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RESEARCH ARTICLE OPEN ACCESS

Analysis and Capacity Based Earthquake Resistance Design of Multy Bay Multy Storeyed Residential Building

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ABSTRACT
Many reinforced concrete (RC) framed structures located in zones of high seismicity in India are constructed without considering the seismic code provisions. The vulnerability of inadequately designed structures represents seismic risk to occupants**.** The main cause of failure of multi-storey reinforced concrete frames during seismic motion is the sway mechanism. If the frame is designed on the basis of strong column-weak beam concept the possibilities of collapse due to sway mechanisms can be completely eliminated. In multi storey frame this can be achieved by allowing the plastic hinges to form, in a predetermined sequence only at the ends of all the beams while the columns remain essentially in elastic stage and by avoiding shear mode of failures in columns and beams. This procedure for design is known as Capacity based design which would be the future design philosophy for earthquake resistant design of multi storey reinforced concrete frames. Model of multi bay multi storied residential building study were done using the software program ETAB2015 and were analyzed using non-linear static pushover analysis.

***Keywords*:** Hinge properties, Non linear static analysis, Pushover analysis, and Capacity based design of RC frame

I. INTRODUCTION

Conventional Civil Engineering structures are designed on the basis of strength and stiffness criteria. The strength is related to ultimate limit state, which assures that the forces developed in the structure remain in elastic range. The stiffness is related to serviceability limit state which assures that the structural displacements remains within the permissible limits. In case of earthquake forces the demand is for ductility. Ductility is an essential attribute of a structure that must respond to strong ground motions. Ductility is the ability of the structure to undergo distortion or deformation without damage or failure which results in dissipation of energy. Larger is the capacity of the structure to deform plastically without collapse, more is the resulting ductility and the energy dissipation. This causes reduction in effective earthquake forces.

The capacity design based on deterministic allocation of strength and ductility in the structural elements for successful response and collapse prevention during a catastrophic earthquake by rationally choosing the successive regions of energy dissipation so that pre-decided energy dissipation mechanism would hold throughout the seismic action. The most accurate method of seismic demand prediction and performance evaluation of structures is nonlinear Push Over Analysis. However, this technique requires the selection and employment of an appropriate set of lateral loads and acceleration and having a computational tool able to handle the

Analysis of the data and to produce ready to use results within the time constrains of design offices. A simple analysis method that has been gaining ground is the nonlinear static push over analysis. The purpose of the push over analysis is to assess the structural performance by estimating the strength and deformation capacities using static, nonlinear analysis and comparing these capacities with the demands at the corresponding performance levels. Model of multi bay multi storeyed residential building were done using the software program ETAB2015 and were analyzed using non-linear static pushover analysis. Parameters selected for analysis and design are cross section of uprights, thickness of uprights. Nonlinear push over analysis found to be a useful analysis tool for multi bay multi storied frame system. giving good estimates of the overall displacement demands, base shears and plastic hinge formation.

1.1 CAPACITY BASED DESIGN

Capacity Design is a concept or a method of designing flexural capacities of critical member sections of a building structure based on a hypothetical behavior of the structure in responding to seismic actions. This hypothetical behavior is reflected by the assumptions that the seismic action is of a static equivalent nature increasing gradually until the structure reaches its state of near collapse and that plastic hinging occurs simultaneously at predetermined locations to form a collapse mechanism simulating ductile behavior. The actual behavior of a building structure during a strong earthquake is far from that described above, with seismic actions having a vibratory character and plastic hinging occurring rather randomly. However, by applying the Capacity Design concept in the design of the flexural members of the structure, it is believed that the structure will possess adequate seismic resistance, as has been proven in many strong earthquakes in the past. A feature in the Capacity Design concept is the ductility level of the structure, expressed by the displacement ductility factor or briefly ductility factor. This is the ratio of the lateral displacement of the structure due to the Design Earthquake at near collapse and that at the point of first yielding. The basic of capacity based design lies on strong column and weak beam concept. The seismic inertia forces generated at its floor levels are transferred through the various beams and columns to the ground. The correct building components need to be made ductile. The failure of a column can affect the stability of the whole building, but the failure of a beam causes localized effect. Therefore, it is better to make beams to be the ductile weak links than columns. This method of designing RC buildings is called the strong-column weak-beam design method.

