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Seismic Performance and Strengthening of Reinforced Concrete Building with Steel Bracing

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Abstract
Nepal lies in seismically active region and Many existing structure that were built according to past design codes and standard are often found vulnerable to earthquake damage. The main objective of this paper is to briefly describe about Analytical Seismic Evaluation Technique for existing RCC Frame Building through Non-Linear Static Pushover analysis and enhancing its seismic resistant capacity by global retrofitting technique of steel bracing. A general finite element package of SAP 2000 has been used to generate three dimensional model of G+3 storey reinforced concrete building to undertake non-linear analysis provided by default hinges to capture the performance of building under design and Maximum Earthquake. After retrofitting with concentric steel bracing of ISNB 150M the seismic capacity of building enhanced from collapse state to elastic Limit for design base earthquake whereas the performance of building is beyond the acceptable limit and cannot be determined for maximum earthquake criteria under the given set of loading.

Keywords
Seismic Evaluation, RC Frame Building, SAP 2000, Pushover Analysis, Performance Point, Steel Bracing

1. Introduction

The Federal Democratic Republic of Nepal lies in one of the active continental collision zone of the world, the Himalaya, where the probability of Earthquake occurrence is very high. Earthquake causes the random ground motion in all directions, radiating from epicenter, which causes structure to vibrate due to which induce inertia forces in them. Many existing structure that were built according to past design codes and standards are often found vulnerable to earthquake damage. Due to this, there is vital requirement to converse this situation and do the seismic assessment of existing structures and propose a suitable retrofitting technique in order to make them seismically resistant.

1.1 Concept of Pushover Analysis and Plastic Hinges

Pushover 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 behavior until an ultimate condition is reached. It can help to demonstrate how progressive failure in building most probable occurs, and identify the mode of final failure. The method also predicts potential weak areas in the structure, by keeping track of the sequence of damages of each and every member in the structure.

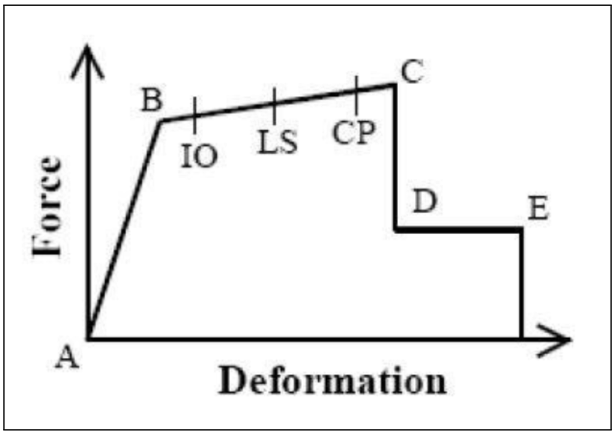

Figure 1: Force-Deformation Relation for Hinge

The decision to retrofit can be taken on the basis of such studies. Point of inelastic action of the structural member is called as Plastic hinge. In this state structural member starts loosing strength to come back in previous position. We assign hinges to Model for observing the structural behavior of sequential loss of strength in differential performance level of the structure due to seismic effect. Consequently, at each event, the structure experiences a stiffness change as shown in figure1, IO, LS, CP and stand for Immediate occupancy,life safety and collapse preventive respectively.

1.2 Retrofitting Technique

Retrofitting is technical interventions in structural system of a building that improve the resistance to earthquake by optimizing the strength, ductility and earthquake loads. Seismic retrofitting is the modification of existing/damaged structures to make them more resistant to seismic activity, ground motion or soil failure due to earthquake.

2. Objective

All structures are subjected to process of degradation with time, which leads to a situation in which they are not able to fulfill the purpose for which they were design. In many cases past built structure build with old code do not guarantee in decreasing vulnerability during earthquake. Thus, there is always a need of seismic evaluation of structure and referring a proper strengthening technique.

