INTERNATIONAL JOURNAL OF ADVANCE RESEARCH, IDEAS AND INNOVATIONS IN TECHNOLOGY

ISSN: 2454-132X
Impact factor: 4.295
(Volume3, Issue4)
Available online at www.ijariit.com

Pushover Analysis of Multistorey Reinforced Concrete Building

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Abstract: The standard building codes define the significant design requirements to ensure the safety of buildings in a sudden ground movement causing inertial forces in the building. We witness post-earthquake effects in many buildings designed as per these codes. Therefore it is important to analyse 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). For performance-based seismic design, the performance levels described in ASCE 41, Seismic Rehabilitation of Existing Building (2007), for both structural and non-structural systems are the most Widely-recognized characterizations. These performance levels are Operational Building Performance Level, Immediate Occupancy Building Performance Level, Life Safety Building Performance Level, and Collapse Prevention Building Performance Level. Non-Linear Pushover Analysis method considers the nonlinear behaviour of the structure which increases the load taking the capacity of the building. It also focuses on the ductility of the structure by providing plastic hinges. Pushover analysis is applicable to new and existing structures which can be a good method for retrofitting of structures after its design life is over. It considers target displacement and defining objectives whenever the performance meets the objectives then the damage at that performance level is acceptable.

Keywords: Ground Movement, Building Performance, Story Drift, Design Basis Earthquake (DBE), Pushover Analysis, Plastic Hinges.

1. INTRODUCTION

The performance of building means how well it satisfies the needs of its users. Acceptable performance levels of damage indicate the 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 an increase in its cost of construction. The performance based design is the approach used by design specialists to design buildings that possess functionality and the continued availability of services. The performance based design methodology is not going to be the immediate substitute for design to the traditional code methods. Rather, it can be viewed as an opportunity to enhance and adapt the design to match the objectives. It will only help in enhancing the design criteria in determining the deformation based response.

Key points of performance based analysis are:

1. The performance based design considers deformation and forced based design considers a strength. However for seismic performance deformation is more important.
2. The Design is done by using a target displacement
3. There is no need of using force reduction factor.
4. The nonlinear behaviour of the structure is considered which gives more strength.
5. Displacement based design can indicate the potential damage in any weak member of the structure, hence it can be retrofitted.
6. Displacement based design is applied to both existing and new structures.

For performance-based seismic design, the performance levels described in ASCE 41, Seismic Rehabilitation of Existing Building (2007), for both structural and non-structural systems are the most widely recognized characterizations. These performance levels are:

1. **Operational Building Performance Level**
   Buildings that meet this building performance level are expected to sustain minimal or no damage to their structural and nonstructural components. The building is able to continue its normal operations with only slight adjustments for power, water, or other utilities that may need to be provided from emergency sources.

2. **Immediate Occupancy Building Performance Level**
   Buildings that meet this building performance level are expected to sustain minimal damage to their structural elements and only minor damage to their nonstructural components. While it is safe to reoccupy a building designed for this performance level immediately following a major earthquake, nonstructural systems may not function due to power outage or damage to fragile equipment. Consequently, although immediate occupancy is possible, some cleanup and repair and restoration of utility services may be necessary before the building can function in a normal mode. The risk of casualties at this target performance level is very low.

3. **Life Safety Building Performance Level**
   Buildings that meet this building performance level may experience extensive damage to structural and nonstructural components. Repairs may be required before re-occupancy, though in some cases extensive restoration or reconstruction may not be cost effective. The risk of casualties at this target performance level is low. This building performance level allows somewhat more extensive damage than would be anticipated for new buildings designed and constructed for seismic resistance. The Life Safety Building Performance Level should prevent significant casualties among able-bodied school occupants.

4. **Collapse Prevention Building Performance Level**
   Although buildings that meet this building performance level may pose a significant hazard to life safety resulting from the failure of nonstructural components, significant loss of life may be avoided by preventing the collapse of the entire building. However, many buildings designed to meet this performance level may be complete economic losses. Sometimes this performance level is selected as the basis for mandatory seismic rehabilitation ordinances enacted by regulatory authorities because it mitigates the most severe life-safety hazards at the lowest cost. The Collapse Prevention Building Performance Level is intended to prevent only the most egregious structural failures and does not allow for continued occupancy and functionality or cost-effective damage repair of structural and nonstructural components.

