

**NON LINEAR STATIC PUSHOVER ANALYSIS OF LOW RISE RC BUILDINGS
BY SAP2000**

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Abstract- The earthquake of October 8th, 2005 in Pakistan indicated the need for evaluation of seismic adequacy of existing buildings since many buildings suffered great damage or collapsed. To evaluate the performance of RC buildings under future expected earthquakes, a non-linear static pushover analysis was conducted. To achieve this objective, buildings were selected from seismic region of zone 2B, zone 3. Force-deformation (Pushover Analysis) relationship was plotted by this analysis in SAP 2000. The results obtained from this study show that properly designed gravity loaded frames will perform well under seismic loads up to some level. The primary observations from the study showed that the accuracy of the pushover results depends strongly on the load path, properties of the structure.

Keywords: Nonlinear static procedure; nonlinear hinge properties; pushover analysis;

I. INTRODUCTION

The 7.6 magnitude (ERRA, 2006) earthquake that struck Pakistan on October 8, 2005 is the most devastating natural disaster in the history of Pakistan. Pakistan is located within most seismically active Himalayan ranges in the north, Hindu Kush mountain ranges in northwest and Suleiman mountain ranges in southwest [1]. High seismic hazard in Pakistan is due to northward movement of the Indian tectonic plate at a rate of 31mm/year which is subducting beneath the Eurasian continent [2]. Earthquake of low magnitude are very common in Pakistan. The building should have enough capacity to resist the demand. But, unfortunately the past earthquake history has indicated that almost every earthquake had caused some damage. Stone and masonry buildings are more exposed to earthquake motions than RC buildings but still RC buildings are damaged and even collapsed in some cases due to ground motions [3]. Structures suffer significant inelastic deformation under a strong earthquake and dynamic characteristics of the structure change with time so investigating the performance of a structure requires inelastic analytical procedures accounting for these features [4]. Inelastic analytical procedures help to understand the actual behavior of structures by identifying failure modes and the potential for progressive collapse [5]. Inelastic analysis procedures basically include inelastic time history analysis and inelastic static analysis which is also known as pushover analysis [6]. The inelastic time history analysis is the most accurate method to predict the force and deformation demands at various components of the structure [6]. However, the use of inelastic time history analysis is limited because dynamic response is very sensitive to modeling and ground motion characteristics [7]. It requires proper modeling of cyclic load-deformation characteristics considering deterioration properties of all important components. Also, it requires availability of a set of representative ground motion records that accounts for uncertainties and differences in severity, frequency and duration characteristics. Moreover, computation time, time required for input preparation and interpreting voluminous output make the use of inelastic time history analysis impractical for seismic performance evaluation. Inelastic static analysis, or pushover analysis, has been the preferred method for seismic performance evaluation due to its simplicity [8]. This paper aims to present development of pushover (capacity) curves for typical low-rise RC buildings constructed in Pakistan and evaluation of seismic vulnerability of low-rise RC buildings in different seismic zones of Pakistan.

II. PUSHOVER ANALYSIS TECHNIQUE

The seismic demands are computed by non-linear static analysis of the structure subjected to monotonically increasing lateral forces with an invariant height-wise distribution until a predetermined target displacement is reached. Both the force distribution and target displacement are based on the assumption that the response is controlled by the fundamental mode and that the mode shape remains unchanged after the structure yields [9]. Obviously, after the structure yields, both assumptions are approximate, but investigations have led to good estimates of seismic demands. However, such satisfactory predictions of seismic demands are mostly restricted to low- and medium-rise structures provided the inelastic action is distributed throughout the height of the structure. The seismic demands are computed by non-linear static analysis of the structure subjected to monotonically increasing lateral forces with an invariant height-wise distribution until a predetermined target displacement is reached. Both the force distribution and target displacement are based on the assumption that the response is controlled by the fundamental mode and that the mode shape remains unchanged after the structure yields. Obviously, after

the structure yields, both assumptions are approximate, but investigations have led to good estimates of seismic demands. However, such satisfactory predictions of seismic demands are mostly restricted to low and medium-rise structures provided the inelastic action is distributed throughout the height of the structure. In force controlled pushover procedure, full load combination is applied as specific, i.e. force controlled procedure should be used when the load is known (such as gravity loading). In displacement controlled procedure, specified drifts are sought (as in seismic loading) where the magnitude of applied load is not known in advance. The magnitude of load combination is increased or decreased as necessary until control displacement reaches a specific value. The purpose of pushover analysis is to evaluate the expected performance of structural systems by estimating performance of structural system by estimating its strength and deformation demands in design earthquakes by means of static inelastic analysis, and comparing these demands to available capacities at the performance levels of interest.