The main objective of this paper is to briefly describe about Analytical Seismic Evaluation Technique for existing RCC Frame Building through Non-Linear Static Pushover analysis and enhancing its seismic resistant capacity by global retrofitting technique of steel bracing. Main objective is further sub divided under following headings:

Performance Objective

- Serviceability Limit of Drift (0.004) AS Per IS 1893(Part 1) :2002.
- Performance design Level of Immediate Occupancy (IO), under seismic Event of Design Earthquake.
- Also Check the performance of sample building under seismic event of Maximum Earthquake.

3. Seismic Evaluation and Retrofitting of a case study RC Frame Building

The aim of seismic evaluation is to assess the possible seismic response of building which may be seismically deficient for earthquake damaged and for its possible future use.

3.1 Basis of Evaluation

Performance level is a limiting damage state or condition described by the physical damage within the building's occupants due to the damage and post-Earthquake serviceability of the building. A building performance level is the combination of a structural performance level and a non-structural performance level.

Description of structural performance levels (ATC 40, 1996)

Structural performance Level

Table 1: Structural performance Level

SN	performance Level	Symbol
1	Immediate occupancy	IO
2	Damage control	
3	Life safety	LS
4	Limited safety	
5	Structural Stability	SS

ATC 40 provides information about seismic coefficient to construct elastic response spectra and these are dependent on zone factor and soil profile type. Nepal lies in higher seismic zone and the soil type of Kathmandu is very soft soil, hence, Ca (Effective peak acceleration of the ground) and Cv (5 percent-damped responses of a 1 second system) values were adopted as 0.18 and 0.30 for Design Earthquake and 0.36 and 0.6 for Maximum Earthquake. (IS 1893:2000)

3.2 Assumptions and Description of Frame Structure

- The building configuration and structural details are limited as stated.
- The performance objectives fixed for the study were Immediate Occupancy performance level at DE.
- Only bare frame is taken for the analysis process. The stiffness due to the infill wall is neglected.
- Adopted design Code = As per IS 1893:2002
- Ca, Effective peak acceleration of the ground = 0.18 (Design Earthquake) 0.36 (Maximum Earthquake)
- Cv, 5 percent -damped response of a 1 second

system = 0.30 (Design Earthquake, = 0.6 (Maximum Earthquake)

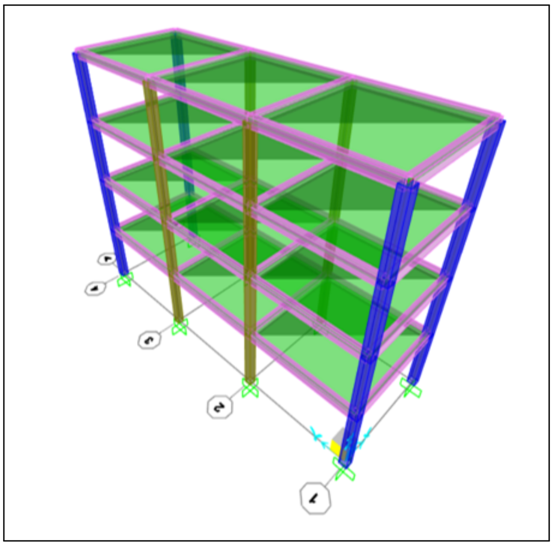

Figure 2: 3D-FEM of G+3 RC Frame in SAP 2000

Description of Reinforced Concrete Frame Structure

1. Number of Story: 4
2. Height of Each Floor: 3 m, 12m Total Height
3. Single Bay in Y-Direction and Three Bay in X-direction with 5.0 m bay spacing.
4. Functional Use: Commercial Building.
5. Live Load: 4.0 KN/m2
6. Floor Finish: 1.5 KN/m2
7. Earthquake Load: As per IS 1893(Part I)-2002
8. Concrete Grade M20, Steel is Fe500
9. Column: C1 = 300mm x 300 mm with 6 Number of 16mm diameter bars.
10. Column: C2 = 350mm x 350mm with 6 Numbers of 16mm diameter bars.
11. Beam = All Beams of 250mm x 350 mm.
12. Slab = 150mm Thick
13. Type of Soil: Type III, Soft Soil.
14. Walls: 230 mm thick brick masonry wall
15. Steel Bracing Used: ISNB 150 M

