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Pushover Analysis of an OMRF Building Located in Dhaka

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Pushover Analysis of an OMRF Building Located in Dhaka

Soumya Suhreed Das [α], Sudipta Roy [σ] & AdhoraTahsin [ρ]

Abstract- Tall and highrise buildings located in seismically vulnerable zones usually need to go through seismic evaluation to check its resilience against cyclic loading produced due to surface waves created by earthquakes. Large seismic waves create undulations in soils which drastically reduces the strength of foundations and ordinary moment resisting frames and the following aftershocks accelerate crack propagation of structural systems and dynamic overloading, leading to a heavy toll on lives. To protect buildings in dynamically active zones, moment resisting frames need seismic detailing alongside seismic testing. These paper deals with nonlinear dynamic analysis(pushover techniques) on a highrise building located in Dhaka city which was originally designed as a simple moment resisting frame, and necessary optimization of structural elements to improve its function against dynamic loading using the help from the BNBC code and the ETABS software.

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I. Introduction

Pushover is a static-nonlinear analysis method where a structure is subjected to gravity loading and a monotonic displacement-controlled lateral load pattern which continuously increases through elastic and inelastic behaviour until an ultimate condition is reached. Federal Emergency Management Agency (FEMA) and Applied Technical Council (ATC) are two agencies which formulated and studied nonlinear static/pushover analysis under seismic rehabilitation and protection guidelines, which followed documents FEMA 356 and ATC-40. Lots of researches have been made on this topic, and still numerous software are being developed every day for dynamic modelling of more complex structures. Dynamic analysis helps assess a structures' vulnerability against different site soil characteristics, and categorizes a moment resisting frame as ordinary, intermediate and special. Special moment resisting frame needs ductile reinforcing to be able to absorb more seismic shocks. Pushover techniques are almost similar to time history analysis which provides the structural dynamic response with time and it is different from the response spectrum analysis which is linear dynamic statistical analysis method measuring the contribution from each natural mode of vibration to indicate the likely maximum seismic response of an essentially elastic structure. Response-spectrum analysis provides insight into dynamic behaviour by measuring pseudo-spectral acceleration, velocity, or displacement as a function of structural period for a given time history and level of damping. It is practical to envelop response spectra such that a smooth curve represents the peak response for each realization of structural period. But unlike these two methods, nonlinear dynamic pushover is way better in analysing the actual behaviour of structures.

There are mainly two methods of this analysis- Displacement Coefficient and Capacity spectrum. BNBC equivalent static force is limited for structures having heights less than 20metres, which is not so rigorous in case of Pushover analysis. K. chopra and K. Goel [2] commented that MPA procedure with rigorous nonlinear response history analysis (RHA) demonstrates that the approximate procedure provides good estimates of floor displacements and story drifts, and identifies locations of most plastic hinges. However, regarding story drift, they concluded that all pushover analysis procedures considered do not seem to compute to acceptable accuracy local response quantities, such as hinge plastic rotations. Thus the present trend of comparing computed hinge plastic rotations against rotation limits established in FEMA-273 to judge structural performance does not seem prudent. R. Shahrin and T. Hossain[3] used masonry infilled walls for seismic performance evaluation against bare frame walls and found out that the former performed better in Pushover.

II. Analysis Works

To perform pushover a highrise building located at Niketan, Dhaka is chosen as a test subject. The test site soil was in S2 condition (a soil profile with dense and stiff soil condition where soil depth exceeds 61 metres). Normally, according to BNBC 2006 and ASCE code requirements, these soils are seismically efficient to absorb and control structural vibrations. Buildings built on these systems are seismically sufficient for a certain degree of shaking, if recurring earthquakes possess a magnitude more than richter scale 6.0 then seismic detailing and pushover analysis are required.

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According to BNBC 2014 article 2.5.14, For regular structures with independent orthogonal seismic-force-resisting systems, independent two-dimensional models may be used to represent each system. For structures having plan irregularities or structures without independent orthogonal systems, a three-dimensional model incorporating a minimum of three degrees of freedom for each level of the structure, consisting of translation in two orthogonal plan directions and torsional rotation about the vertical axis, shall be used. Where the diaphragms are not rigid compared to the vertical elements of the seismic-force-resisting system, the model should include representation of the diaphragm flexibility.