1.2 PRINCIPLE OF CAPACITY DESIGN

Structural seismic design adopted in the past did not succeed despite the designers being able to reasonably predict the behavior (including the capacity) of the structure. The main reason for this failure was the underestimation of the demand. Seismology is an ever evolving discipline and the estimation of seismic demand at a time is as good as the seismologists' understanding of the earthquake phenomenon at that time. As shown in **Fig. 1**, structures would generally be designed such that the capacity is reasonably larger than the perceived seismic demand and if an earthquake with seismic forces larger than the demand used in the design occurred, the designed capacity would not be enough to keep the response within elastic limit as intended in the design and the structure might undergo a brittle failure. It is not that designers can accurately predict the seismic demand now; but the current design philosophy is such that the underestimation of the seismic demand does not lead to catastrophic brittle failures. This is done through the principles of capacity design.

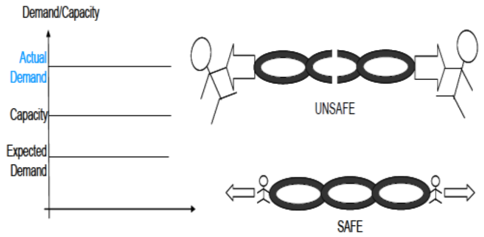

Fig.1: Inherent problem of elastic design

1.3 PUSH OVER ANALYSIS

In the pushover analysis, the structure is represented by a 2-D or 3-D analytical model. The structure is subjected to a lateral load that represents approximately the relative inertia forces generated at locations of substantial masses such as floor levels. The static load pattern is increased in steps and the lateral load-roof displacement response of the structure is determined until a specific target displacement level or collapse is reached. The internal forces and deformations computed at the target displacement levels are estimates of strength and deformation capacities which are to be compared with the expected performance objectives and demands. The sequence of component cracking, yielding and failure as well as the history of deformation of the structure can be traced as the lateral loads (or displacements) are monotonically increased. A typical lateral load-roof displacement performance relationship for a structure obtained from the pushover analysis is shown in **Fig.2**

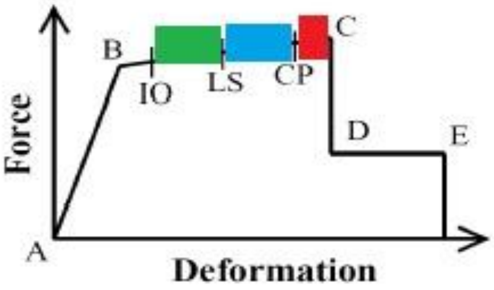

Fig.2: Performance Levels

Immediate occupancy IO: damage is relatively limited; the structure retains a significant portion of its original stiffness.

Life safety level LS: substantial damage has occurred to the structure, and it may have lost a significant amount of its original stiffness. However, a substantial margin remains for additional lateral deformation before collapse would occur.

Collapse prevention CP: at this level the building has experienced extreme damage, if laterally deformed beyond this point, the structure can experience instability and collapse

Deformation levels represented a speak roof displacements the capacity curve of the frames are firstly predetermined and the response parameters such as story displacements, inter-story drift ratios, story shears and plastic hinge locations are then estimated from the results of pushover analyses for any lateral load pattern at the considered deformation level or damage level in colored Fig2.