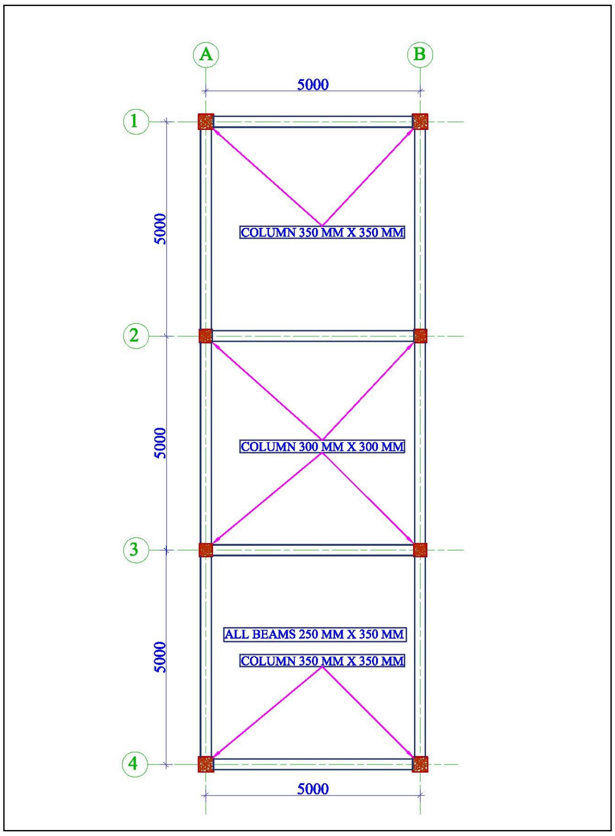

Figure 3: Plan of Building with frame Section Property

3.3 Modeling Approach

The general finite element package SAP 2000 V 21.0.2 has been used for the analysis. A three dimensional model of the structure have been created to undertake the non-linear analysis, Beams and columns are modeled as nonlinear frame elements with lumped plasticity at the start and the end of each element. SAP 2000 provide default hinges which recommends PMM hinges for columns and M3 hinges for beams as described in FEMA 356.

3.4 Pushover Analysis

After designing and detailing the reinforced concrete frame structure, a non-linear pushover analysis is carried out for evaluating the structural seismic response. The pushover analysis consists of the application of gravity loads and representative lateral loads were accelerations in x-direction and Y-direction representing the forces that would be experienced by the structures when subjected to ground shaking. Capacity Spectrum Method is used for the non-linear static analysis procedure which provides a graphical representation of the expected seismic performance of the structure by intersecting the structure's capacity spectrum with the response spectrum of the earthquake. The intersection point is called as performance point, and the displacement coordinate dp of the performance point is the estimated displacement demand on the structure for the specified level of seismic hazard.

3.5 Strengthening with Steel Bracing

Adding Steel Bracing is a structural-level approach of retrofitting which involves global modifications to the structural system. The Steel bracing system can be used for steel structures as well as concrete structures to upgrade the strength and stiffness of structure during seismic loading. Column shear failure is not specifically prevented; therefore, close attention must be given to limit drifts of the strengthened frame. X-Configuration bracing of ISNB 150M is used in periphery of frame as shown in figure.

