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INVESTIGATION ON EVALUATION OF PUSHOVER ANALYSIS PROCEDURES FOR FRAME STRUCTURES

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Abstract : Nonlinear static analysis, or pushover analysis, has been developed over the past twenty years and has become the preferred analysis procedure for design and seismic performance evaluation purposes as the procedure is relatively simple and considers post elastic behavior. However, the procedure involves certain approximations and simplifications that some amount of variation is always expected to exist in seismic demand prediction of pushover analysis. Although, in literature, pushover analysis has been shown to capture essential structural response characteristics under seismic action, the accuracy and the reliability of pushover analysis in predicting global and local seismic demands for all structures have been a subject of discussion and improved pushover procedures have been proposed to overcome the certain limitations of traditional pushover procedures. However, the improved procedures are mostly computationally demanding and conceptually complex that use of such procedures are impractical in engineering profession and codes. As traditional pushover analysis is widely used for design and seismic performance evaluation purposes, its limitations, weaknesses and the accuracy of its predictions in routine application should be identified by studying the factors affecting the pushover predictions. In other words, the applicability of pushover analysis in predicting seismic demands should be investigated for low, mid and high-rise structures by identifying certain issues such as modeling nonlinear member behavior, computational scheme of the procedure, variations in the predictions of various lateral load patterns utilized in traditional pushover analysis, efficiency of invariant lateral load patterns in representing higher mode effects and accurate estimation of target displacement at which seismic demand prediction of pushover procedure is performed.

Keywords: Pushover analysis, frame building, Performance Point, Capacity Curve.

Introduction

The pushover analysis is a method to observe the successive damage states of a building. The method is relatively simple to be implemented, and provides information on strength, deformation and ductility of the structure and distribution of demands which help in identifying the critical members likely to reach limit states during the earthquake and hence proper attention can be given while designing and detailing. This method assumes a set of incremental lateral load over the height of the structure. Local nonlinear effects are modeled and the structure is pushed until a collapse mechanism is developed. With the increase in the magnitude of loads, weak links and failure modes of the buildings are found. At each step, the base shear and the roof displacement can be plotted to generate the pushover curve .This method is relatively simple and provides information on he strength, deformation and ductility of the structure and distribution of demands. This permits to identify the critical members likely to reach limit states during the earthquake by the formation of plastic hinges. On the building frame load/displacement is applied incrementally, the formation of plastic hinges, stiffness degradation, and lateral inelastic force versus displacement response for the structure is analytically computed.

To perform a pushover analysis, a lateral load versus deformation curves for the member is required.

The results from a pushover analysis will give the load versus deformation curves. Moreover, the pushover analysis gives only curve of the base shear versus roof displacement behavior of a building. The actual performance of a building may differ from the calculated performance, since the load versus deformation curves and the earthquake levels used in the analysis are estimates.

The structural engineering profession has been using the nonlinear static procedure (NSP) or pushover analysis described in FEMA-356 and ATC-40, when pushover analysis is used carefully it provides useful information that cannot be obtained by linear static or dynamic analysis procedure.Pushover analysis is an approximate analysis method in which the structure is subjected to monotonically increasing lateral forces with an invariant height-wise distribution until a target displacement is reached. Pushover analysis consists of a series of sequential elastic analyses, superimposed to approximate a force-displacement curve of the overall structure. A two or three dimensional model which includes bilinear or trilinear load-deformation diagrams of all lateral force resisting elements is first created and gravity loads are applied initially. A predefined lateral load pattern which is distributed along the building height is then applied. The lateral forces are increased until some members yield. The structural model is modified to account for the reduced stiffness of yielded members and lateral forces are again increased until additional members yield. The process is continued until a control displacement at the top of building reaches a certain level of deformation or structure becomes unstable. The roof diplacement is plotted with base shear to get the globalcapacity.

II. Pushover analysis of structure

2.1 Research Significance

The present study is to evaluate the behavior of G+3 reinforced concrete frame structure subjected to earthquake forces in zone II. The reinforced concrete structures are analyzed by nonlinear static analysis (Pushover Analysis) using SAP2000 software. It shows the performance levels, behavior of the components and failure mechanism in a building. It also shows the types of hinge formation, the strength and capacity of the weakest components.