The lateral forces shall be applied at the mass center of each level(control point) and shall be proportional to the distribution obtained from a modal analysis for fundamental mode of response in the considered direction, and the lateral loads shall be increased incrementally in a monotonic manner. The analysis will be continued until the displacement of the control point is at least 150% of the target displacement. A bilinear curve shall be fitted to the capacity curve, such that the first segment of the bilinear curve coincides with the capacity curve at 60% of the effective yield strength, the second segment coincides with the capacity curve at the target displacement, and the area under the bilinear curve equals the area under the capacity curve, between the origin and the target displacement. The effective fundamental period and target displacement shall be expressed as-

$$T_e = T_1 \sqrt{\frac{V_1/\delta_1}{V_y/\delta_y}}$$

$$\delta_T = C_0 C_1 S_a \left(\frac{T_e}{2\pi}\right)^2 g$$

Where V1, δ1, T1 are determined for the first increment of lateral load. And spectral aceleration as well as coffiecient shall be calculated accordingly.

According to FEMA 356[4] seismic performance levels, structural response in divided into several categories: Immediate occupancy(IO), Life Safety(LS), Collapse Prevention(CP). When structure is at IO level, this level is without any damage(although some cracks might be seen near slab-column connection or drop panel location, minor cracking in columns-not visible). When the structure is at LS level, slabs sustain extensive cracking at connections (at drop panels), and flexure cracking is seen at the top of column which may necessitate retrofitting. And the final stage, CP causes extensive damage in diaphragms, and top of columns. So, for a structure to be seismically resilient, it needs to be in seismic performance level IO.

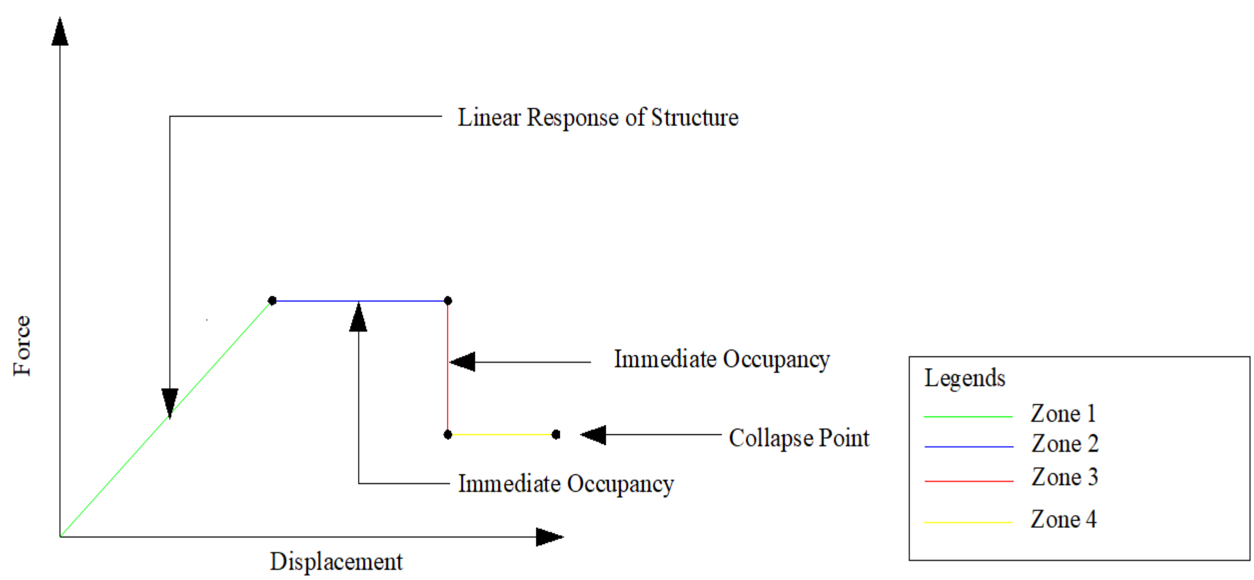

Fig. 1: Structural response curve due to dynamic loading

From force displacement curve of structural frames the following data can be found. With application of load, the dynamic response is linear upto certain point, then the structure enters the IO zone, and after that it enters the strain hardening zone and afterwards collapse. In ETABS 2015 or other versions, pushover analysis depicts these conditions in green, cyan, red and orange.