2. LITERATURE REVIEW

1. **Ramaraju et al. (2012)** carried out the nonlinear analysis (pushover analysis) for a typical six-storey office building designed for four load cases, considered three revisions of Indian (IS: 1893 and IS: 456) codes. In that study, nonlinear stress–strain curves for confined concrete and user-defined hinge properties as per Eurocode 8 were used. A significant variation was observed in base shear capacities and hinge formation mechanisms for four design cases with default and user-defined hinges at yield and ultimate. This may be due to the fact that, the orientation and the axial load level of the columns cannot be taken into account properly by the default-hinge properties. Based on the observations in the hinging patterns, it was apparent that the user-defined hinge model was more successful in capturing the hinging mechanism compared to the model with the default hinge.

2. **Shahrin Hossain (2011)** followed the procedures of ATC 40 in evaluating the seismic performance of residential buildings in Dhaka. The present study investigated as well as compared the performances of the bare frame, full infilled and soft ground story buildings. For different loading conditions resembling the practical situations of Dhaka city, the performances of these structures were analysed with the help of capacity curve, capacity spectrum, deflection, drift and seismic performance level. The performance of an in filled frame was found to be much better than a bare frame structure. It is found that consideration of the effect of the infill leads to significant change in the capacity. Investigation of buildings with soft storey showed that soft storey mechanism reduced the performance of the structure significantly and makes them most vulnerable type of construction in earthquake prone areas.

3. METHODOLOGY

1. Literature Review for understanding the concept.
2. Identifying the building plan and material properties.
3. Modelling the plan in ETABS 2016 & designing for worst load combinations as per IS-456- 2000 & to evaluate for Performance Based Design.
4. Develop plastic hinge properties to both ends of each beam and column section as per FEMA 356.
5. Analysis of the building using pushover. Results in terms of pushover curve (Base shear vs Displacement).

4. MATERIALS

1. Steel Properties:

Young's Modulus(E)	$2*10^5$ KN/m^2
Poisons Ratio (nu)	0.3
Density	76.8195 KN/m^3
Thermal Coefficient(a)	$1.2*10^{-5}$/c
Critical Damping Ratio	0.03

2. Concrete Properties:

Young's Modulus(E)	21718500 KN/m^2
Poisons Ratio (nu)	0.17
Density	23.5616 KN/m^3
Thermal Coefficient(a)	10^{-5}
Critical Damping Ratio	0.05

5. MODELLING

The Buildings are designed to resist Dead load, Live load, and seismic load. As per IS- 456-2000 various load combination was taken and the worst case was considered in the designing of the building. The dead load consists of a Self weight, brick infill, and floor load. Self-weight which indicates the load of beams and columns that are being calculated by ETABS 2015 itself based on the dimensions applied. Considering slab thickness 230mm floor load was calculated based on the unit weight of concrete to be 5.75 kN/m2 and brick infill load was taken as a uniform force of 20 KN/m.

Zone Factor (Delhi) Z= 0.24 (Zone IV)