2.2 Performance Based Design for Nonlinear Static Pushover Analysis

Create the basic computer model of four storey building frame structure. Define properties and acceptance criteria for the pushover hinges .The program includes several built-in default hinge properties that are based on average values from ATC-40 for concrete members and average values from FEMA-356 for steel members. These built in properties can be useful for preliminary analyses, but user defined properties are recommended for final analyses. Locate the pushover hinges on the model by selecting one or more frame members and assigning them one or more hinge properties. Define the pushover load cases. Pushover load case is used to apply gravity load and then lateral pushover load cases are specified to start from the final conditions of the gravity pushover. Pushover load cases can be force controlled, that is, pushed to a certain defined force level, or they can be displacement controlled, that is, pushed to a specified displacement.

The numbers of hinges are shown in the and In each member showing the hinges in beams the immediate occupancy, life safety, collapse prevention and some limited hinges are shown in column to define the force deflection behavior of the hinge. The lateral load is applied on the frame, which when deflected forms hinges. Frame is estimating the plastic hinge formation at the yielding and significant difference in the hinging patterns at the ultimate state. The hinge locations are shown in the frame. In frame hinges shows a ductile beam mechanism in which the columns are stronger than the beam. Damage or failure occurs at the beam.

2.3 Use of Pushover Results

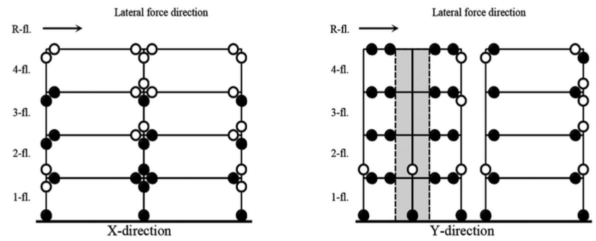
shover analysis has been the preferred method for seismic performance revaluation of structures by the major rehabilitation guidelines and codes because it is5 conceptually and computationally simple. Pushover analysis allows tracing the sequence of yielding and failure on member and structural level as well as the progress of overall capacity curve of the structure. The expectation from pushover analysis is to estimate critical response parameters imposed on structural system and its components as close as possible to those predicted by nonlinear dynamic analysis. Pushover analysis provide information on many response characteristics that cannot be obtained from an elastic static or elastic dynamic analysis.These are

- estimates of interstory drifts and its distribution along the height
- determination of force demands on brittle members, such as axial force demands on columns, moment demands on beam-column connections
- determination of deformation demands for ductile members
- identification of location of weak points in the structure (or potential failure modes)
- consequences of strength deterioration of individual members on the behavior of structural system
- identification of strength discontinuties in plan or elevation that will lead to

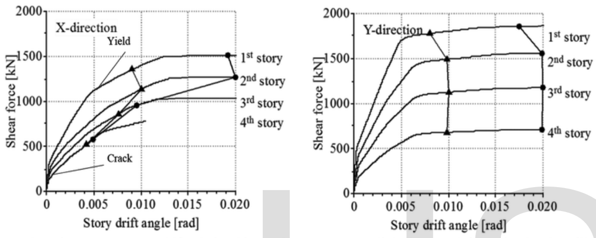
changes in dynamic characteristics in the inelastic range

• verification of the completeness and adequacy of load path

Pushover analysis also expose design weaknesses that may remain hidden in an elastic analysis. These are story mechanisms, excessive deformation demands, strength irregularities and overloads on potentially brittle members.



(a) Hinge distribution; filled circles mark locations of inelastic rotations at larger drifts highlighted in (b)



(b) Story shear force versus story drift relationship; pushover curves are linked at two deformation levels to illustrate the distribution of deformations across the stories. Link-lines were drawn where the maximum story drift angles reached 0.01 and 0.02. Link-lines at the higher deformations correspond to the hinge locations shown in (a)

2.4 Pushover Methodology :-

Pushover analysis is a static, nonlinear procedure in which the magnitude of the lateral force is incrementally increased, maintaining the predefined distribution pattern along the height of the building. With the increase in the magnitude of the loads, weak links and failure modes of the building are found. Pushover analysis can determine the behavior of a building, including the ultimate load and the maximum inelasticdeflection. Local Nonlinear effects are modeled and the structure is pushed until a collapse mechanism gets developed. At each step, the base shear and the roof displacement can be plotted to generate the pushover curve.