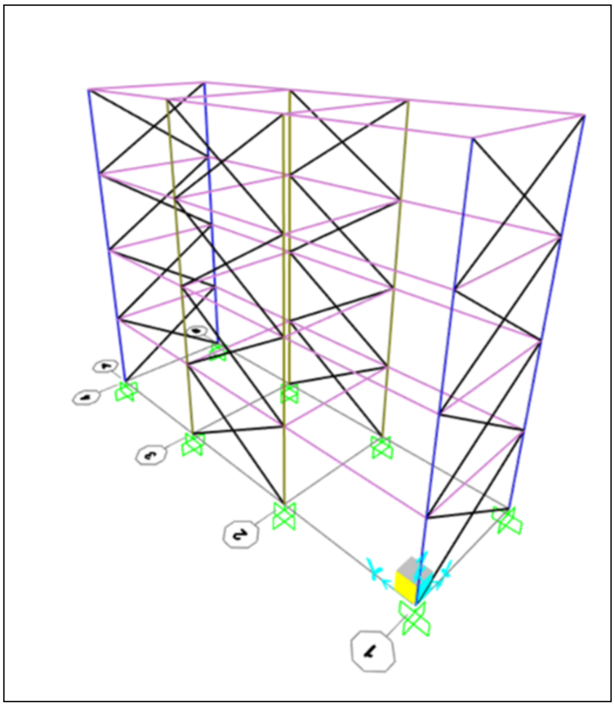

Figure 4: FE Model with Steel Bracing

4. Result and Discussion

A G+3 concrete frame building was taken to analysis for Analytical seismic evaluation. The evaluation is done in two stages, first with Static linear approach with base shear of 466.79 KN and time period of 0.48 second. In second stage evaluation is done with static Non-linear approach through Push X and Push Y.

4.1 Seismic Performance Evaluation of Existing Building

4.1.1 Storey Drift (Static Linear approach)

The storey drift ratio and roof displacement of sample G+3 building frame is 0.62 percentage and 58.41 mm determined through the static linear analysis which is greater than the permissible limit of 0.4 percentage for the relative storey drift and H/250 (48 mm) for the roof displacement as per code.