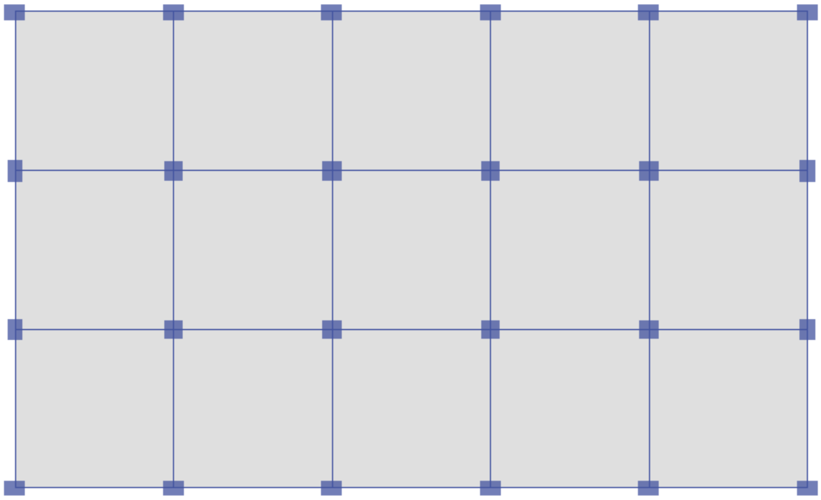
Importance Factor I= 1.0

Response reduction factor (RF) = 5 (Special Moment Resisting Frame)

