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Review on Pushover Analysis of Mixed Framed Type RC Building

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ABSTRACT

Pushover analysis (PA) is a static process that estimates seismic structural deformations using a simplified nonlinear technique.Most of the structural engineers are designing the structures up to elastic limits ignoring the plastic state of the structure. However, for seismic loading the structures are not always deformed in elastic limit but also enters in inelastic range, so it is necessary to analyse the structures up to plastic ranges with probable location of hinges. Based on the results obtained from the pushover analysis whether collapse occurs in members or at structural level can be identified. Many researchers have used pushover method to study behaviour of various Reinforced concrete (RC) structure, mixed framed buildings with and without infill wall, steel framed building & steel-concrete composite structure. The literature available related to analysis of various structures using pushover method is reviewed and presented in this paper. Expected outcome of this paper is to find out the seismic performance of the different types of structures and possible location of hinges along with performance point using pushover method by studying the past literatures.

Keywords: *Hinges, Mixed frame building, Pushover analysis, Performance point.*

I. INTRODUCTION

Function of any structural system is to resist the loads acting on it and provide a skeleton that subdivides and encloses the space to create a safe environment. A structural system as a whole is divided into different sub-systems viz. Load Bearing System, Framed System, Shell System, Strut and Tie, Hybrid or Mixed System. Hybrid buildings are one that have two or more lateral load-resisting systems. Buildings are normally designed for static as well as seismic forces. As there is discontinuity in both lateral and vertical load transfer processes, hybrid structureshave a distinct seismic response than traditional structural systems and the response under lateral loads becomes complex. Post–earthquake observations have revealed poor performance of Reinforced concrete (RC) and masonry hybrid structures and such structures are typically classified as a highly vulnerable class of buildings. As hybrid structureis made up of two different materials, the strength and rigidity properties are noticeably different. Hence modelling of the joint connection between the two materials is the most important since the behavior of these connections cannot be predicted.The inelastic action of such joints produces calculation complexities.The rigidity of the joint connection between the two different material elements determines the extent of moment dispersion.The amount of shear transfer is determined by the stiffness

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of the joint.The shear transferred from the RC beam to the masonry wall determines how the wall behaves during seismic loading.How the degree of fixity at the joint can be determined and incorporated accurately in the modelling is a real challenge.

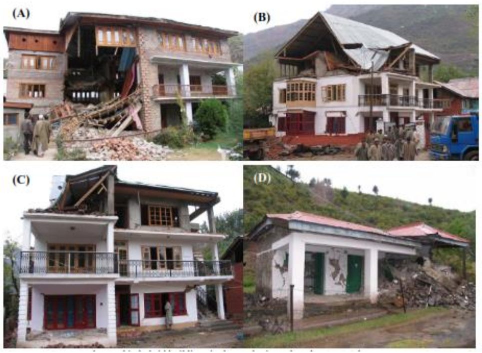
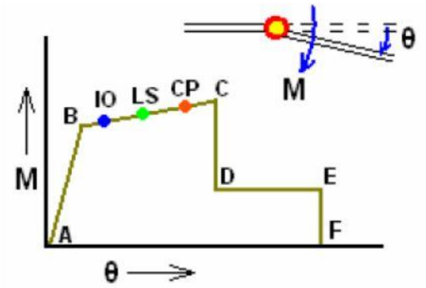


Fig -1: Damage observed in hybrid buildings in the Kashmir earthquake, 2005 (photo courtesy: CVR Murty)