III. Plan Selection

A highrise residential apartment complex has been chosen as a model for Pushover analysis. This building is a G+10 storied building located in Mirpur, Dhaka-Bangladesh. Site soil condition is S2(strong soil upto necessary depth, also satisfactory for piling operation). Structural plan is regular with fourteen number of columns. Necessary visual information regarding terrain condition, soil profile and building structural plan have been collected from computer aided drawing.

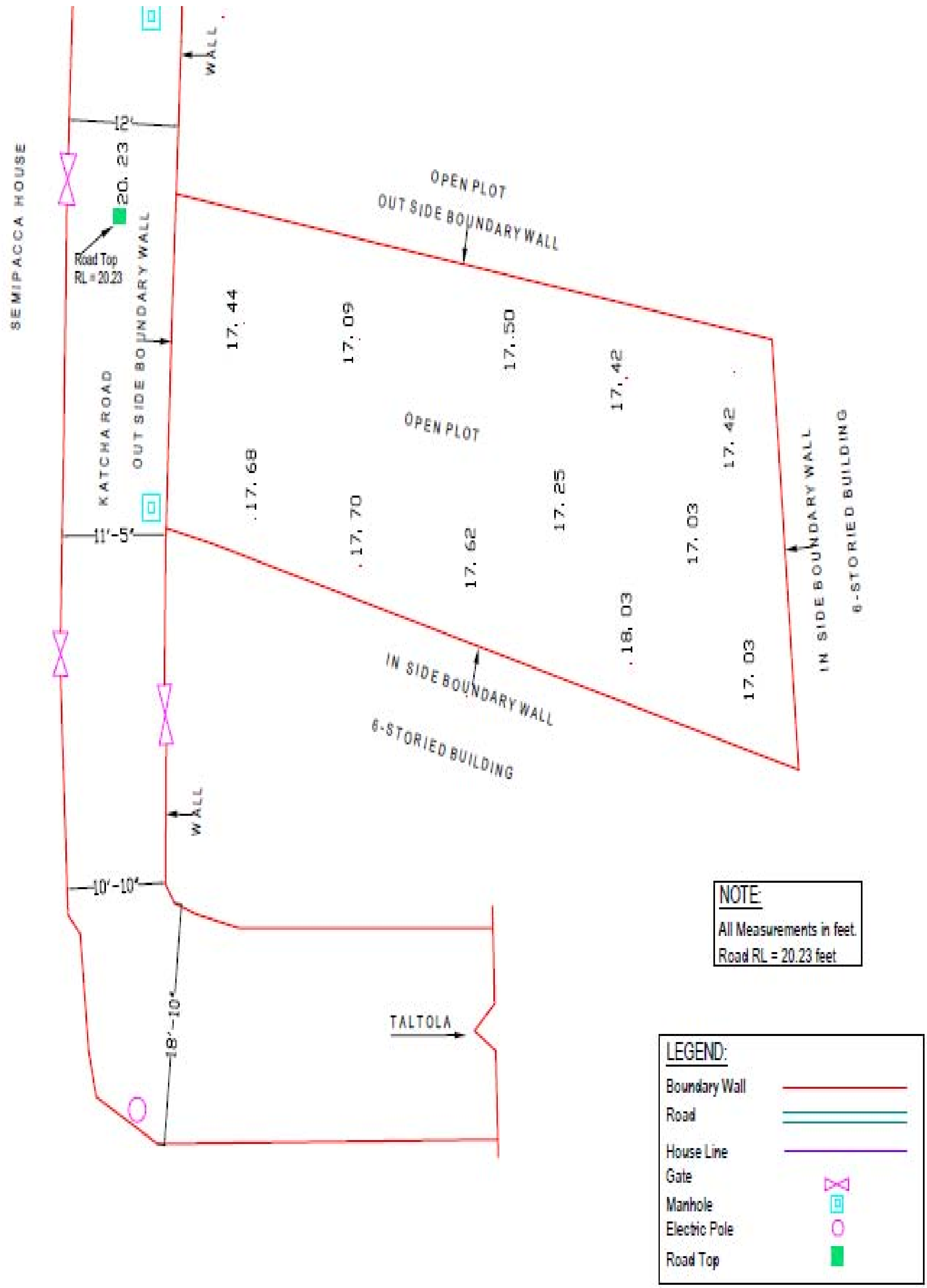

Fig. 2: Topographical map of target highrise site

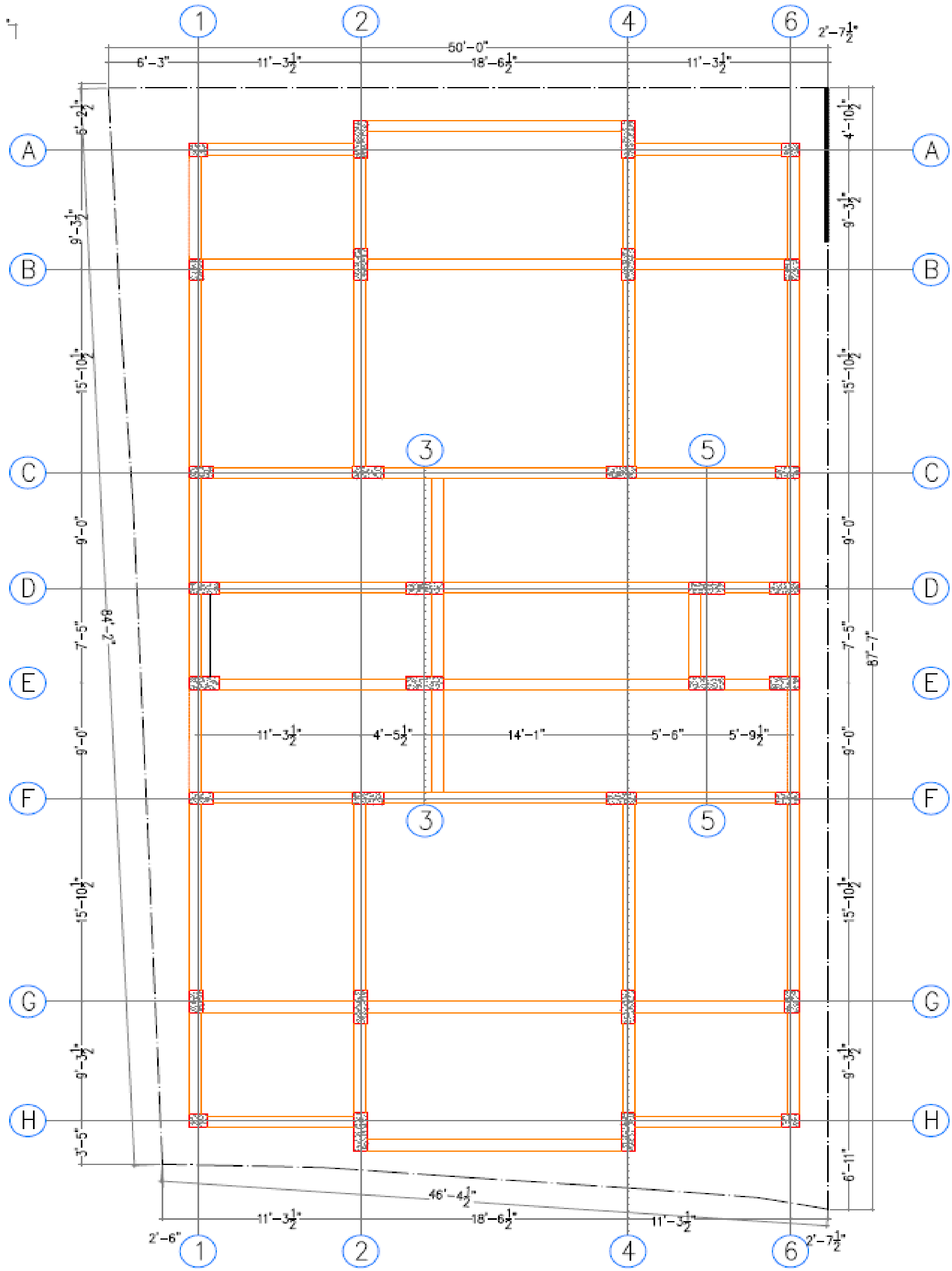

Fig. 3: Structural Drafting of Target Highrise building.