II. ANALYTICAL WORK

Building consists of 14m in X directions and 8.5m in Y-direction for Perform Pushover Analysis on computer program ETABS2015 to estimate ultimate capacity of structure for globally failure, so from preliminary design the sizes of various structural members were estimated as follows

Brick masonry wall Thickness: 230mm
Storey height: 3m for all floors.
Grade of steel: Fe-415
Grade of concrete: M-25
Column Size: 300X600mm
Beam Size: 300X 600mm
Slab thickness: 125 mm
Dead Load (DL):
Intensity of wall (Ext.& Int. wall) = 12.34 KN /m
Intensity of floor finish load =1.5 KN /m^2
Intensity of roof treatment load =1.5 KN /m^2
Live load (LL):
Intensity of live load =3 KN /m^2
Lateral loading **(**IS 1893 (Part I):2002):
Building under consideration is in Zone –V
Period Calculation: Program Calculated
Top Storey: Storey- 10
Bottom Storey: Ground Floor or Base
Response reduction factor, R = 5
Importance factor, I = 1
Building Height H = 30m
Soil Type = II (Medium Soil)
Seismic zone factor, Z = 0.36
Case: Push X & Push Y

Define hinges: The defined M3 hinge is assigned at ends of the beam member where flexural yielding is assumed to occur and P-M2-M3 for columns axial force with biaxial moments. Calculated Moment-curvature values for MRF are entered as input in ETABS2015.

III. RESULTS AND DISCUSSION

3.1 CAPACITY (PUSHOVER) CURVE

Capacity curves (base shear versus roof displacement) are the load-displacement envelopes of the structures and represent the global response of the structures. Capacity curves for the study frames were obtained from the pushover analyses using aforementioned lateral load patterns and are shown in below figures.

3.1.1 Capacity Curve Results for PushX

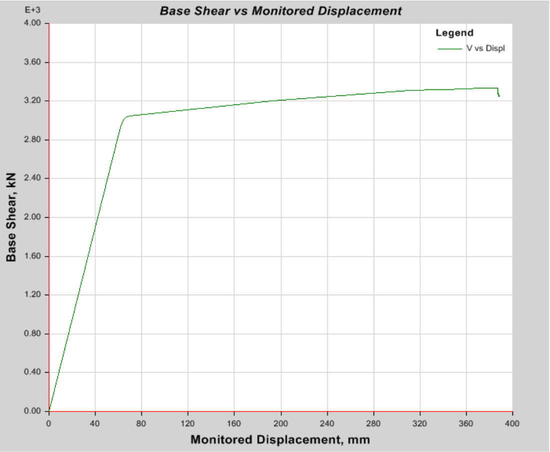

Fig.3: Capacity Curve for PushX (X-direction)