It gives an idea of the maximum base shear that the structure was capable of resisting at the time of the earthquake. For regular buildings, it can also give a rough idea about the global stiffness of the building.

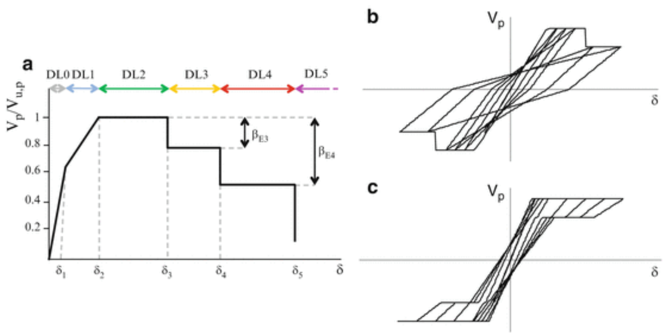
2.5. Nonlinear Plastic Hinges Properties :-

The building has to be modeled to carry out nonlinear static pushover analysis. This requires the development of the force - deformation curve for the critical sections of beams, columns. The force deformation curves in flexure were obtained from the reinforcement details and were assigned for all the beams and columns.

The Nonlinear properties of beams and columns have been evaluated using the section designer and have been assigned to the computer model in SAP2000. The flexural default hinges (M3) and shear hinges (V2) were assigned to the beams at two ends. The interacting (P-M2-M3) frame hinges type a coupled hinge property was also assigned for all the columns at upper and lower ends .

3.Performance level of a structure :-

The structural and non- structural components of the buildings together comprise the building performance. The performance levels are the discrete damage states identified from a continuous spectrum of possible damage states. The structural performance levels based on the roof drifts are as follows:Five points labeled A, B, C, D and E are used to define the force deflection behavior of the hinge and these points labeled as Pushover Analysis of G+3 Reinforced Concrete Building with soft storey



The performance levels (IO, LS, and CP) of a structural element are represented in the load versus deformation curve as shown below,

1. A to B – Elastic state,

i) Point 'A' corresponds to the unloaded condition.

ii) Point 'B' corresponds to the onset of yielding.

2. B to IO- below immediate occupancy,
3. IO to LS – between immediate occupancy and life safety,
4. LS to CP- between life safety to collapseprevention,
5. CP to C – between collapse prevention and ultimate capacity,
i) Point 'C' corresponds to the ultimate strength
6. C to D- between C and residual strength,
i) Point 'D' corresponds to the residual strength
7. D to E- between D and collapse
i) Point 'E' corresponds to the collapse.

III. Result and Discussion :-

A Four storied reinforced concrete frame structure of building was taken to analysis. The frame was subjected to design earthquake forces as specified in the IS code for zone II along longer directions. Bare frame pushover curves for the building in X directions as. These curves show the behavior of the frame in terms of its stiffness and ductility. For bare frame maximum base shear from pushover analysis is 951.78 KN and maximum displacement of 240.65mm in X direction. Capacity spectrum is the capacity curve spectral acceleration Vs spectral displacement (Sa Vs Sd) co-ordinates. The performance point is obtained by superimposing demand spectrum on capacity curve transformed into spectral coordinates. The frame shows the performance of the on the spectral acceleration corresponding to the performance point. The performance point is obtained at a base shear level of 550KN and displacement of 45mm in the X direction.

IV. Conclusion

The pushover analysis is a simple way to explore the nonlinear behavior of the buildings. The results obtained in terms of pushover demand, capacity spectrum and plastic hinges the real behavior of structures. In a four storey building seismic zone – II is designed and constructed using IS-456-1978 and the revised code IS1893- 2000 provisions. Hinges have developed in the beams and columns showing the three stages immediate occupancy, Life safety, Collapse prevention. The column hinges have limited the damage.

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