IV. Analysis Process

This target highrise building is modeled on the ETABS 2015 interface using ACI 318-14 design code. It contained a shear wall and several flights of stairs. For simplicity of the analysis no lateral wind load was calculated, so load combination became very simpler, as the frame was simple OMRF.

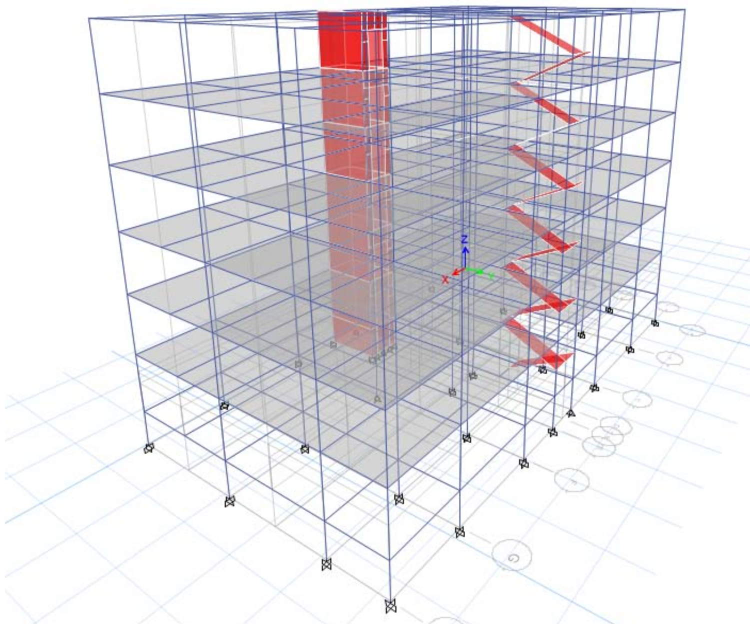

Fig. 4: 3D model of finished building in ETABS 2015 interface.

The beams were 18inches x 18inches in section(4000psi strength), columns were 15inches x 18inches(5000psi strength) and the slab contained a thickness of 6 inches. Shear wall was 7 inches thick. A few conceptual terms are described below to avoid confusion during analysis process.

Capacity: It is defined as the ultimate strength of the structural components excluding the reduction factors commonly used in design of concrete members.

Capacity Curve: Plot between base shear and roof displacement is termed as capacity/pushover curve.

Capacity Spectrum: The capacity curve transformed from base shear vs roof displacement to spectral acceleration vs spectral displacement is termed as capacity spectrum.

Capacity Spectrum method: A nonlinear static procedure that produce a graphical representation of expected seismic performance of building by intersecting capacity curve and response spectrum representation of earthquakes displacement demand on structure, the intersecting point is called performance point.

Demand: It is represented by an estimation of displacement/deformation structure is expected to undergo.

Plastic Hinges: The maximum moments occur near the ends of beams and columns, the plastic hinges are likely to form there and most ductility requirements apply near the section of the junction.

There are mainly four steps for this analysis:
(a) Modeling, (b) Static Analysis, (c) Design, (d) Pushover Analysis

At first the plan was executed on ETABS 2015 interface. Earthquake and Wind forces have been introduced for static loading, and diaphragm has been initiated into the floor plan to pinpoint locations of building stiffness centre. And after the design of concrete moment resisting frame and reinforcement detailing, pushover has been introduced. The building has been shaken in X and Y direction with a maximum target displacement of 31.84 inches and capacity curves have been formed. Afterwards plastic hinges have been formed on each beam span at 0.05 and 0.95 distances(near each end portions)of beams and columns. It is to be noted that active hinge formations are important for development of yield zones in frames.

