International Journal of Research in Engineering, Science and Management
Volume-3, Issue-1, January-2020
www.ijresm.com | ISSN (Online): 2581-5792

Earthquake Behavioural Analysis of Symmetric and Asymmetric RCC Structure Using Pushover Method

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***Abstract*: In present age civil engineering construction of various types of structure are becoming more inimitable like other engineering products. But in last few decades it raised the question about the performance of structure during strong seismic motion. Under such circumstances to avoid the various types of structure and life hazard a nonlinear static pushover analysis can be conducted. Pushover analysis evaluate the performance level of building using base shear, roof displacement and hinge mechanism at various position of building. This study focused 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 high base shear and high roof displacement than the symmetrical structure for same rise building.**

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

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.

Capacity spectrum method (CSM) and Displacement coefficient method are simplified nonlinear static analysis procedures. Capacity spectrum method provides force displacement curve and compares it with earthquake demand. Structure must have the capacity to handle demand of earthquake. Elastic analysis gives a good insight into the elastic capacity of the structure but fails to account for the redistribution of forces. Inelastic method of analysis demonstrates how building really works during severe ground shaking considering that elastic capacity of the structure is exceeded.

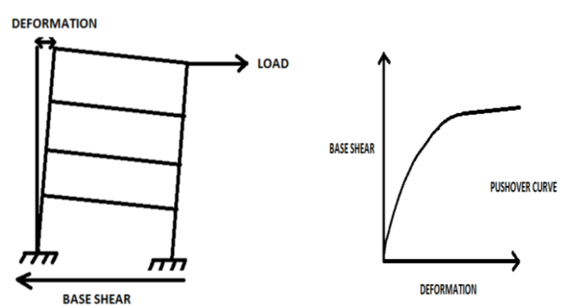

Fig. 1. Pushover curve development

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 center 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.

3. Demand

During ground shaking, deformations are produced in the structure whose pattern may vary with time. It is very time consuming to analyze this motion at each and every step of Displacement demand of the RC frame during earthquake can be defined as maximum expected response of the structure during ground shaking.

4. Nonlinear plastic hinge

Hinges are points on the structure which show high shear or flexural displacement during loading. Location of hinges can be at either ends of beams or columns. During severe ground shaking, one can expect cross diagonal cracks in RC frame structure.

5. Capacity

Strength and deformation limits of individual structural components define the overall capacity of the structure. Non-linear pushover analysis is performed to find capacity beyond elastic limits.

6. Capacity Spectrum method (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 provide 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.

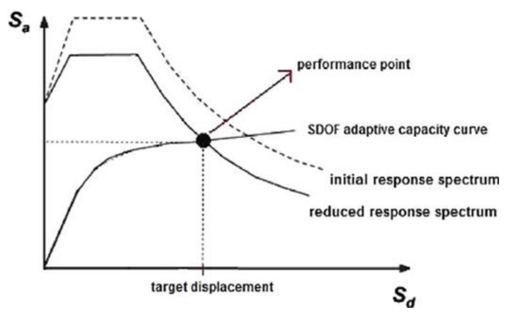

Fig. 2. Capacity Curve according to ATC – 40

Performance of building during earthquake is evaluate by load deformation behavior of building

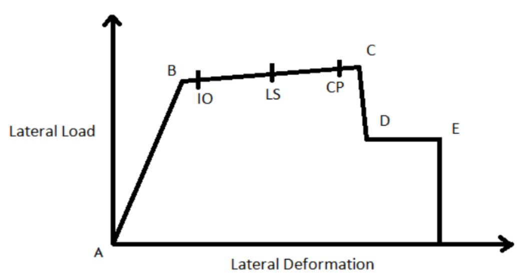

Fig. 3. Load deformation behaviour

1. Point A – It represents the unloaded condition.
2. A to B - Load deformation relation shall be described by the linear response from A to an effective yield B.
3. B to C -The stiffness reduction occurs from point B to C. Its slope is generally taken between 0 and 10% of the initial slope. Points between B and C represent acceptance criteria for the hinge, which are Immediate Occupancy (IO), Life Safety (LS) and Collapse Prevention (CP).
4. Point C - It has a resistance equal to the nominal strength.
5. C to D - Decrease in lateral load resistance occurs from C to D, It corresponds to an initial failure of the member.
6. D to E - The DE Line represents the residual strength of the member. These points are specified according to FEMA to determine hinge rotation behaviour of RC members.
7. Point E - The response is at reduced resistance at E and final loss of resistance occurs.

