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Adaptive NSP on L-shaped building

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ABSTRACT: The demand of reliable nonlinear static pushover analysis on structures subjected to earthquake forces has resulted in adaptive pushover analysis in the recent times, which considers the effect of higher modes of vibration and progressive stiffness degradation of structural members. The irregularities in the buildings are considered to be damage amplifiers since they make the failure in structures brittle during the incidence of an earthquake force. This study evaluates the performance of the plan irregular building (L-shaped in the plan) using nonlinear adaptive pushover when subjected to seismic forces.

KEYWORDS: Plan irregularity, Nonlinear static procedure (NSP), Nonlinear dynamic analysis, Seismic forces

I. INTRODUCTION

The Nonlinear dynamic analysis is undoubtedly a most accurate method for response analysis of structures subjected to earthquake forces. But it is computationally demanding and time-consuming in an office environment. These drawbacks paved the way for the evolution of nonlinear static method.

In Nonlinear static method, a mathematical model is simulated by incorporating the nonlinear characteristics like load-deformation relations into the constituent elements of the structure. The model is loaded with gravity loads and subjected to monotonically increasing lateral load representing the inertia forces in an earthquake. The structure will be pushed till the target displacement is exceeded at the control node. This conventional pushover method recommended by ATC-40 [1] and FEMA-356 [3] considers the only effect of the dominant mode of vibration. In the case of irregular structures, mainly in plan irregular buildings, the torsional mode of vibration will cause considerable damage to the structures during earthquake incidences. However, the effect of torsional mode of vibration will be neglected in conventional pushover analyses.

The consideration of higher mode of vibration led to the development of adaptive nonlinear static pushover analysis. The concept of adaptive pushover method was first developed by Pinho and Antoniou [6]. Incorporation of adaptive methodology in the conventional pushover analysis is done in following steps. (1) Definition of nominal load vector and inertia force. (2) Calculation of load vector after the lateral load increment. (3) Calculation of scaling vector and updating the loading vector. The first step is carried out only at the beginning of the analysis and other steps are repeated at every equilibrium stage of the analysis is reached. Following the above-mentioned steps, the effect of higher modes of vibration is also taken into account in the analysis.

II. LITERATURE SURVEY

The lateral load's nature, distribution and its magnitude are the critical parameters that determines the suitability of a nonlinear analysis method in the estimation of the seismic demand of the irregular structure. Also, the convergence criteria and iterative strategy play a significant role in the effectiveness and reliability of the conventional pushover methods. Based on this the conventional pushover method fails in taking the progressive changes in modal properties during the nonlinear yielding and cracking in the structure leads to period elongation. In the conventional type, the usage of constant lateral load pattern ignores the potential redistribution of inertia forces and higher mode effects and

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yielding cracking governs the inelastic behaviour (Krawinkler et al., 1998). And they concluded the conventional method as inadequate and misleading.

The irregularities in the plan will have an asymmetric distribution of mass, stiffness, and strength which become a source of damage during the seismic event. Because they cause the torsional effect (De Stefano et al., 2008) [2]. So higher mode consideration for the analysis become necessary. This leads to the development of Adaptive pushover analysis whereby the loading vector is updated at each analysis step, considering one or more response modes, reflecting in this way the effects that damage progression has on the response characteristics of structures subjected to increasing loading levels (Pinho et al., 2006) [6]. So in the current study adaptive methodology is considered for the determination of the seismic response of the plan irregular building.

III. MODELLING

The basic cause of torsional effect in the structure is due to eccentricity between the mass centre and stiffness centre. This type of eccentricity may occur in two different cases (1) Symmetrical structural plan with the shift of mass centre in one or both horizontal directions (2) Asymmetrical structural plan.

In this study, the second case is considered for the study. The building is a reinforced concrete framed structure with the L-shaped plan as shown in figure 1.