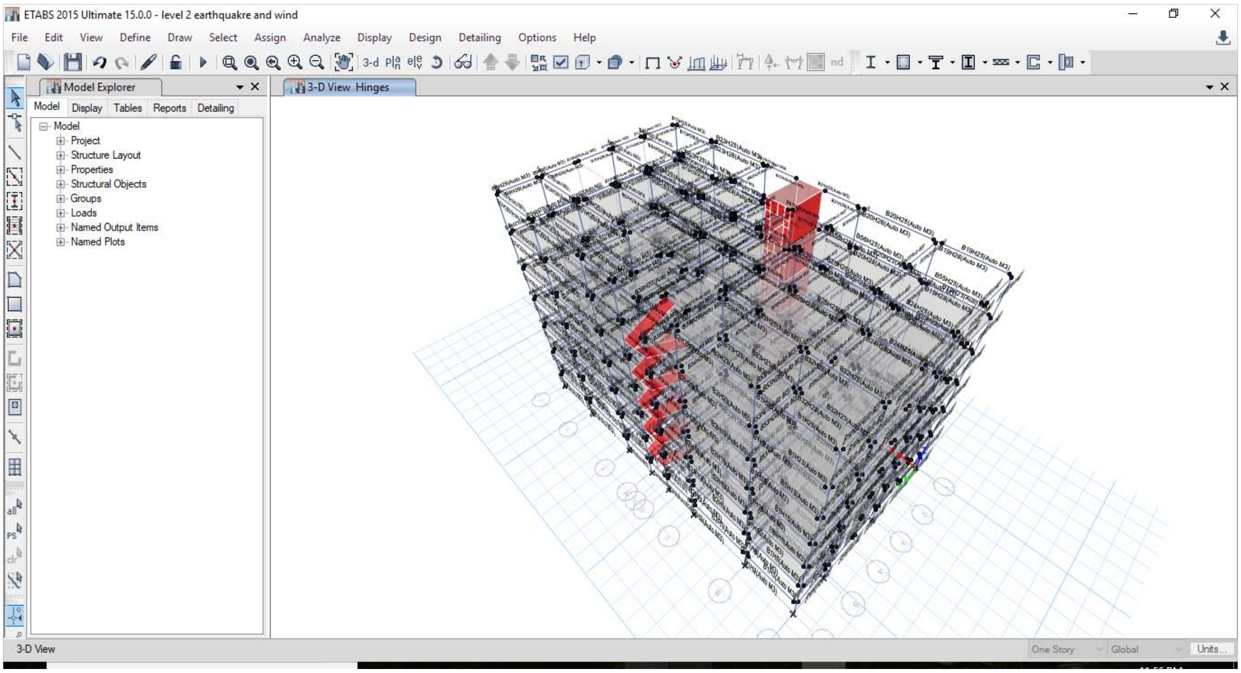

Fig. 5: Plastic hinge formation of target building.

After the analysis pushover curves and hinges are formed. As the target building did not cross the allowable displacement limit, it did not budge from LS(Life safety level-green zone of the pushover curve). Also in PushX and PushY three steps of force-displacement have been generated, showing green hinges, and proving load displacement was in linear static level.

Hinge results and capacity curves formed are below.