3.1.2 Formation of Plastic hinges in Model for different damage level at diff. steps (PushX)

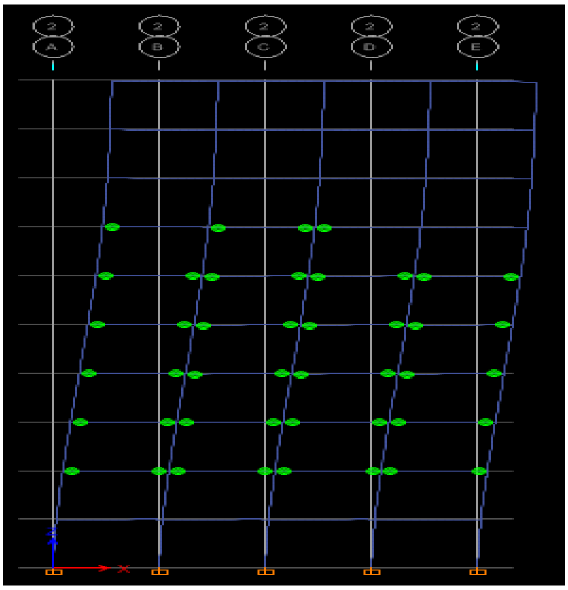

Fig.4:Plastic hinges at step 5

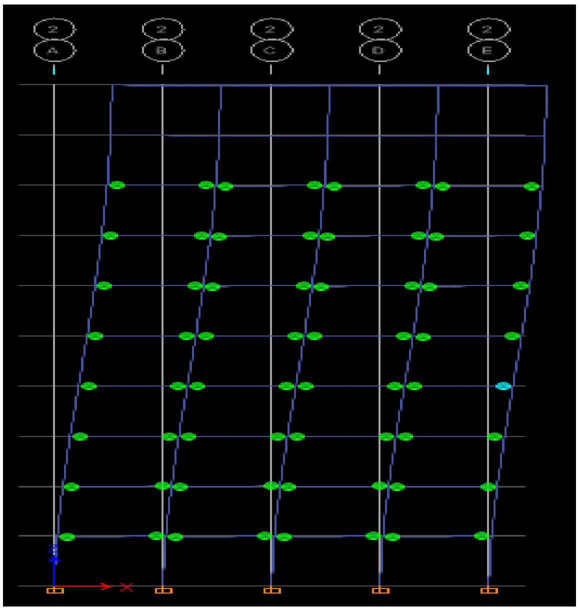

Fig.5:Plastic hinges at step 8

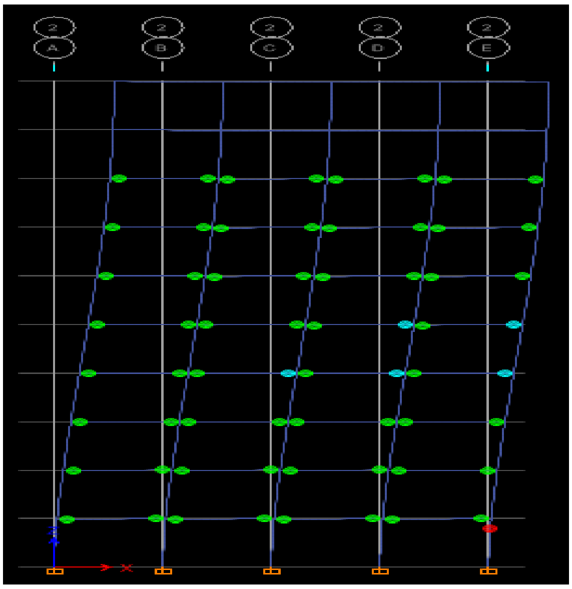

Fig.6:Plastic hinges at step 21

3.1.3 Capacity Curve Results for Push Y

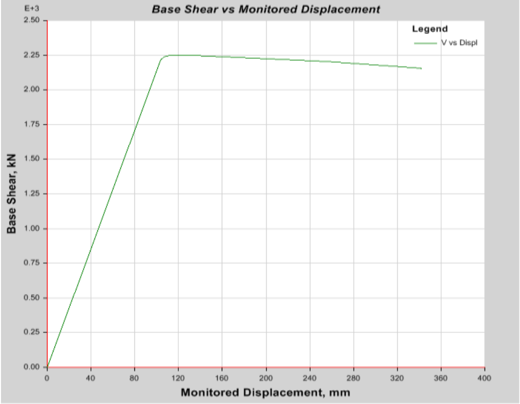

Fig.7: Capacity Curve for Push Y (Y-direction)

