Seismic Evaluation of Reinforced Concrete Structure with Friction Damper

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ABSTRACT - *Conventional methods of seismic reintegration with concrete shear walls or rigid steel bracing are considered expensive and tedious. The schedule and tight budget meant that these conventional options are not feasible. The principle of friction brake is most widely adopted available method to extract kinetic energy from a moving body. It is the most reliable, effective and economical mean to dissipate energy. Therefore, several types of friction dampers have been developed. The present study aims at evaluation of Reinforced Concrete Structure according to IS 456:2002 (Part I) with Non-linear static analysis i.e., pushover analysis using SAP2000 software. Pushover Analysis on a 9 storey structure installed with and without friction damper is carried out in X-direction. The results of 9 storey structure installed with and without friction damper are comparatively studied in the process. The results of analysis have been compared for both frames with and without friction dampers in terms of base shear, displacement. Also the performance point of both frames is compared as per ATC-40 capacity spectrum.*

Key Words: Static Pushover Analysis, Friction Damper

1. INTRODUCTION

Now-a-days, structural control is an advanced technology in the field of engineering to equip energy dissipation devices or control systems into structures to reduce excessive structural vibration and to enhance human comfort and prevent catastrophic structural failure due to strong winds and earthquakes. Structural control technology is now widely used for retrofitting of historical structures especially against earthquakes. Energy dissipation capacity and capability of structures subjected to severe earthquakes plays a vital role to prevent them from catastrophic instability and failure. In conventional structures the main source of energy dissipation is the inelastic behavior of structural material. The high cost of structural retrofitting, aftermath of a severe earthquake along with the need to predict the actual seismic behavior of structures, are the main causes to localize the capability of energy dissipation by devices installed in structures. Therefore, installation of friction dampers in a structure would render it to behave non-linearly even if all other members were designed to remain linear.

1.1 Friction Damper

For centuries, mechanical engineers have successfully used the concept of the friction brake to control the motion of machinery and automobiles. This concept is widely used to extract kinetic energy from a moving body as it is the most effective, reliable and economical mean to dissipate energy. The development of friction damping devices was pioneered in the late seventies. Friction dampers suitable for different types of construction have been developed for (1) Concrete shear walls, both precast and cast-in-place (2) Braced steel/concrete frames (3) Low-rise buildings and (4) Clad-frame construction. Patented Pall friction dampers are available for tension cross bracing; single diagonal bracing; chevron bracing; cladding connections; and friction base isolators. These friction dampers has a high standard of quality control. Every Friction damper is load tested to ensure proper slip load before it is shipped to site. Pall friction dampers are simple, fool-proof in construction and inexpensive in cost. These dampers consist of series of steel plates which are specially treated to develop most reliable friction.

Fig - 1: Concordia's Library Building Connected with Pall Friction Damper

2. PUSHOVER ANALYSIS

Pushover analysis is a method in which the limit state and ultimate strength is efficiently investigated after yielding and now it is being applied in practice for the seismic design of the structure. It is one of the simplest analysis methods and it is used for inelastic analysis of the structure, under a vector of forces or a vector of displacements. The vector of forces presents the expected inertial forces in structures, due to earthquake loads while displacement vector presents the expected displacement response in the structures. In pushover analysis the vector of forces or displacements is increasing monotonically on the structure

The output generated by static pushover curve plots a strength-based parameter against deflection. For example, performance may relate the strength level achieved in certain members to the lateral displacement at the top of the structure, or bending moment may be plotted against plastic rotation. The results provide insight into the ductile capacity of the structure which indicate the mechanism, load level, and deflection at which failure occurs.

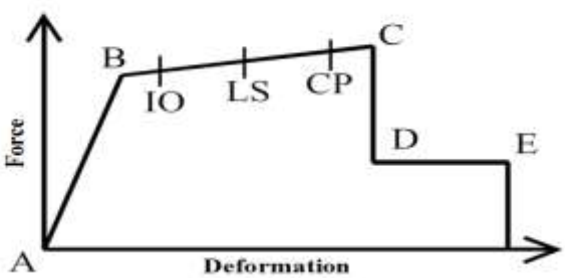

Fig - 2: Shear Force vs Deformation Curve

2.1 Structural Levels

The Structural Performance Level of a building can be selected from four discrete Structural Performance Levels. The discrete Structural Performance Levels are Immediate Occupancy (IO), Life Safety (LS), Collapse Prevention (CP) and Not Considered. These levels are discrete points on a continuous scale describing the structure performance, how much damage to the structure, loss of economy and disruption may occur.