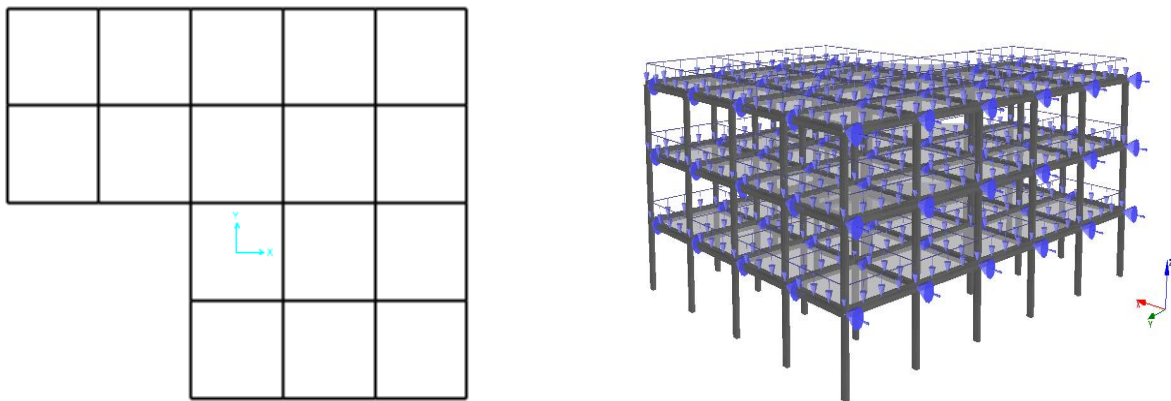


Figure 1: Model used in the study having the re-entrant L-shaped in plan with 40% projection x-direction and 50% in Y-direction and its 3-D elevation simulated in seismostruct software showing the gravity loads and pushover loads.

The 3-D plan irregular building model is created based on IS 1893 part (1): 2002 [4] code. Study model has 3m inter-storey height at all levels and each bay measuring a dimension of 5m. The characteristic compressive strength of concrete is 20N/mm^2 and yield strength of the reinforcement is 500N/mm^2 . The nonlinear material behaviour of concrete is modelled using uniaxial nonlinear constant confined Mander's model and steel reinforcement is modelled using Menegotto pinto's steel model.

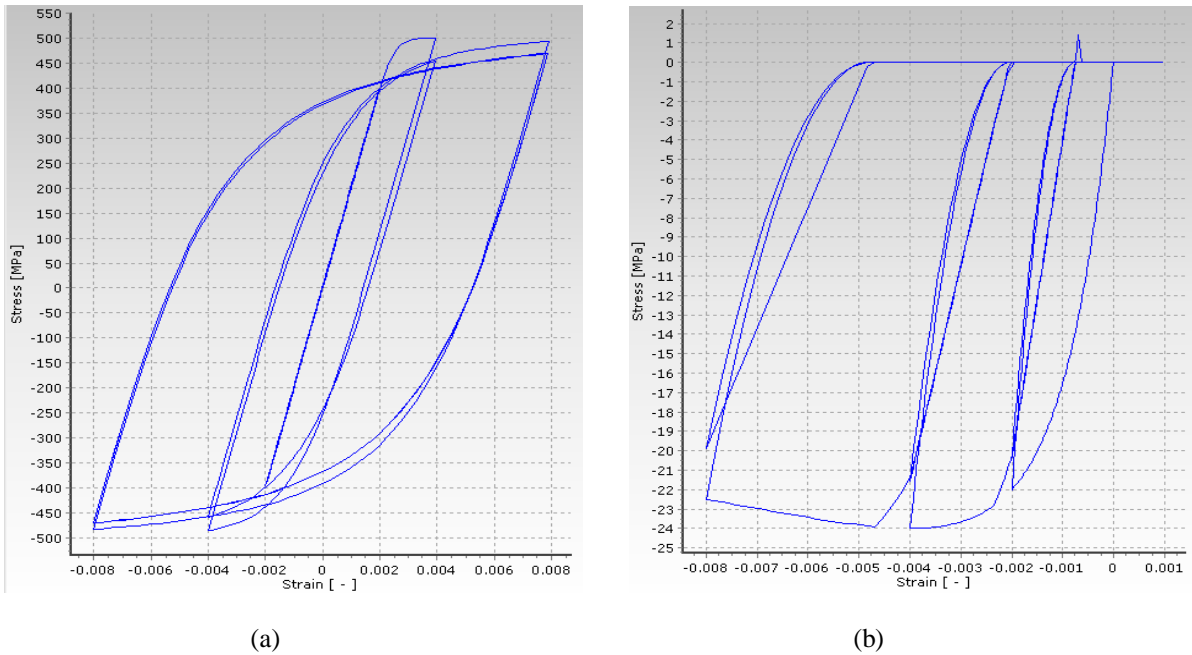


Figure 2: (a) Menegotto pinto's steel model showing the Stress-Strain relation for the reinforcement having the yield strength 500N/mm^2 used in the models. (b) Mander's concrete model showing the Stress-Strain relation for structural concrete used in the model having the characteristic compressive strength 20N/mm^2 .