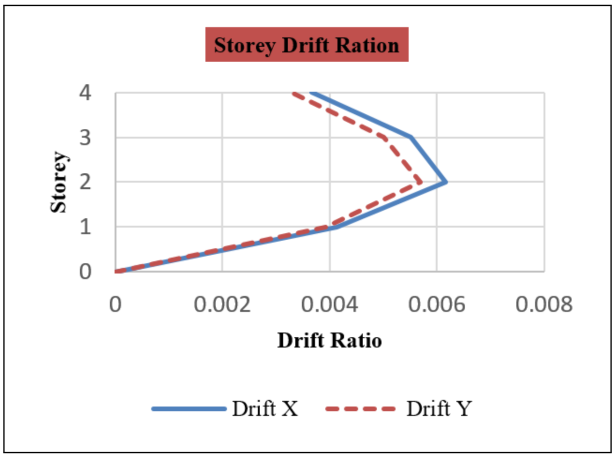

Figure 5: Storey Drift Ratio along EQX and EQY

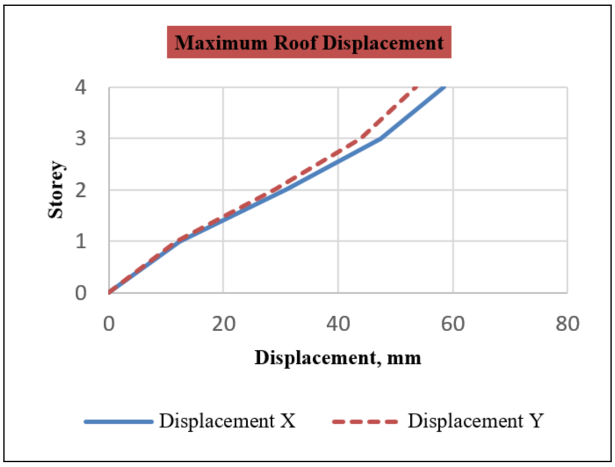

Figure 6: Maximum Roof Displacement along EQX and EQY

4.1.2 Capacity Spectrum (Design Earthquake)

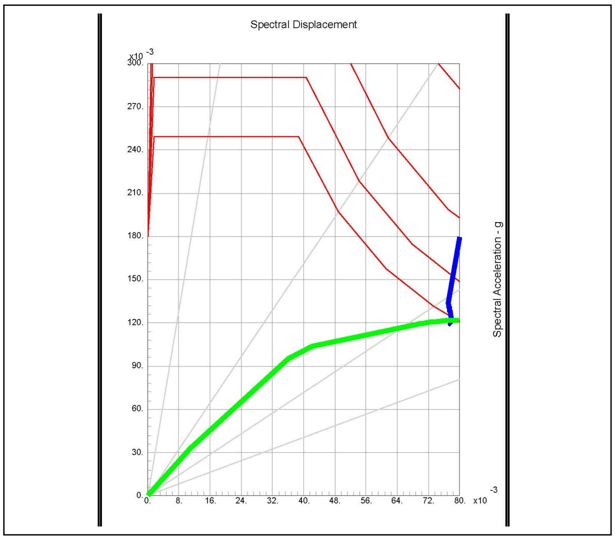

Figure 7: Sa vs Sd in push X for DBE (Performance Point: 577.019 kN, 94.042 mm)

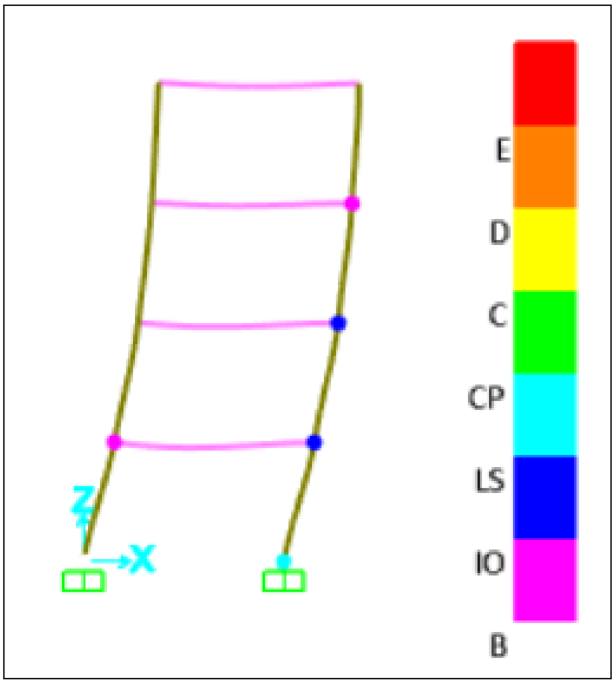

Figure 8: Plastic Hinge Formation along Push X

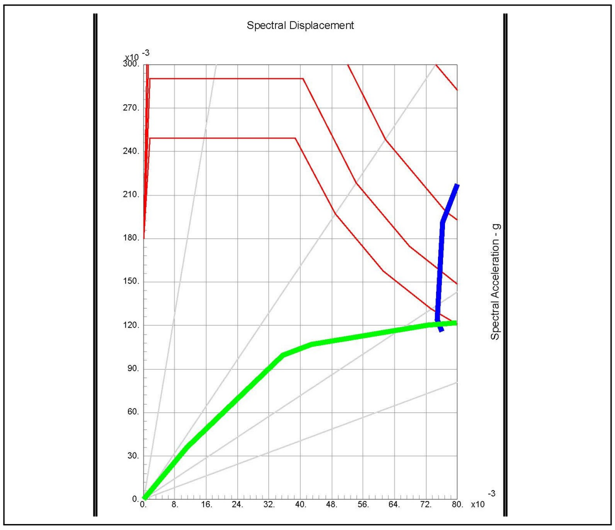

Figure 9: Sa vs Sd in push Y for DBE (Performance Point: 573.655 kN, 90.299 mm

The capacity spectrum (Pushover curve in ADRS format) of the RC G+3 Building frame was plotted against the family of demand curve for considered earthquakes for Nepal; design earthquake (Ca=0.18, Cv=0.30). At performance point, the roof displacement, base shear and time period along push X is 94.042 mm, 577.019 KN and 1.603 second while for push Y data are 90.299 mm, 573.655 KN and 1.585 second respectively.