3.1.4 Formation of Plastic hinges in Model for different damage level at diff. steps (Push Y)

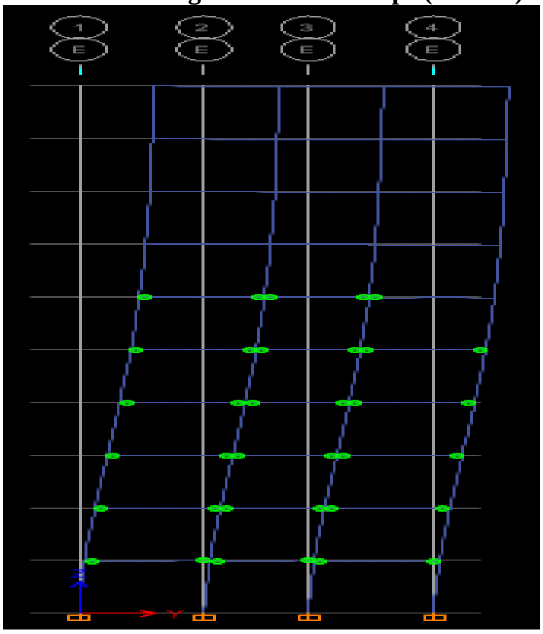

Fig.8:Plastic hinges at step 12

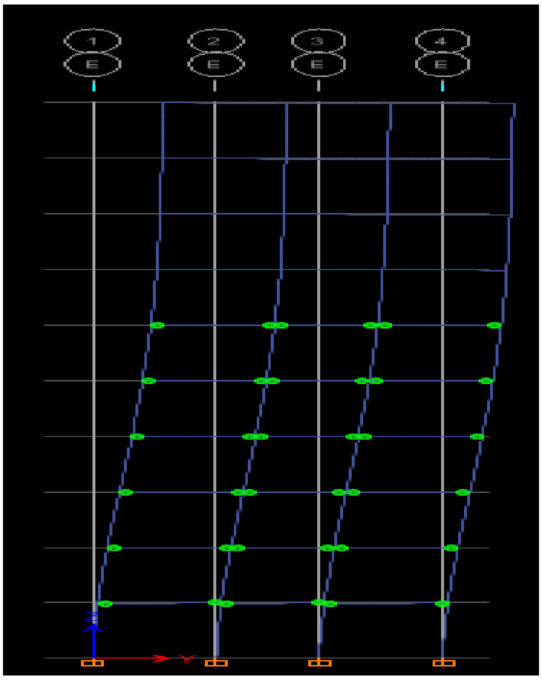

Fig.9:Plastic hinges at step 24

3.2 CAPACITY SPECTRUM CURVE

Capacity Spectrum curve is one way to know the performance of a structure. This method is used then the output parameter on ETAB2015 is performance point structure. This method is essentially a procedure that is done to get the actual transition structure building that generates big drift of the roof structure. The capacity spectrum curve, obtained the intersection of pushover curve with response spectrum curve. After the curve is obtained with certain modifications to the capacity of the revamped format ADRS into the capacity spectrum curve.

3.2.1 Capacity spectrum curve for PushX

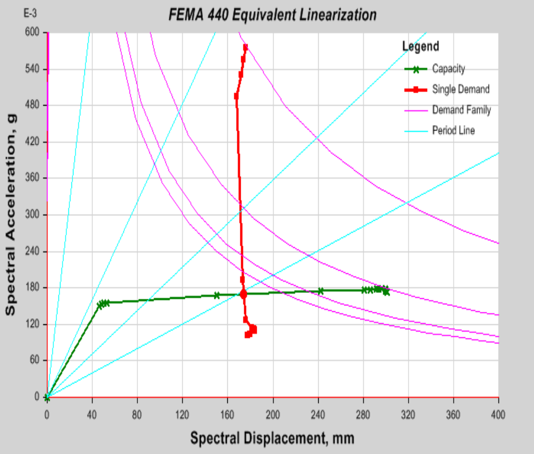

Fig.10: Capacity spectrum Curve for Push X

Table 3.2.1 Program generated data (Push X)

General Input Data	**Demand Spectrum Input Data**
Name:Pushover1	Source:ASCE7-10
Load Case: Push X	Site Class: D
Plot Type:FEMA440 EL	
Performance Point	
Point Found: Yes	T secant:2.02 sec
Shear:3231.0772 KN	T effective:1.8 sec
Disp.:223.2 mm	Ductility Ratio:3.661256
Sa:0.169469	Eff. Damping:0.1774
Sd:174.1 mm	Modi.Factor:0.799733
Demand Spectra Ductility Ratios:1; 1.5; 2; 2.5	
Constant Period Lines:0.5; 1; 1.5; 2	