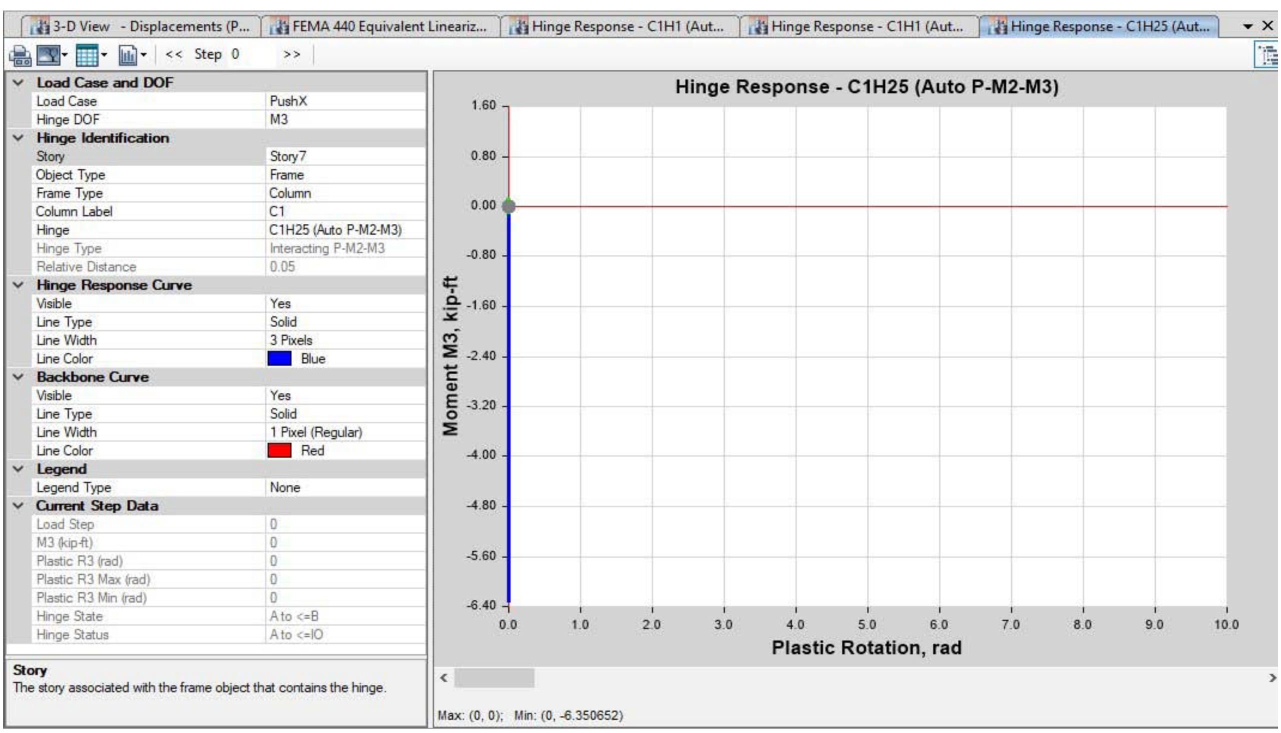

Fig. 6: Hinge response of story 7.

Similar to story 07, all other stories have been seen to be form zero rotation hinges, which subsequently indicate loading was within target level. Pushover curves have also been formed from FEMA 440 equivalent linearisation process.

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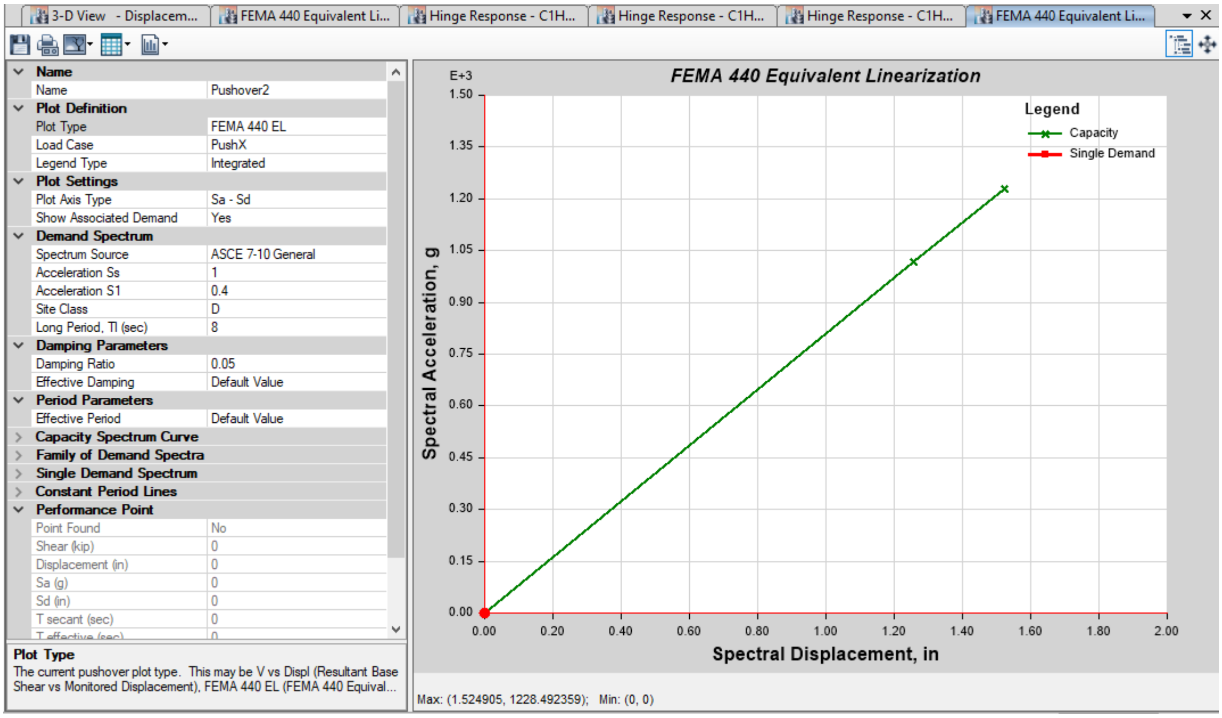

Fig. 7: Pushover capacity curve for Direction X.