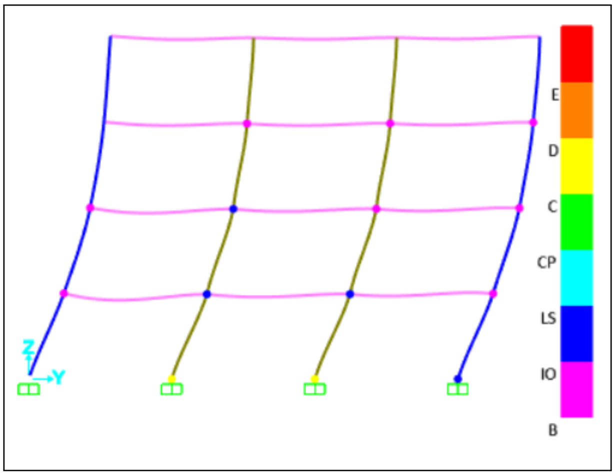

Figure 10: Plastic Hinge Formation along Push Y

The largest hinge formation at the performance point of the building models is at collapse state which is along Push Y . Hence, the result shows that the seismic performance of the G+3 building can not withstand against the design earthquake under proposed loading condition and need to be retrofitted.

4.2 Seismic Performance Evaluation after Strengthening Building with Steel Bracing ISNB 150 M

4.2.1 Storey Drift (Static Linear approach)

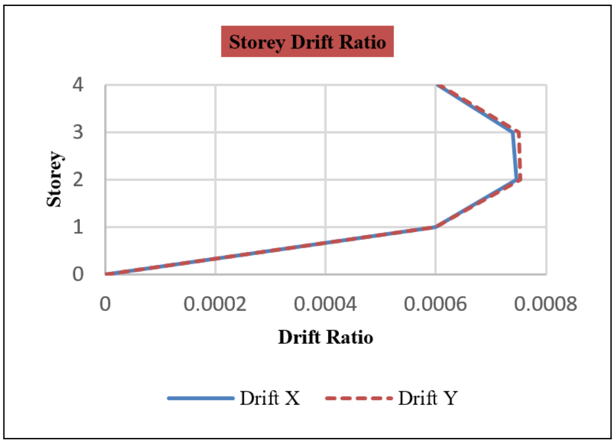

Figure 11: Storey Drift Ratio along X and Y direction after steel bracing

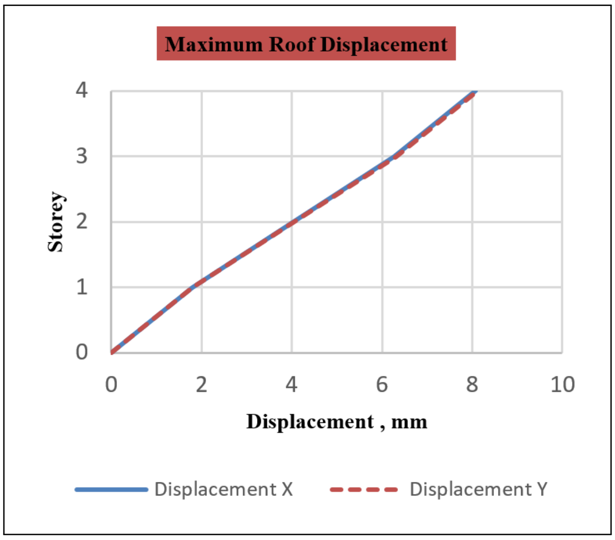

Figure 12: Maximum Roof Displacement along X and Y direction after adding steel bracing

The storey drift ratio and roof displacement determined through the static linear analysis was found to be 0.0007 and 8.13 mm after bracing the structure. These values are within the permissible value (i.e 0.4 percent for the relative storey drift and H/250 for the roof displacement as per code.)