3.2.2 Capacity spectrum curve for Push Y

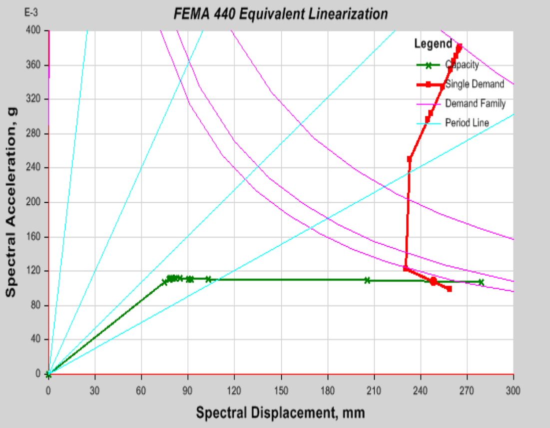

Fig.10: Capacity spectrum Curve for Push X

Table 3.2.2 Program generated data (PushY)

General Input Data	**Demand Spectrum Input Data**
Name:Pushover1	Source:ASCE7-10
Load Case: Push Y	Site Class: D
Plot Type:FEMA440 EL	
Performance Point	
Point Found: Yes	T secant:3.035 sec
Shear:2176.6439 KN	T effective:2.6 sec
Disp.:305.4 mm	Ductility Ratio:3.19901
Sa:0.107986	Eff. Damping:0.1654
Sd:248.3 mm	Modi.Factor:0.732178
Demand Spectra Ductility Ratios:1; 1.5; 2; 2.5	
Constant Period Lines:0.5; 1; 1.5; 2	

3.3 Lateral Displacement

In this portion, lateral displacement of all the models are presented in graphical form specifically each quantity in X and Y direction for both Pushover analysis and Response spectrum analysis.

3.3.1 Lateral Disp. from Pushover analysis

Table 3.3.1 Lateral Disp. from Push X & Push Y

		Push X	**Push Y**
Story	**Elevation**	**X-Dir Max**	**Y-Dir Max**
	m	**mm**	**mm**
Story10	30	388.6	342
Story9	27	379.6	336.6
Story8	24	357.2	327.5
Story7	21	320.3	311
Story6	18	273.5	283.7
Story5	15	220.1	243.4
Story4	12	163.5	191
Story3	9	107.6	131.9
Story2	6	56.9	73.5
Story1	3	16.9	25.2
Base	0	0	0

the structure is being pushed such that at every pushover step modal displacements of all modes are increased by increasing elastic spectral displacements, defined at the first step in the same proportion, they simultaneously reach the target “spectral displacements” on the response spectrum. Shown in Table3.3.1 are corresponding to the first yield, to an intermediate pushover step, and again increased displacement to the final step, which are plotted in the ADRS (Acceleration-Displacement Response Spectrum) format and superimposed onto the modal capacity diagrams.

Table 3.3.2 Lateral Disp. from Spec X & Spec Y

		Spec X	**Spec Y**
Story	**Elevation**	**X-Dir Max**	**Y-Dir Max**
	M	**Mm**	**mm**
Story10	30	28.9	46.4
Story9	27	27.6	44.4
Story8	24	25.8	41.5
Story7	21	23.5	37.9
Story6	18	20.7	33.6
Story5	15	17.6	28.8
Story4	12	14.1	23.6
Story3	9	10.4	17.9
Story2	6	6.5	11.8
Story1	3	2.7	5.5
Base	0	0	0

Therefore in Response spectrum analysis model the target displacement is within the capacity of the structure whereas in Pushover analysis model the target displacement is beyond the capacity of the structure.