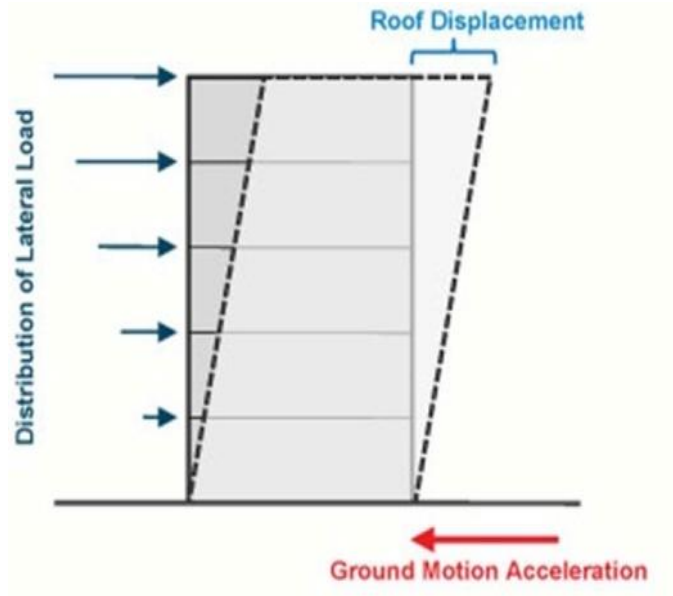


Figure 1 Monotonically lateral loads on building

[4] PUSHOVER CURVE

The FEMA-356 NSP requires development of a pushover curve, which is the relationship between the base shear and lateral displacement of a control node, defined as the center of mass at the roof of a building. The pushover curve is developed by first applying gravity loads, followed by monotonically increasing lateral forces with a specified height-wise distribution [10].

IV. STUDY OF BUILDINGS

Two buildings (Building A, Building B) are selected from Abbottabad (zone 3) and their structural drawings are collected from Cant Board Abbottabad. Building C is selected from Islamabad (zone 2B) and its structural drawing was collected from CDA Islamabad. Building D is selected from Peshawar (zone 2B) and its structural drawing is collected from Cant Board Abbottabad.

Building A

Building A is a twelve-story building having column C1 and beam B1 used throughout building. Pushover curve and performance points on curve are provided, while $F_c' = 4\text{ksi}$ and $F_y = 60\text{ksi}$ are material properties. C1 is 18" X 18" having 12 # 6 bras. B1 is 15" X 24".

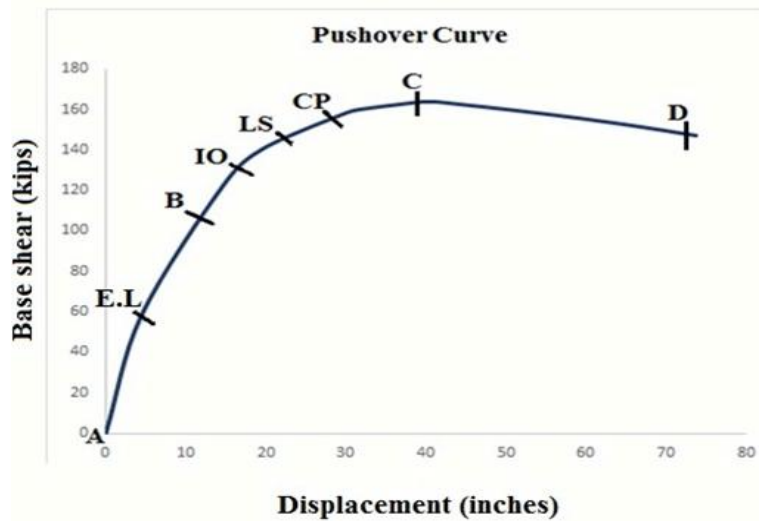


Figure 2 Pushover Curve of Building A

Following discussions can be made from graph:

- Point A is origin.
- Point E.L represents elastic limit and stiffness (resistance to deformation) at point E.L is 8.20 kips/inch and 13.02 kips/inch at point B.
- Stiffness at IO is 10.1 kips/inch, 8.2 kips/inch at LS, 6.25 kips/inch at CP, 4.17 kips/inch, 2.99 kips/inch and 2.3 kips/inch at point C, D and E respectively.
- Building A is stiff and is ductile (ability to deform beyond elastic limit).

Building B

Building B is four storeys building having columns C1, C2 and beam B1. There is a sudden drop in capacity curve of Building B after point B indicating sudden loss of moment carrying capacity. This mechanism is known as soft story Mechanism. If variation in stiffness between adjacent members is greater than thirty percent, if there is transfer of moment from stiffer member to less stiff member (hinge formation), less stiff member will collapse and sudden drop in capacity curve is observed in such case. Details of Building B, pushover curve and performance points on pushover curve are shown. Material properties of Building B are similar to that of Building A. C1 is 12" X 12" having 8 # 6 bars. C2 is 12" X 12" having 6 # 6 bars. B1 is 12" X 15".

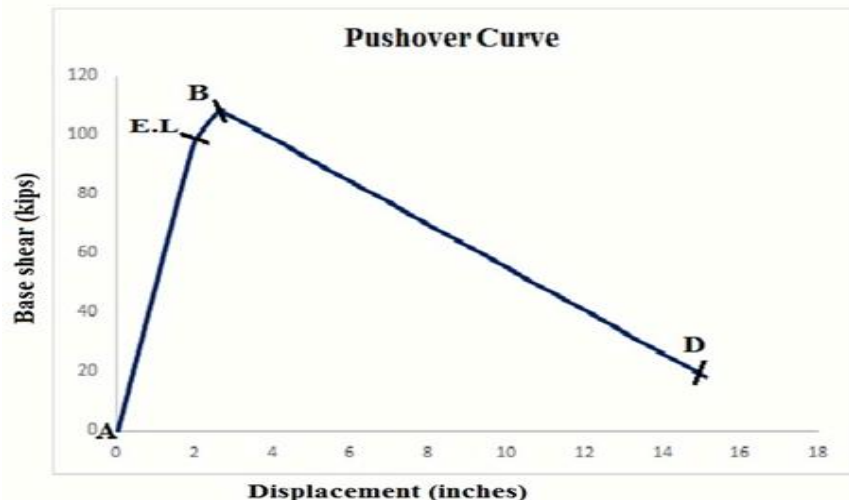


Figure 3 Pushover curve of Building B

Following discussions can be made from graph:

Point A is origin.

- Point E.L represents elastic limit and stiffness (resistance to deformation) at E.L is 32.23 kips/inch and 36.02 kips/inch at point B.
- Performance points i.e. IO, LS, CP do not exist in this case.
- Building B is stiff and have ductility.

Building C

Building C is a seven stories building having columns C1, C2 and beams B1, B2 used throughout building. Pushover curve and performance points on curve are provided, while $F_c' = 4\text{ksi}$ and $F_y = 60\text{ksi}$. C1 is 18" X 18" having 12 # 6 bars. C2 is 15" X 24" having 14 # 6 bars. B1 is 12" X 24".

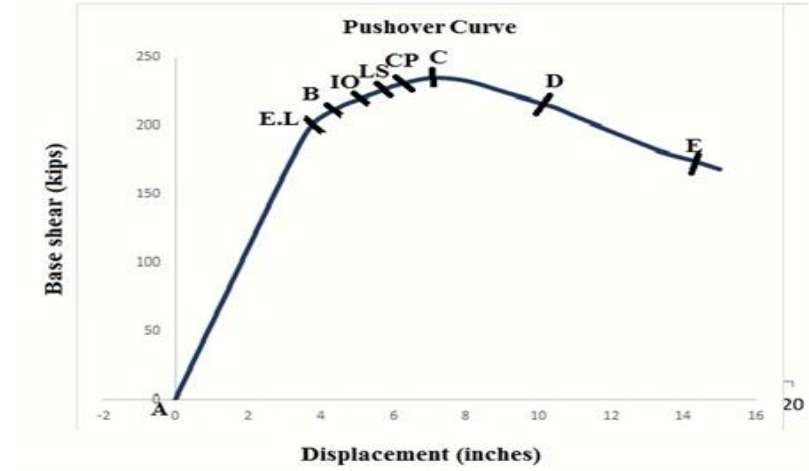


Figure 4 Pushover Curve of Building C

Following discussions can be made from graph:

- Point A is origin.
- Point E.L represents elastic limit and stiffness (resistance to deformation) at E.L is 42.4 kips/inch and is 64.66 kips/inch at point B.
- Stiffness at IO is 50.21 kips/inch, 40 kips/inch at LS, 34.5 kips/inch at CP and 4.17 kips/inch at C.
- Building C is stiffer and is less ductile (ability of material to deform beyond elastic limit).

Building D

Building D is a three storeys building having column C1 and beam B1 used throughout building. Pushover curve and performance points on curve are provided, while $F_c' = 4\text{ksi}$ and $F_y = 60\text{ksi}$ are material properties. C1 is 18" X 18" having 12 # 6 bars and B1 is 12" X 18" beam.

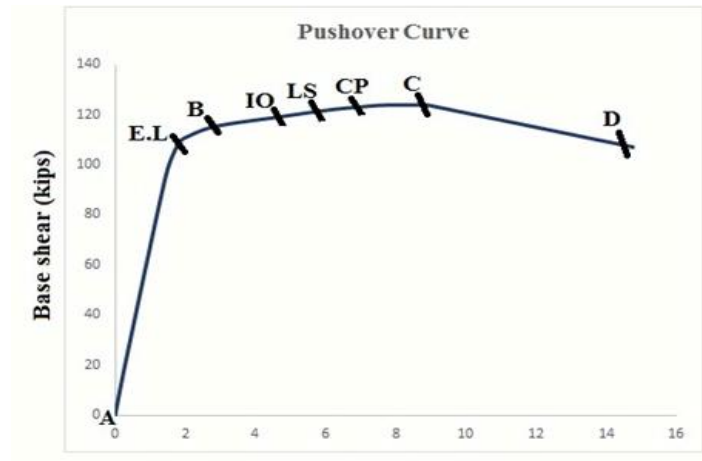


Figure 5 Pushover Curve of Building D

Following discussions can be made from graph:

- Point A is origin.
- Point E.L represents elastic limit and stiffness (resistance to deformation) at E.L is 55 kips/inch and 60.66 kips/inch at B.
- Stiffness at IO is 30.21 kips/inch, 24.23 kips/inch at LS, 19.5 kips/inch at CP and 15.25 kips/inch at C.
- Building D is stiffer and is more ductile (ability of material to deform beyond elastic limit).

V. RESULT ANALYSIS

Ductility factor of building A which is located in Abbottabad (zone3) is 7.8 and yield strength of building A is 151.23 kips. Ductility factor of Building A is more because of having yield moment of columns greater than that of beams (Large dimensions and more reinforcement). So, its design is safe against any seismic event that may occur in zone 3. Ductility factor and yield strength of building B which is also selected from zone 3 and have same material properties as that of building A are 2.4 and 108.6 kips respectively. There is clear decrease in ductility and yield strength of building B and it is due to soft story mechanism. From the capacity curve of building B it is inferred that it will collapse immediately after the elastic limit is crossed because of variation in stiffness between adjacent stories and hence its design is not safe against any seismic scenario that may occur in zone 3. Building C, which is located in Islamabad (zone2B), is stiffer and less ductile as its ductility factor is 3.47 and yield strength is 201.21 kips because of having less height and stiffer elements. Thus design of building C is safe against any seismic scenario that may occur in zone 2B because of having enough ductility and high yield strength. Building D which was selected from Peshawar (zone2B) has ductility factor of 8.61 and yield strength of 110.1 kips because of having yield moment of columns greater than beams, which indicates that in any seismic scenario that may occur in zone 2B, it will be safe because of having high ductility and yield strength.

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