4.2.2 Capacity Spectrum (Design Earthquake)

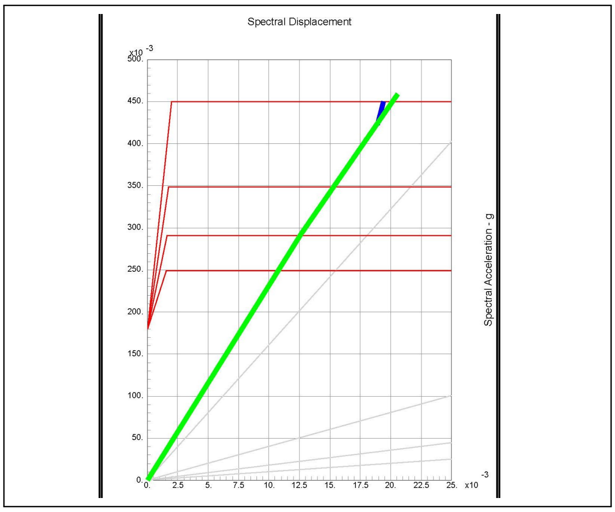

Figure 13: Sa vs Sd in push X for DBE after bracing (Performance Point: 1921.339 kN, 24.298 mm

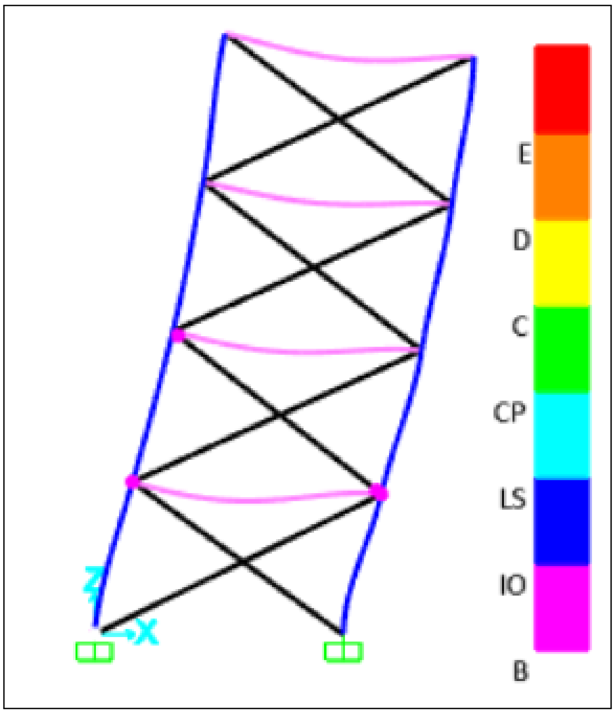

Figure 14: Plastic Hinge Formation along Push X after bracing

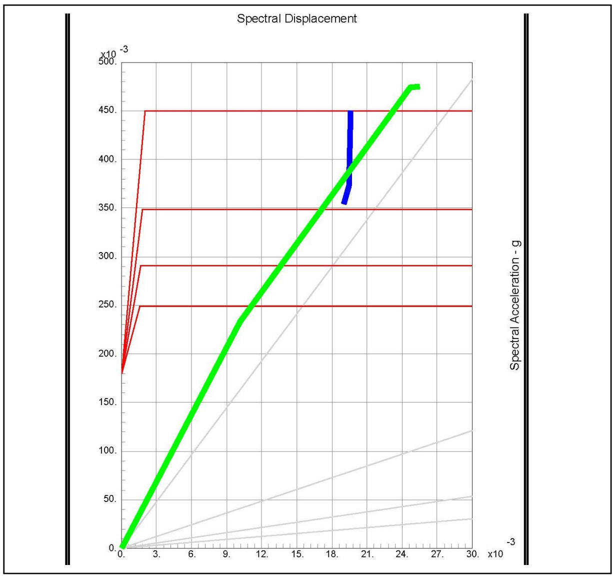

Figure 15: Sa vs Sd in push Y for DBE after bracing(Performance Point: 1778.417 kN, 24.69 mm