The structural performance levels (IO, LS, and CP) of a structural element are represented in the load versus deformation curve as shown below,

1. A to B – Elastic state,
i) Point 'A' corresponds to the unloaded condition.
ii) Point 'B' corresponds to the onset of yielding.
2. B to IO- below immediate occupancy,
3. IO to LS – between immediate occupancy and life safety,
4. LS to CP- lies between life safety to collapse prevention,
5. CP to C – lies between collapse prevention and ultimate capacity,
i) Point 'C' corresponds to the ultimate strength
6. C to D- lies between C and residual strength,
i) Point 'D' corresponds to the residual strength
7. D to E- between D and collapse
i) Point 'E' corresponds to the collapse.

3. MODEL PARAMETERS OF FRICTION DAMPER

The properties assigned to friction damper are as follows:
Link Type = Plastic (Wen)
Stiffness = 10000
Yield strength = Slip Load
Post Yield Stiffness Ratio = 0.0001 = 0
Yield Exponent = 10
Slip load of friction damper is found by trial and error method and the optimum value which shows the minimum displacement for earthquakes is installed in the friction damper for performing pushover analysis.

4. MODELLING APPROACH

Pushover analysis is carried out in SAP2000. For analysis nine storey reinforced concrete structure in zone V is considered. The initial grid size is 16m x 20m (X and Y direction) with bay width of 4m in both directions. 4 bays are considered in X-direction whereas 5 bays are considered Y-direction. Grade of concrete is M25 and that of steel is FE415. The sizes of beams (B) and columns (C) are as follows:

B1 = 300mm x 600mm; B2 = 300mm x 500mm
C1 = 300mm x 500mm; C2 = 400mm x 400mm;
C3 = 400mm x 500mm

The Thickness of slab is 125mm. Live load on all floor is $3kN/m^2$.

Pushover analysis is carried out on G+9 RC frame with friction damper and without friction damper installed in X-direction.