7. Design seismic base shear

The total design lateral force or design seismic base shear (Vb) along any principal direction shall be determined by the following expression:

$$V_b = A_h.W$$

Where,
A_h = horizontal acceleration spectrum
W = seismic weight of all the floors

$$A_h = \frac{Z\, I\, S_a}{2\, R\, g}$$

Where,
V_b = Base shear
Z = Zone factor, for maximum considered earthquake (MCE)
Z/2 is used to reduce the MCE to Design basis Earthquake (DBE)
I = The Importance Factor depending upon the functional use of structures characterized by hazardous consequences of its failure.
R = Response reduction factor depending on the perceived seismic damage performance of the structure. & S_a/g is the average response acceleration coefficient.

8. Modelling and Analysis 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 & 21 m
Height of each storey = 3 m

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

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

Design seismic Base Shear of model (1) building is,

$V_{bx} = 51785 \times 0.053 = 2744.605$ kN

$V_{by} = 51785 \times 0.0596 = 3086.38$ kN

Similarly, Base Shear of model (2) building is calculated as 4758 kN.

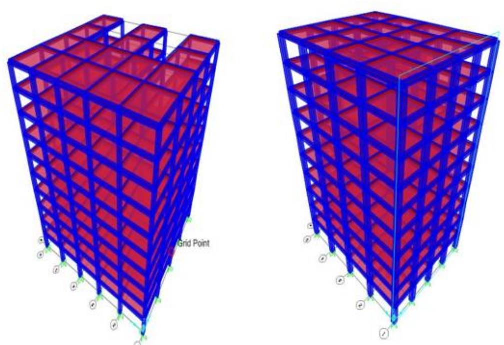

Fig. 4. Elevation view of model 1 & model 2

9. 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.

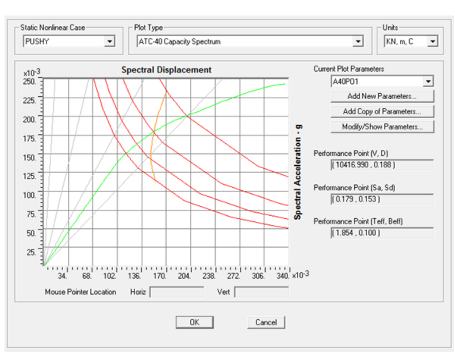

Fig. 5. Capacity spectrum curve of model (2) building due to PUSH Y

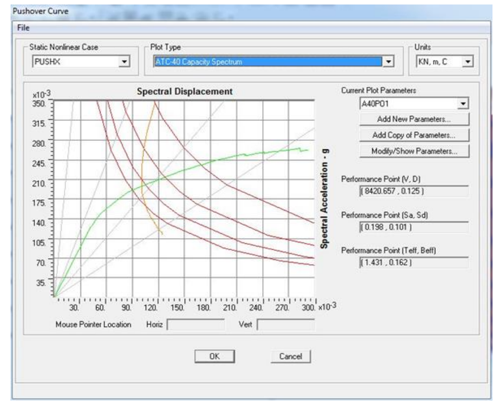

Fig. 6. Capacity spectrum curve of model (1) building due to PUSH X

The base shear obtained for PUSH X and for PUSH Y at performance point is greater than the design base shear so building is safe against earthquake loading. Similarly, behavior of hinge formation is also observed at each incremental step which is shown below,

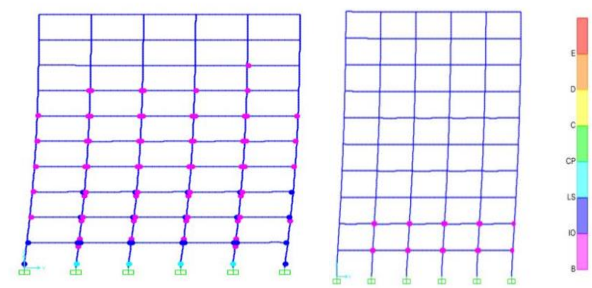

Fig. 7. Hinge formation of model 1 & 2 building due to PUSHX

10. 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. Formation of the hinges starts at the supports and progressively moves towards the upper stories with the increment of load. Step by step development of hinges is observed in results.
3. 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.
4. 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.
5. 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.

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