International Journal of Research in Engineering, Science and Management
Volume-3, Issue-2, February-2020
www.ijresm.com | ISSN (Online): 2581-5792

Seismic Evaluation of Reinforced Concrete Structure with Viscous Damper

Sushil Sankre[1], Pukhraj Sahu[2]
[1]M.Tech. Scholar, Department of Civil Engineering, Government Engineering College, Jagdalpur, India
[2]Assistant Professor, Department of Civil Engineering, Government Engineering College, Jagdalpur, India

***Abstract*: In last decade, Bhuj earthquake of 2001 raised the questions about the adequacy of framed structures to resist strong seismic motions. Under such circumstances, to evaluate the performance of reinforced concrete (RC) framed buildings for future expected earthquakes, a non-linear static (pushover) analysis can be conducted. Pushover analysis evaluates the performance level of the building components and maximum base shear carrying capacity of the structure for various zones. This analysis is carried out for hinge properties, roof displacement and base shear, available in programs based on the FEMA-356 and ATC-40 guidelines. This study focuses on seismic performance of building with different symmetric and asymmetric frame structure. To identify the nonlinear behavior of frame elements in the structure, Pushover analysis is performed using SAP 2000. The results show how different structures performed in terms of roof displacement, hinge behavior, and base shear. Asymmetrical structures have more base shear and more roof displacement than the symmetrical structure for same rise building. To reduce the base shear and roof displacement of irregular structure viscous damper is used in both X & Y axis, and the results have been found to decrease significantly.**

***Keywords*: Pushover curve, Roof displacement (Target displacement), Base shear, Hinge behavior, SAP 2000, ATC – 40, Capacity spectrum, Viscous damper.**

1. Introduction

Pushover analysis is a static nonlinear procedure in which the magnitude of the structural loading along the lateral direction of the structure is incrementally increased in accordance with a certain pre-defined pattern by applying monotonically increasing lateral loads to the structure representing the inertial forces that would be experienced by the structure during severe earthquakes. Magnitude of lateral load increases until the structure reaches target displacement. Target displacement represents the top deformation that the structure will be subjected during earthquake. Capacity curve (Pushover curve) is generated during pushover analysis which shows the relationship between base shear force and roof top displacement

2. Target displacement

The target displacement serves as an estimate of the global displacement of the structure is expected to experience in a design earthquake. It is the roof displacement at the centre of mass of the structure. Even in IS1893 (part 1): 2002, there is no any kind of suggestion regarding the calculation of target displacement of structure. However, in American code (ASCE 41 – 06) there is some method regarding the calculation of target displacement.

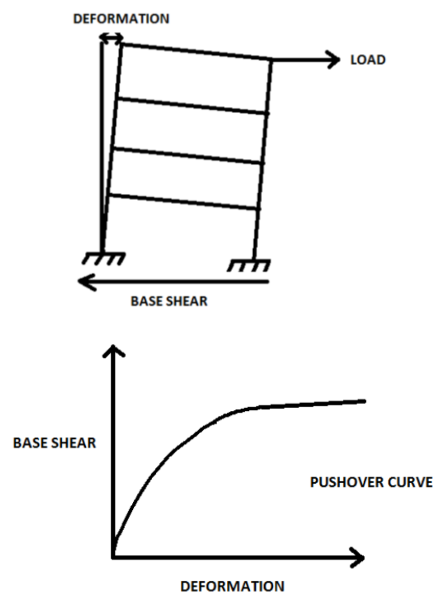

Fig. 1. Pushover curve development

3. Capacity Spectrum method (ATC -40)

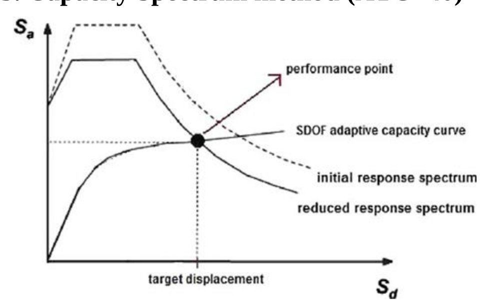

Fig. 2. Capacity Curve according to ATC – 40

Capacity spectrum is obtained by the use of pushover curve (capacity curve). It is a nonlinear static procedure in which capacity curve is transformed from base shear vs, roof displacement (V_b vs. d**)** coordinate into spectral displacement vs spectral acceleration (S_a vs. S_d). It provides a graphical representation of expected seismic performance of the existing or retrofitted structure by the intersection of capacity curve with a response spectrum (demand spectrum) of earthquake displacement demand in the structure. The intersection is the performance point, and the base shear and displacement obtained at intersection point is the maximum estimated value for given earthquake ground motion.