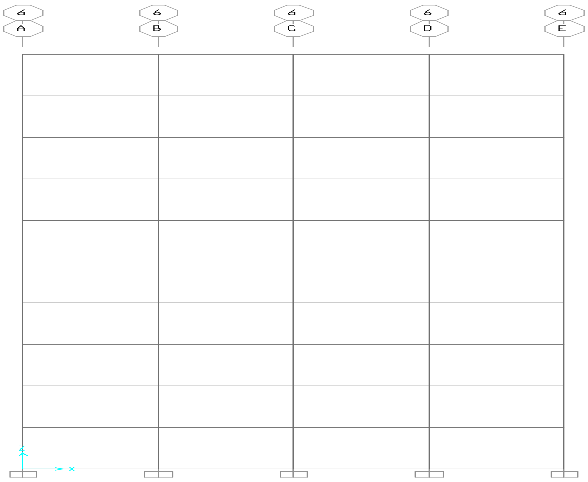

Fig – 4.1: Structure in X-direction

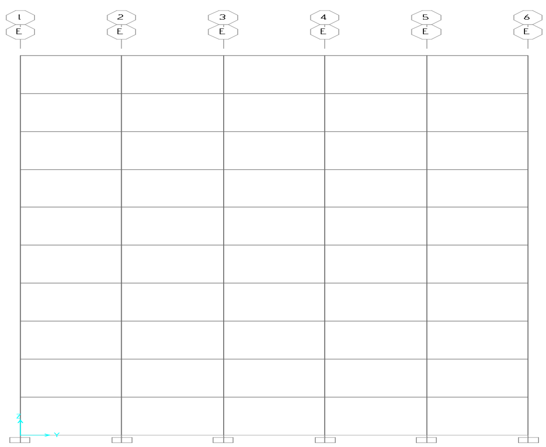

Fig – 4.2: Structure in Y-direction

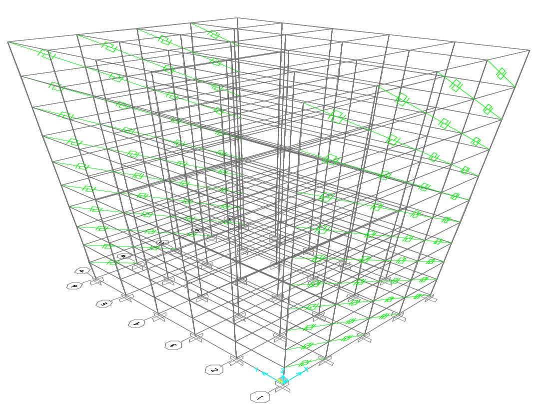

Fig – 4.3: 3D view of structure with Friction Damper installed in X-Direction

5. RESULTS OF PUSHOVER ANALYSIS

Table - 5: Performance levels of G+9 structure without and with Friction Damper

WITHOUT FRICTION DAMPER			
PERFORMANCE LEVELS	IO	LS	C
DISPLACEMENT (mm)	0.14815	0.30074	0.40134
BASE SHEAR (kN)	2720.65	2843.39	2706.31
WITH FRICTION DAMPER			
PERFORMANCE LEVELS	IO	LS	C
DISPLACEMENT (mm)	0.13938	0.28595	0.37317
BASE SHEAR (kN)	3249.72	3360.87	3216.55