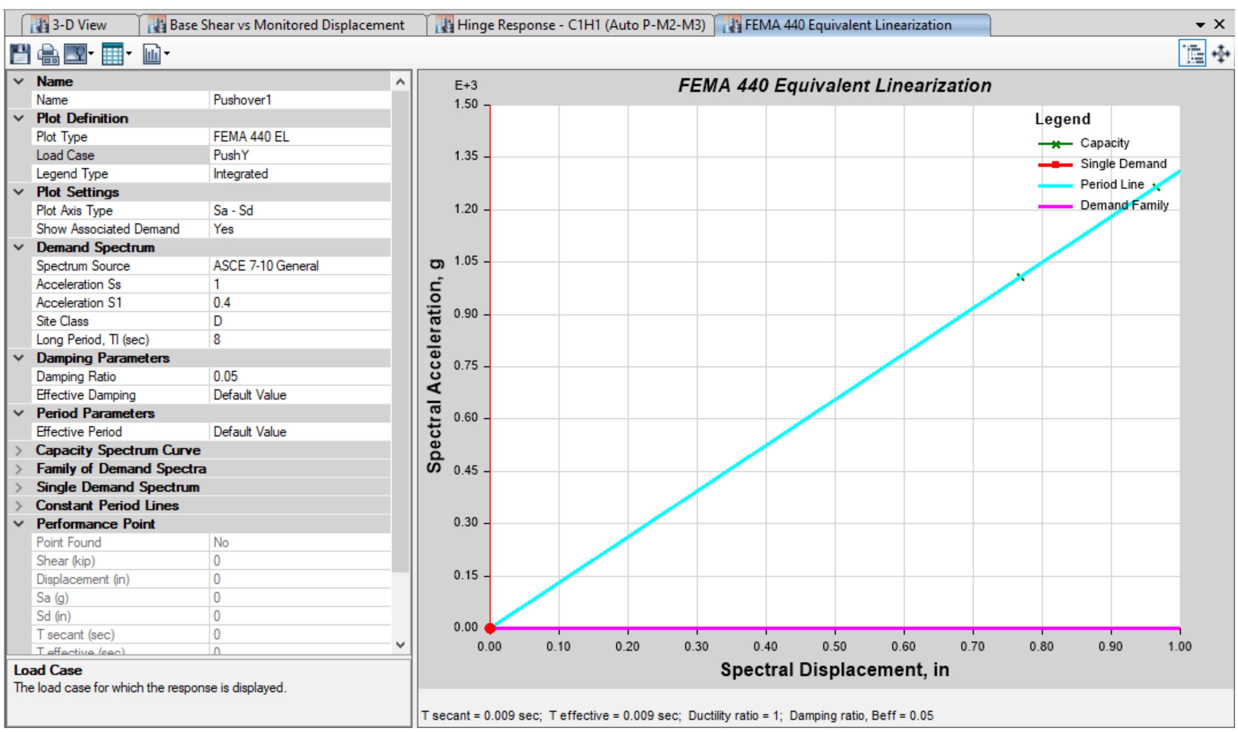

Fig. 8: Pushover capacity curve for Direction Y

V. Scope for Future Studies

This work mainly focused on static pushover of a simplified OMRF frame system which does not contain any kind of seismic detailing, but the study can be further expanded for IMRF and SMRF frames containing steel or composite frame system(framing with bearing walls). Framing systems with irregular plan systems can also be tested by this method. This article focuses on creating two or three steps on push X and Y directions which can be magnified to get a good look on the hinge formation. Finally, critical systems as flat plate slab systems can be tested to examine their behavior under seismic shaking.

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