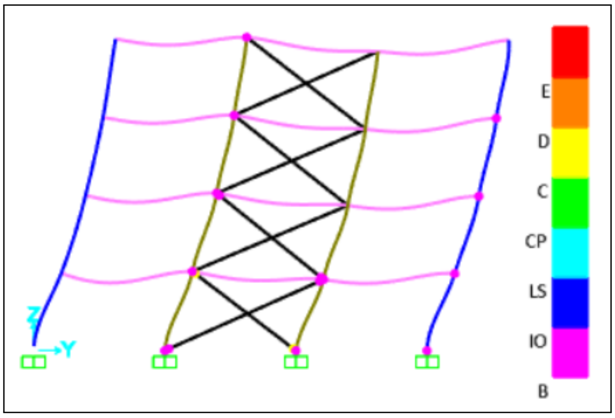

Figure 16: Plastic hinge formation along Push Y after bracing

After Strengthening, at performance point roof displacement, base shear, time period for push X is 24.298 mm, 1921.339 KN and 0.423 second while for push Y result data are is 24.69 mm,1778.417 KN and 0.444 second respectively.

The Stiffness of structure is the ratio of overall lateral force to overall displacement. From study it is clear that concentric bracing increases the stiffness of the structure which can be observe with increase in base shear value and decrease in time period by almost 3 times at performance point.

The intervention of steel bracing found to be more effective in reducing the inter-storey drift by 8 to 9 times and maximum roof displacement by 7 to 8 times.

The largest hinge formation at the performance point of the models are within elastic limit. Two Steel bracing show hinges in collapse state along push Y they do not alter our performance objective and is desirable to ensure the inelastic action under earthquake should take place in bracing members. Hence, the result shows that the seismic performance of the G+3 building can withstand against the design earthquake under proposed loading condition.

4.2.3 Capacity Spectrum (Maximum Earthquake)

The building sample is loaded for Maximum Earthquake and the capacity spectrum (Pushover curve in ADRC format) even did not interested the family of demand curve. Hence, the performance of this building is beyond the acceptable limit and cannot be determined.

5. Conclusions

Following conclusions can be drawn on the basis of seismic performance evaluation and retrofitting analysis of G+3 reinforced concrete building for design base earthquake and Maximum Earthquake in context of Nepal.

1. Analytical Seismic performance evaluation is done by static linear approach and pushover analysis with capacity spectrum method, the pushover curve were plotted, as well as the formation of the largest hinge at performance point were evaluated in both Push X and Push Y.
2. After evaluation of existing frame, the values of roof displacement and storey drift ratio were found to be beyond permissible limit and the largest hinge formation at the performance point of the building is at collapse state which is along Push Y direction.
3. The result shows that the seismic performance of the G+3 building cannot withstand against the design earthquake under proposed loading condition and need to be retrofitted.
4. After strengthening with steel bracing Performance evaluation is done again to check if the performance objective is achieved. In first stage, story drift and roof displacement were checked, and these values are well within permissible limit.
5. The largest hinge formation at the performance point of the building models is within elastic limit. Hence, the G+3 reinforced concrete

building model after adding steel bracing can withstand against design earthquake under proposed loading condition. Two steel bracing at ground floor show hinges at collapse state but do not alter the performance objective.

6. After adding concentric X type steel bracing base shear of sample building frame increases and time period decreases at performance point. This shows that under seismic excitation frame retrofitted with bracing results to experience high base shear.
7. The cross-bracing of ISNB 150M is provided as steel bracing and the columns attached with these bracing were encased in a steel lattice composed of angles at the corners and diagonal flat plates. The encasement provided in column provide additional strength necessary to carry the increased axial force anticipated in the columns of the braced bays.
8. The performance of this building is beyond the acceptable limit and cannot be determined for Maximum Earthquake criteria.

6. Scope of Further Study

1. Non-Linear time history analysis can be used for the structure to have a more accurate assessment of the structure's capacity and understanding a more realistic demand scenario.
2. User defined Hinges in model is more successful in capturing the hinging mechanism compare to the model of default hinge.
3. Different other bracing forms can be used for strengthening and the behavior of building frame can be studied for better configurations.

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