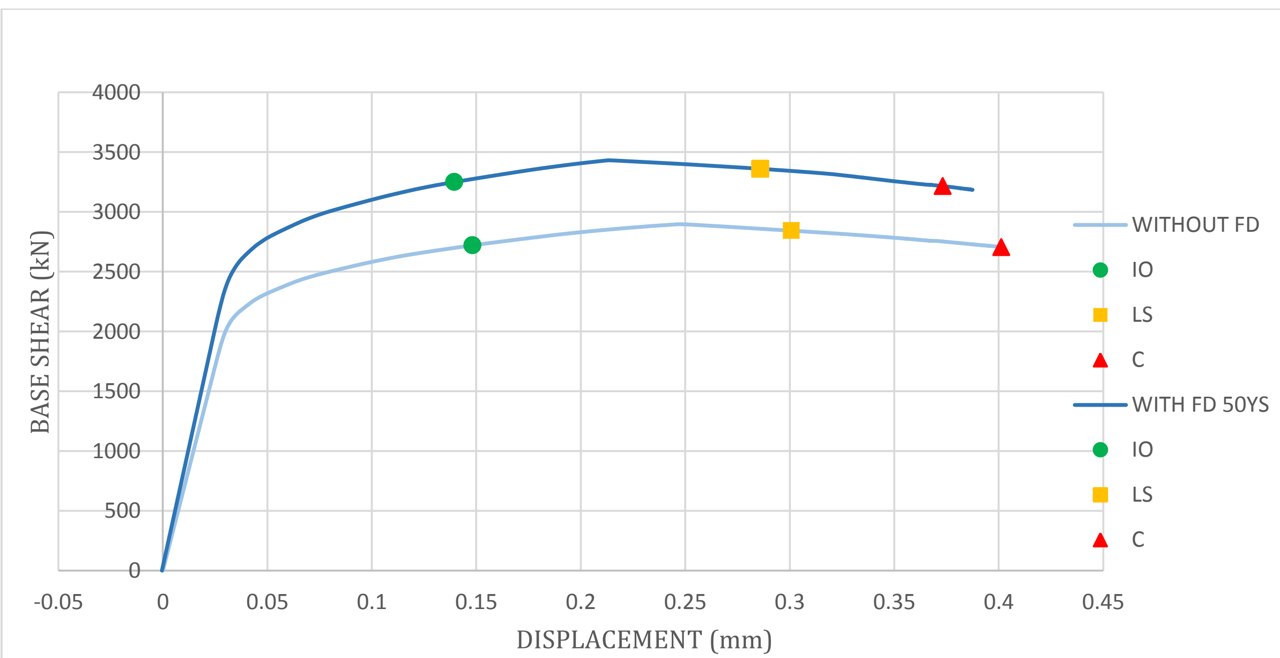

Chart 5: Pushover analysis of G+9 structure with and without friction damper

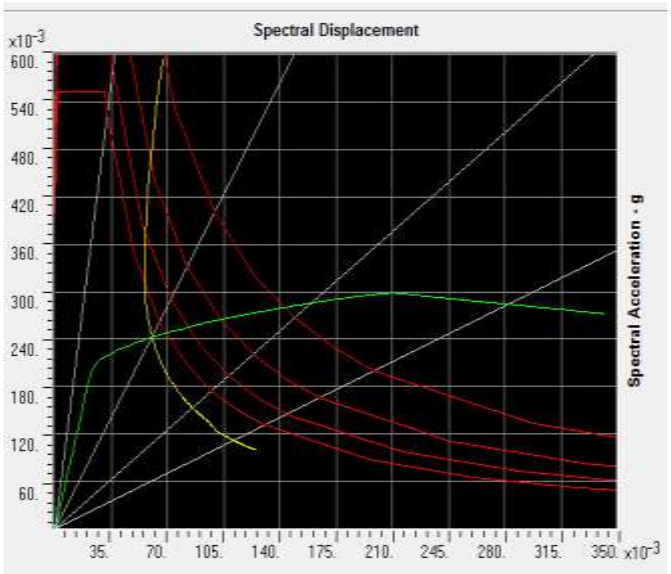

Fig - 5.1: Capacity Spectrum Curve without friction damper

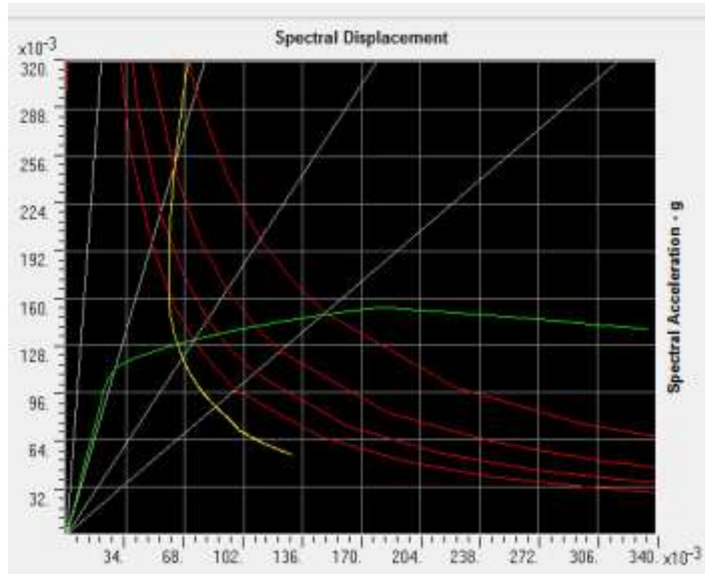

Fig - 5.2: Capacity Spectrum Curve with friction damper

Discussion

A nine storied reinforced concrete frame structure is taken for pushover analysis. The frame was subjected to design earthquake forces as specified in the IS code for zone V. Bare frame pushover curves for the building in X directions as shown in Figure 5. These curves show the behaviour of the frame in terms of its stiffness and ductility. Different performance levels have been plotted in the chart i.e., Immediate Occupancy (IO), Life Safety (LS), Collapse (C) or ultimate strength of the structure. For the structure without friction damper maximum base shear from pushover analysis is 2706.533 kN for maximum displacement of 401.571 mm whereas for structure installed with friction damper maximum base shear from pushover analysis is 3185.142 kN for maximum displacement of 387.474 mm in X direction respectively.
Fig. 5.1 and fig. 5.2 represents capacity spectrum curves for both without and with friction damper respectively. Capacity spectrum is the capacity curve i.e., spectral acceleration Vs spectral displacement (Sa Vs Sd) co-ordinates. The performance point of the structure is obtained by superimposing demand spectrum on capacity curve transformed into spectral coordinates. The frame shows the performance point of both structures (frame without friction damper and frame with friction damper). The performance point of frame without friction damper is obtained at the base shear level of 2463.593 kN at a displacement of 72 mm in the X direction and performance point of frame with friction damper is obtained at the base shear level of 3163.686 kN at a displacement of 114 mm in X direction.

6. Conclusion

Pushover analysis is a simple way to explore the nonlinear behaviour of the buildings. The results are obtained in terms of pushover curve (showing different structural performance levels), capacity spectrum. In nine storey structure seismic zone V is designed in SAP 2000 as per the guidelines of the code i.e. IS-456:2002 (Part I).

1. The structure installed with friction damper provided effective means of lateral load resistance system as compared to the structure without friction damper installed.
2. The structural performance and overall displacement can be effectively controlled by adopting installation of friction damper to the structure.
3. The installation of the friction damper device represents an effective alternative to the conventional ductility based earthquake resistant design both for new construction and for upgrading existing structures.

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