3.4 Design of RCC frame

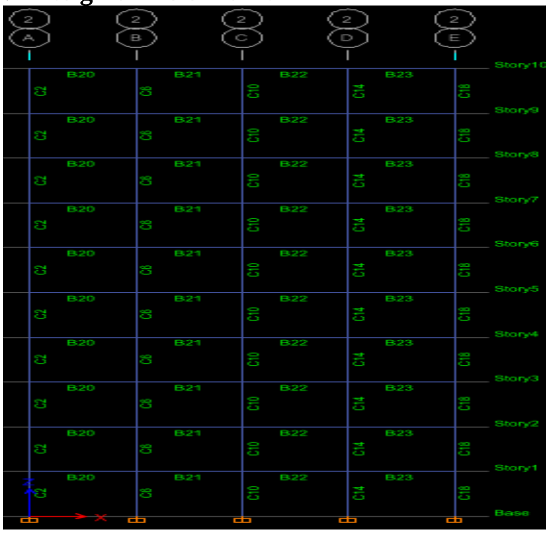

Fig.11: Model represents Beam & Column name

Table3.4 Comparison of Longitudinal Reinforcements from RSM & Pushover analysis

Analysis	RSM		Pushover	
CL name	C18	C2	C18	C2
Storey	Bottom			
Section	C300X600			
Area of rein.(mm^2)	3312	3312	O/S	9024
% of rein.	1.84	1.84	O/S	5
Hinge performance level	Nominal yield	Nominal yield	> CP	IO-LS

IV. CONCLUSION

After perform the Pushover analysis and response spectrum analysis on same building model following conclusions are drawn

1. The seismic performance of a building can be evaluated in terms of pushover curve, performance point, displacement ductility, plastic hinge formation etc. The base shear vs. roof displacement curve is obtained from the pushover analysis from which the maximum base shear capacity of structure can be obtained. This capacity curve is transformed into capacity spectrum by ETAB2015 as per ATC40 and demand or response spectrum is also determined for the structure for the required building performance level. The intersection of demand and capacity spectrum gives the performance point of the structure analyzed.

2. In Pushover analysis, as the loads are increased, the building undergoes yielding at a few locations. Every time such yielding takes place, the structural properties are modified approximately to reflect the yielding. The analysis is continued till the structure collapses, or the building reaches certain level of lateral displacement. It provides a load versus deflection curve of the structure starting from the state of rest to the ultimate failure of the structure. The load is representative of the equivalent static load of the fundamental mode of the structure. It is generally taken as the total base shear of the structure and the deflection is selected as the top-storey deflection. The selection of appropriate lateral load distribution is an important step.

3. Under increasing lateral loads with a fixed pattern the structure is pushed to a target displacement Dt. Consequently it is appropriate the likely performance of building under push load up to target displacement. The expected performance can be assessed by comparing seismic demands with the capacities for the relevant performance level. Global performance can be visualized by comparing displacement capacity and demand.

4. The sequence of plastic hinge formation and state of hinge at various levels of building performance can be obtained from ETAB2015 output. This gives the information about the weakest member and so the one which is to be strengthened in case of a building need to be retrofitted. Accordingly the detailing of the member can be done in order to achieve the desired pattern of failure of members in case of severe earthquakes. It is concluded that pushover analysis is a successful method in determination of the sequence of yielding of the components of a building, possible mode of failure, and final state of the building after a predetermined level of lateral load is sustained by the structure.

5. In general, a carefully performed pushover analysis is provided insight into structural aspects that control performance during severe earthquakes. For structures that oscillate primarily in the fundamental mode, the pushover analysis is provide good estimates of global as well as local inelastic deformation demands. The analysis is also expose design weaknesses that may remain hidden in an elastic analysis.

6. Injuries is occurred during the earthquake shaking; however, it is expected that the overall risk of life-threatening injury as a result of structural damage. It should be possible to repair the structure, however for economic reasons. The amount of damage in the buildings is limited and collapse is prevented. In the perspective, we want to integrate this pushover analysis to the seismic provisions for the seismic vulnerability assessment of reinforced concrete buildings.

7. All beams have reached their nominal yield capacity at all points and the excess moment beyond the yield is assumed to be carried by the contribution of hardening. Only columns has reached its beyond nominal yield capacity. Overall, columns in this study need more strengthening than beams.

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