Soil type= Medium Soil

Damping ratio = 0.05

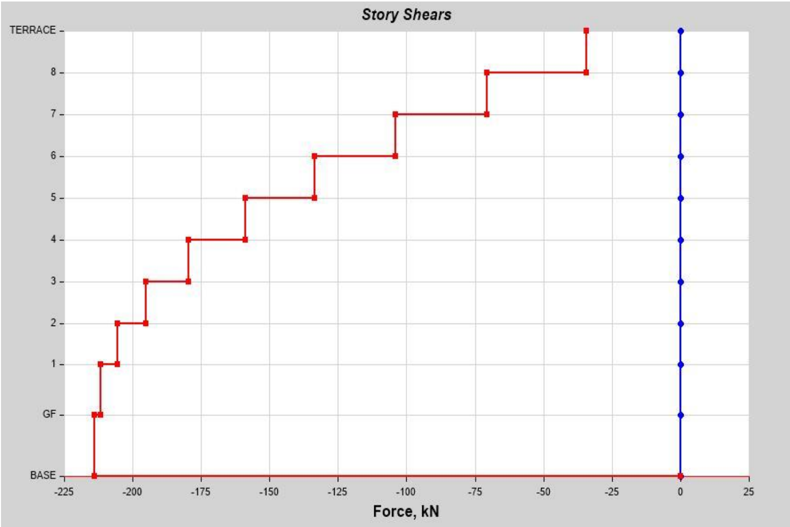
VB= Z/2 * I/R * Sa/g *W



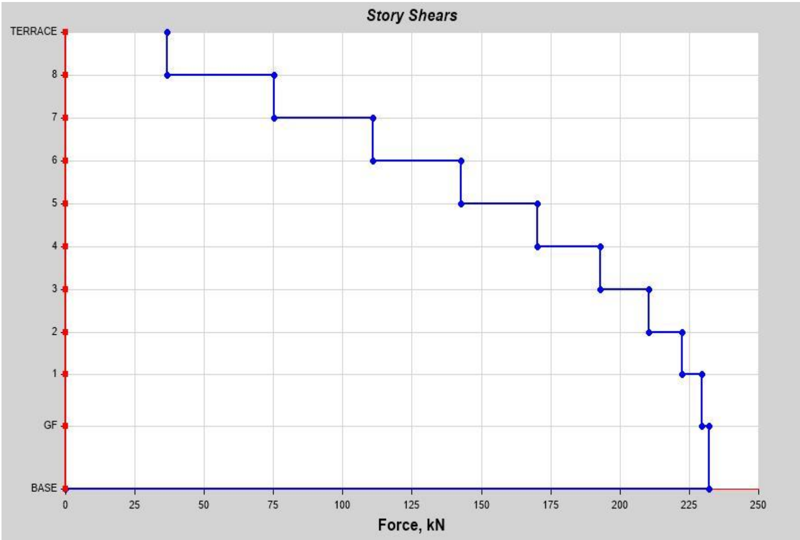
Plan

6. RESULT

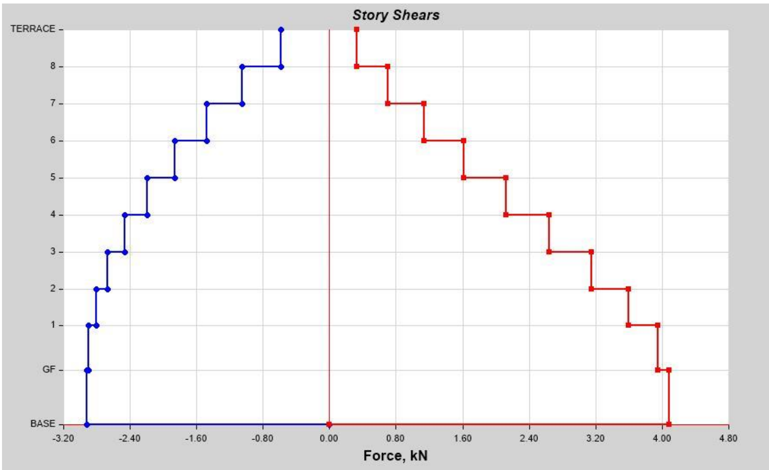
6.1. Response Spectrum



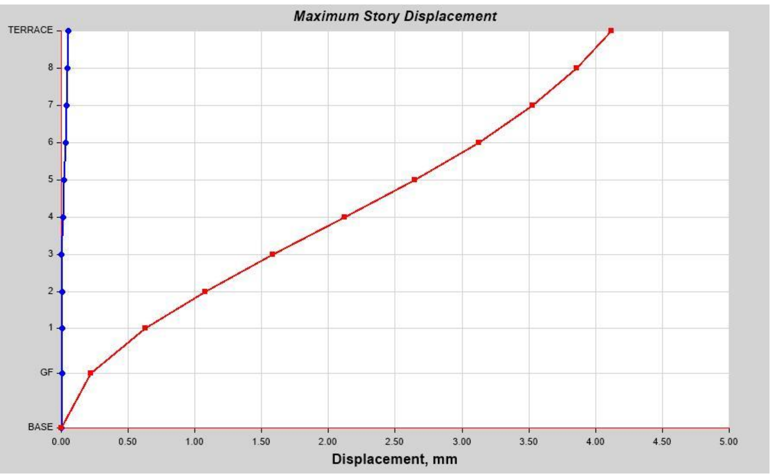
Base Shear in Mode 1



Base Shear in Mode 2

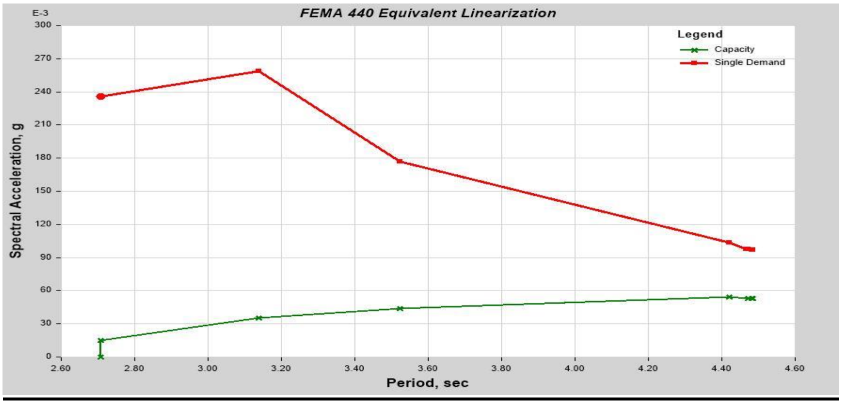


Base Shear in Mode 3



Maximum story displacement in Mode 1

6.2. Pushover Analysis



Base shear Vs. Displacement

Base Shear Vs Displacement

Table Showing Results At Different Steps

Base Shear vs Monitored Displacement

Step	Monitored Displ mm	Base Force kN	A-B	B-C	C-D	D-E	>E	A-IO	IO-LS	LS-CP	>CP	Total
0	-0.007	0	1428	0	0	0	0	1428	0	0	0	1428
1	119.712	6097.6225	1418	10	0	0	0	1428	0	0	0	1428
2	258.896	10184.3...	1206	222	0	0	0	1288	140	0	0	1428
3	282.612	10532.3...	1142	286	0	0	0	1265	160	0	3	1428
4	308.108	10721.2...	1100	328	0	0	0	1262	160	0	6	1428
5	336.714	10829.549	1074	354	0	0	0	1241	180	0	7	1428
6	348.136	10855.4...	1064	364	0	0	0	1233	187	0	8	1428
7	352.403	10872.5...	1063	365	0	0	0	1204	214	0	10	1428
8	357.725	10885.7...	1060	368	0	0	0	1203	215	0	10	1428
9	360.662	10897.073	1051	377	0	0	0	1195	223	0	10	1428
10	366.389	10902.9...	1048	380	0	0	0	1175	243	0	10	1428
11	376.571	10903.3...	1045	383	0	0	0	1167	251	0	10	1428
12	384.454	10924.896	1044	384	0	0	0	1158	247	13	10	1428

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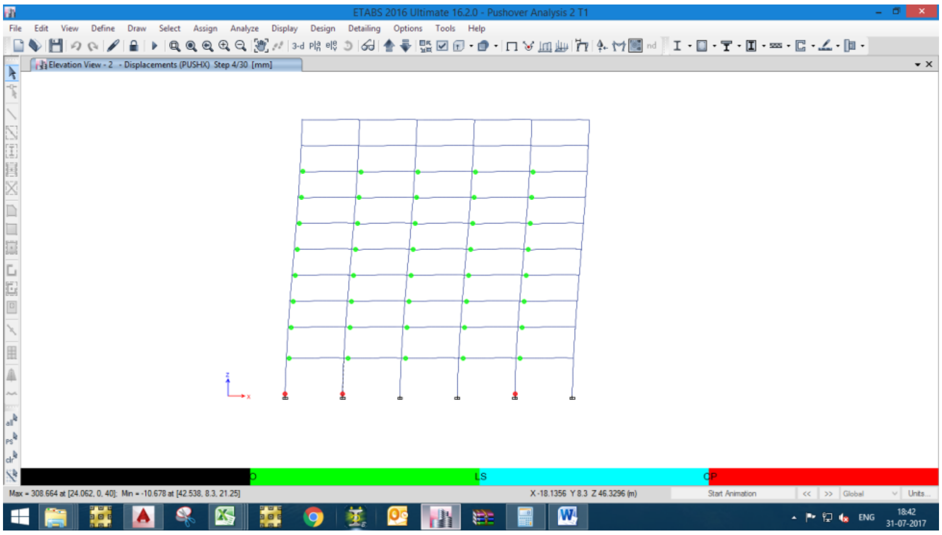
The above table & chart suggests a maximum Base shear of 10924 kN at Step 18 for a maximum displacement of 473.9mm.