4. Displacement coefficient method (FEMA-356)

The Displacement Coefficient Method is an approximate method which is given by FEMA-356. It provides a method to directly calculate numerical value of maximum global displacement demand of structures. Deformation demand (dt) which is inelastic, is calculated by changing deformation elastic demand with the help of displacement modification factors. Bilinear representation of capacity curve is needed which can be used in the method. Once the bilinear curve is constructed, effective fundamental period (T_e) of the building structure is calculated with the help of following equation:

$$T_e = T_i \sqrt{\frac{K_i}{K_e}}$$

Where,

T_e is the effective fundamental period (sec)

T_i is the elastic fundamental period for given direction.

K_i is the elastic lateral stiffness of the building in given direction.

K_e is the lateral stiffness of building in given direction.

K_e and K_i is obtained from the using of following graph.

The target displacement, δt, at each floor level shall be calculated in accordance with Equation.

$$\delta_t = c_0 c_1 c_2 c_3 s_a \frac{Te^2}{4\pi^2} g$$

Where,

$c_0, c_1, c_2,$ & c_3 is the modification factor.

5. Performance based design

It is important to analysis the building performance before physically constructing it. The performance based design gives you the choice to check the story drift, displacement at the roof level and the capacity before the building fails for certain ground motions. The performance based design ensures the safety for the Design Basis Earthquake (DBE) and Collapse prevention for Maximum Considered Earthquake (MCE).

The performance of building means how well it satisfies the needs of its users. Acceptable performance levels of damage indicate the uninterrupted functionality of the buildings structural elements as well as non-structural elements. The safety of non-structural elements can be ensured through performance based design with increase in cost of the construction. Consequently, performance-based design is the procedure or approach used by design specialists to construct buildings that possess functionality and the continued availability of services. For critical section of beams and columns, Pushover analysis requires the development of force deformation curve as shown below.

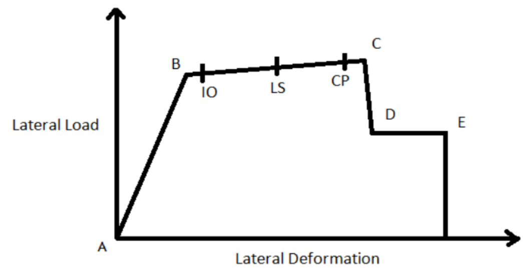

Fig. 3. Load deformation behaviour

Where IO, LS & CP represent the immediate occupancy, life safety and collapse prevention.

Key characteristics of immediate occupancy:

- The members nearly retain their strength and stiffness.
- No crushing of concrete.
- Hairline crack can be seen.
- Minor cracking or spalling of plaster in brick walls.
- Risk of life threatening injury is negligible.
- Minor structural repairs may be necessary.
- Building can be reoccupied before the repairs.

Key characteristics of Life safety performance level:

There is significant damage to the structure.

- Strength and stiffness of building is reduced.
- Some permanent drift occurs.
- There will be spalling of concrete cover in beam and column.
- Life threatening hazard is low and major structural repair can be done.

Key characteristics of collapse prevention performance level:

- Degradation of lateral load resisting system.
- Formation of hinges in ductile element.
- Structure undergoes large permanent drift.
- Structure has no strength after earthquake.
- Structure may collapse at any time.
- The building may not be repairable.

6. Damping

Damping may be defined as the process by which free vibration steadily diminishes in amplitude. The extent of damping depends upon the constructional materials used, the type of construction, and the presence of non-structural elements. Damping is measured as a percentage of critical damping. In a dynamic system, critical damping is the minimum amount of damping necessary to prevent oscillation altogether.

Viscous damper: In this damper, by using viscous fluid inside a cylinder, energy is dissipated. Due to ease of installation, adaptability and coordination with other members also diversity in their sizes, viscous dampers have many applications in designing and retrofitting.

