

Figure 11: Acceptance criteria for Beam (M3).

IV. CONCLUSION

The performance-based seismic design allows engineers to design buildings with additional expected and dependable performance when subjected to earthquake ground motions.

It allows the building owner to quantify the expected risk (financial or otherwise) to their buildings so they can select the level of performance that meets their needs while maintaining a basic level of safety. For monitored displacement of 0.1m, the structure remains in an elastic state with zero hinge formation in each failure stage. As the monitored displacement increases for the max base force, the displacement remains almost the same. The hinge formation shifts from elastic to nonlinear C-D (elastoplastic state). The maximum displacement reached is the same as the monitored displacement up to 0.5m later. It's observed that as the monitored displacement increases, the displacement doesn't reach the applied monitored displacement level, showing a decrease in base force. The study shows the importance of taking up nonlinear pushover analysis.

FUNDING STATEMENT

The authors declare they have no conflicts of interest to report regarding the present study.

CONFLICT OF INTEREST

The Authors declare that they have no conflicts of interest to report regarding the present study.

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