The building model is assumed to be founded on type 2 (medium) soil and earthquake zone V, according to IS-1893 part (1): 2002 code [4]. The analysis is performed using the nonlinear earthquake analysis software seismostruct. When the analysis is carried out the shape of the load vector is automatically defined based on the nonlinear behaviour and updated according to the above-mentioned adaptive algorithm. To avoid the distortion in the load vector configuration due to the nonlinear response characteristic of the structure in any step the initial nominal load vector is considered as a uniform pattern.

For modelling three-dimensional beam-column element is used. These elements are capable of incorporating the geometric and material nonlinearities. The stress-strain state of the beam column section is obtained by the integration of nonlinear uniaxial material response of the individual fibres. The inelasticity is spread along the member length and across the section depth. Because of the spread inelasticity, it is capable of capturing the inelastic behaviour along the entire length of the structural member. The damping for the structural member is defined at element level using non-classical Rayleigh damping coefficient. The member discretisation and the direction of the elemental forces are shown in figure 3.

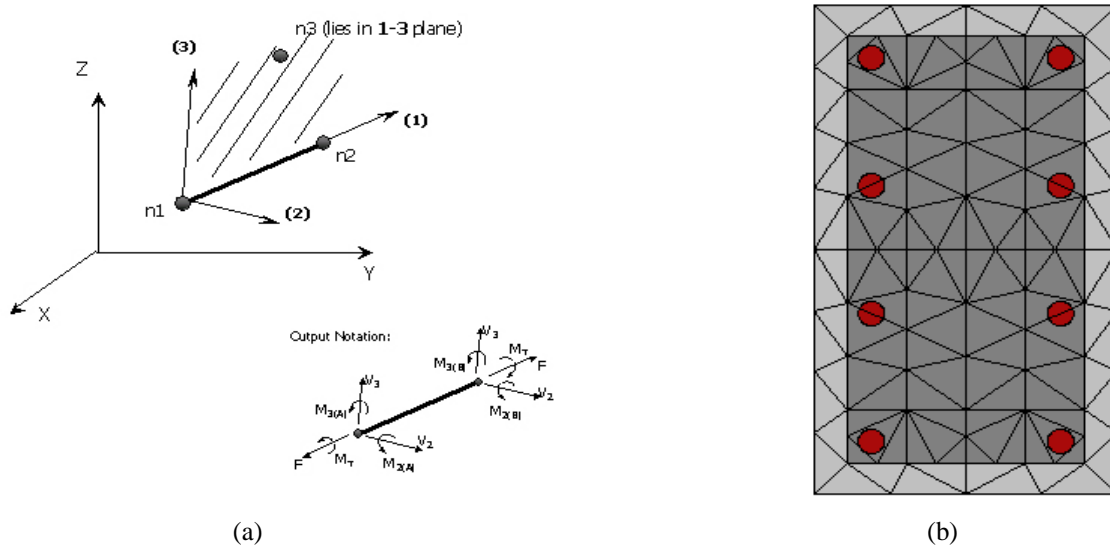


Figure 3: (a) Direction of elemental forces and their local axes of the structural elements. (b) Discretisation of column element.

IV. METHODOLOGY

The adaptive nonlinear static analysis is carried out using seismostruct software. The lateral load is applied in a uniform pattern. A mathematical model to carry out the adaptive pushover analysis are simulated and analysis is carried out in positive X-direction and Y-direction as well as in negative X-direction and Y-direction. The performance criteria for steel are yielding of steel and fracture of steel and the performance criteria for concrete are spalling of concrete and crushing of concrete are considered. The performance criteria in the section is cracking of the structural member.

V. RESULTS

The various performance criteria used in the analysis of the models are as below.

1. Cracking of structural members can be observed when the strain in the concrete is larger than the ratio between tensile strength and initial stiffness of the concrete element. The value corresponding to this performance criterion is taken as 0.0001.
2. Spalling of concrete cover can be recognised by checking for (negative) cover concrete strains larger than the ultimate crushing strain of the unconfined concrete material. The value corresponding to this performance criterion used in this analysis is -0.002.
3. The crushing of concrete core can be checked by comparing the (negative) core concrete strains larger than the ultimate crushing strain of confined concrete material. The value corresponding to this performance criterion used in this analysis is -0.006.
4. The yielding of steel can be identified by checking for (positive) steel strains larger than the ratio between yield strength and young's modulus of the steel material. The value corresponding to this performance criterion used in this analysis is + 0.0025.