7. Modelling of building

a) Model 1
Length of building (X direction) = 16 m
Length of building (Y direction) = 20 m
Bay spacing in X direction = 4 m
Bay spacing in Y direction = 5 m
Height of building = 30 m
Height of each storey = 3 m

b) Model 2 (E Shape)
Length of building (X direction) = 24 m
Length of building (Y direction) = 25 m
Bay spacing in X direction = 6 m
Bay spacing in Y direction = 5 m
Height of building = 30 m
Height of each storey = 3 m

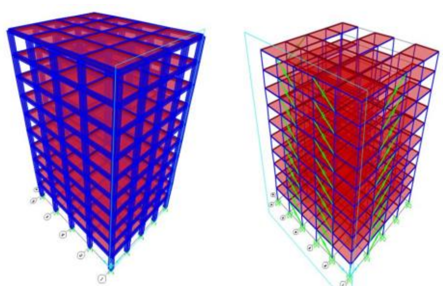

Fig. 3. Isometric view of model 1 & model 2 (with viscous damper)

Table 1
Member Properties & Specifications for the Models Sizes of the member

S.no.	Specification	Size
1	Plan dimension	24 m x 25 m & 16 x 25 m
2	Floor to floor height	3 m.
3	Total height of building	30 m.
4	Type of structure	SMRF
5	Soil type	Type 1 (hard soil)
6	Response reduction factor	5
7	Seismic zone factor	V (0.36)
8	Importance factor	1
9	Grade of concrete & steel	M 25 & Fe 415
10	Size of beam and column	0.5 m x 0.3 m & 0.6 m x 0.4 m
11	Slab & wall thickness	0.150 m & 0.200 m
12	Live load	3.5 kN / m^2
13	Floor finish	1 kN / m^2
14	Dead load	Calculated as per self-weight
15	Seismic load	Calculated as per IS: 1893 (Part I):2002

8. Result and Discussion

In the present study, a static non-linear (pushover) analysis of the building under the loading was carried out using SAP 2000. The objective of this study is to get the variation of load – displacement graph and check the maximum base shear and roof displacement at performance point, with and without damper.

According to ATC – 40 and FEMA – 356 Base Shear of both the building is shown below.

Table 2
Base Shear from Pushover analysis in X and Y direction

S.No.	Type of building	ATC - 40		FEMA 356	
		PUSH X	PUSH Y	PUSH X	PUSH Y
		kN	kN	kN	kN
1	G+9	8420.657	8498.810	10567.665	10556.160
2	E Shape	11173.28	10416.990	15530.065	13624.454

Similarly, target displacement obtained by analyzing all three building is tabulated below.

Table 3
Target displacement from Pushover analysis in X and Y direction

S.No.	Type of building	ATC - 40		FEMA 356	
		PUSH X	PUSH Y	PUSH X	PUSH Y
		m	m	m	m
1	G+9	0.125	0.131	0.226	0.239
2	E Shape	0.164	0.188	0.313	0.327

Base Shear and Target displacement of G+9 (E SHAPE) building with and without damper according to FEMA 356 is described below.

Table 4
Target displacement & Base Shear with and without damper

S.No.	Type of building	FEMA 356			
	G+9 (E Shape)	Base Shear		Target displacement	
		PUSH X	PUSH Y	PUSH X	PUSH Y
1	Without damper	15530.065	13624.45	0.313	0.327
2	With damper	5462.131	3454.145	0.219	0.287

9. Conclusion

1. Weak elements in the structure can be identified with the help of pushover analysis However, Pushover analysis may not accurately represent dynamic behaviour of the structure as it is an approximate method based on static loading.
2. Nonlinear behaviour of base shear vs displacement curve of both the building is semi- ductile and it gives information about yielding of structure, due to this sudden collapse of building is avoided.
3. Pushover analysis can identify weak point in element by predicting the failure mechanism during progressive yielding. This is helpful for undertaking restoration and rehabilitation work.
4. In all three building, base shear at performance point is greater than the design base shear, so building is safe against the earthquake motion to which it has been subjected.
5. Base shear in case of irregular building G+9 (E-shape) with the dampers is less as compare to that without damper in both X & Y direction due to Push X & Push Y.

6. Target displacement in case of irregular building G+9 (E-shape) with the dampers is also less as compared to that without damper in both X & Y directions due to Push X & Push Y.

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