6.3. Hinge State



Hinges State

6.4. Story Response

Story Response

TABLE: Story Response				
Story	**Elevation**	**Location**	**X-Dir**	**Y-Dir**
	m		mm	mm
TERRACE	40	Top	120.006	0.247
8	36.25	Top	112.047	0.237
7	32.5	Top	102.296	0.221
6	28.75	Top	90.51	0.2
5	25	Top	76.881	0.173
4	21.25	Top	62.131	0.142
3	17.5	Top	46.949	0.11
2	13.75	Top	32.122	0.077
1	10	Top	18.736	0.046

CONCLUSION

After studying all the curves and tables we came to the following conclusion that the Pushover Analysis result shows that the Building was able to achieve the performance point within its elastic range for most of the members. The Capacity of the structure was much more than the demand.
Further, we can conclude that:

1. Pushover analysis the simplest way to get the response of existing or new structures.
2. Considering different RC building it was concluded if the buildings are designed with proper sections and reinforcement details as per standard codes will perform better under seismic forces.
3. The performance of the pushover analysis mostly depends on the material used in the structure

REFERENCE

[1] Ramaraju et al. (2012), Performed Nonlinear analysis (pushover analysis) for a typical six-storey office building,
[2] Shahrin Hossain (2011), evaluated the seismic performance of residential buildings in Dhaka.
[3] ASCE 41, Seismic Rehabilitation of Existing Building (2007),
[4] IS-456- 2000 : Plain & Reinforced Concrete- Code of Practice,
[5] FEMA 356.