Based on the criteria defined above the points at which this failure occurs, the base shear and displacement at the control node are noted and tabulated. The base shear and top displacement corresponding to the first crushing of concrete and first spalling of the cover are tabulated in table 1. The base shear and displacement at the control node for first yielding in steel and cracking of concrete is tabulated in table 2.

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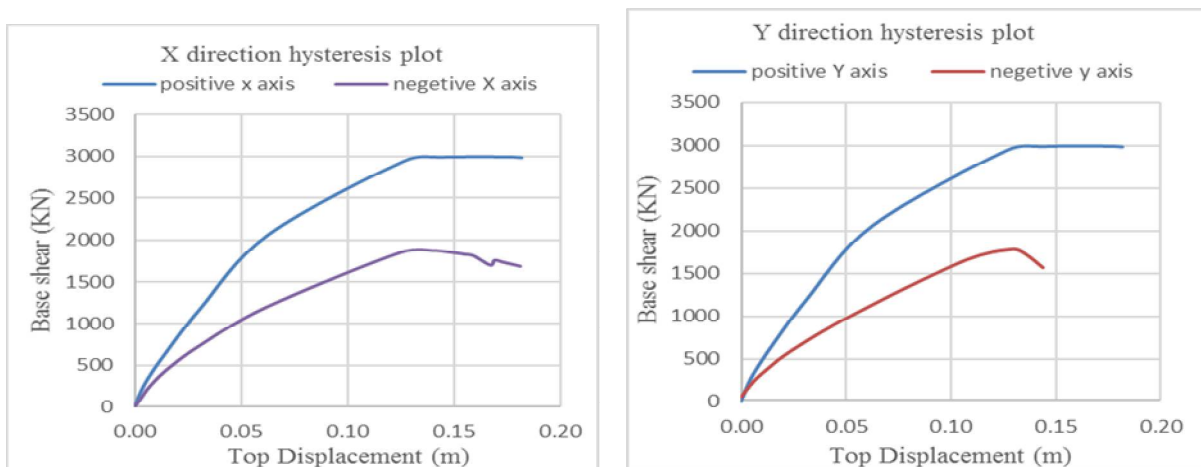
Table 1: Performance Criteria Co-ordinates For First Crushing Concrete And First Spalling Of Cover.

Performance criteria	First crushing concrete		First spalling cover	
	Top displacement	Base shear	Top displacement	Base shear
Positive X-direction	0.102	2504.74	0.102	2504.74
Negative X-direction	0.158864	1810.026	0.144816	1862.478
Positive Y-direction	0.126	1774.001	0.126	1774.001
Negative Y-direction	0.126474	2945.565	0.126474	2945.565

Table 2: Performance Criteria Co-ordinates For First Yield Of Steel And First Spalling Of Cover.

Performance criteria	First yield of steel		First crack of member	
	Top displacement	Base shear	Top displacement	Base shear
Positive X-direction	Not observed		Not observed	
Negative X direction	0.12487845	1849.81401	0.06173141	1199.08839
Positive Y-direction	Not observed		Not observed	
Negative Y direction	0.12647386	2945.56516	0.03075149	1185.53515

The capacity curves in the form of base shear and displacement at the control node plots for the seismic force incidence in positive X-direction, negative X-direction is shown in figure 4(a). Also, the capacity curves in the form of base shear and displacement at the control node plots for the seismic force incidence in positive Y-direction, negative Y-direction is shown in figure 4(b).



(a)

(b)

Figure 4: The capacity curves plotted as Base Shear versus top displacement at the control node plot for Pushover analysis with different direction of incidence of the seismic force.

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VI. CONCLUSION

1. From the results of the base shear versus top displacement at the control node, it can be incurred that when the earthquake along the negative y-direction is more vulnerable.
2. The seismic energy observed during the negative y-direction incidence is less when compared to any other direction of incidence.
3. The co-ordinates at which the various performance criteria occur are tabulated above.
4. The response of the structure varies with the direction of incidence of the seismic force.

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