1.1PUSHOVER ANALYSIS

Pushover analysis (PA) is a static non-linear study of a structure under permanent vertical loads and gradually rising lateral loadsalong the building's height. It is also use to determine behaviour of a building under dynamic conditions. In this method local nonlinear effects are modelled, and the structure is pushed to its limit until a collapse mechanism emerges.The base shear and roof displacement can be plotted at each step to construct the pushover curve.This technique yields a plot of total base shear vs top displacement in a structure, which can reveal any early failure or weakness. The analysis is carried out up to failure of structure. Plastic rotation is tracked in a building frame and the lateral inelastic force versus displacement response for the entire structure is calculated analytically. This form of examination allows the detection of structural flaws.The purpose of pushover analysis is to evaluate the expected performance of structural systems by estimating performance of a structural system by estimating its strength and deformation demands in design. Global drift, inter-story drift, inelastic element deformations, deformations between elements, and element connection forces among the performance parameters are assessed.The inelastic static pushover analysis is a method for estimating seismic force and deformation demands that accounts for the redistribution of internal forces that can no longer be resisted within the elastic range of structural behaviour in an approximate way. The pushover is supposed to provide information on a variety of response characteristics that an elastic static or dynamic analysis would not be able to provide.

In a structure hinges are formed when the structure approaches its ultimate strength under cyclic loading. Hinges are the locations where cracking and yielding are expected to occur in a disproportionately higher intensity. When a building is subjected to seismic loading, hinges are found at the either ends of beams and columns.Flexural hinges and shear in beams and columns whereas axial hinges are considered in case of infill walls while modelling. As masonry infills have a significant impact on the seismic behaviour of a structure, modelling them with equivalent diagonal struts is prevalent in PA.Under seismic loads, the hinge depicts the localised force-displacement relationship of a part through its elastic and inelastic phases. A flexural hinge, for example, represents the moment-rotation relationship of a beam, such as the one shown in Fig.3.From unloaded condition A to its effective yield B, AB shows a linear elastic range, followed by an inelastic yet linear response of decreasing (ductile) stiffness from B to C. CD exhibits a sudden drop in load resistance, which is followed by a drop in resistance from D to E, and then a complete loss of resistance from E to F. In a framed building, hinges are commonly installed in the structural components as seen in Fig.4. Within their ductile range, these hinges have non-linear states named 'Immediate Occupancy' (IO), 'Life Safety' (LS), and 'Collapse Prevention' (CP). This is generally done by dividing B-C into four parts and denoting IO, LS and CP, which are states of each individual hinges.



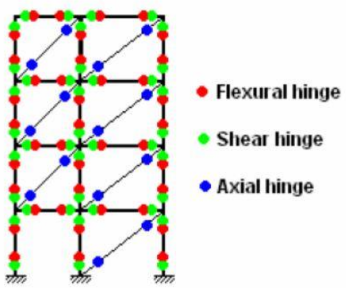


Fig -3: A Typical Flexural Hinge Property, showing Fig -4: Typical Locations of Hinges in a Structural ModelIO (Immediate Occupancy), LS (Life Safety)
and CP (Collapse Prevention)
(photo courtesy: Rahul Leslie for Fig-3,4)

II. LITERATURE REVIEW

Various literature reviewed on pushover analysis of RC structures, RC framed structure with and without infill wall, steel frame buildings and steel-concrete composite frame structures are presented in brief in this section.

2.1 Pushover Analysis of Reinforced Concrete Structures

N.K. Manjula, Praveen Nagarajan, T.M. Madhavan Pillai (2013)have carried out pushover analysis of a RC building frame designed as per IS 1893-2002 provisions. Seismic zones 3 and 4 were considered in the study. The building's performance was evaluated using three pushover analysis methods: FEMA 356 (Displacement Coefficient Method), FEMA 440 (Displacement Modification Method), and ATC 40 (Capacity Spectrum Method).They observed higher base shear (Vb) values for FEMA 440 EL and ATC 40 as compared to FEMA 356 and FEMA 440DM [1].

R. A. Hakim, M. S. Alama, S. A. Ashour (2014) evaluated performance of four different buildings with different storeys,designed according to Saudi Building Code, using pushover analysis. Building performance levels were determined in accordance with ATC-40, FEMA-356, and FEMA-440 using SAP2000 software. The methods yielded varied outcomes and thr worst results were given by ATC 40 method. Whereas all three approaches suggested that the margin of safety against collapse was high, sufficient strength and displacement reserves exist. They also observed that the maximum story drifts vary between 0.04 (0.01H) and 0.08 (0.02H), which falls within the damage control category (DC) [2].

D.N. Shinde, Nair Veena V, PudaleYojana M (2014)analysed multi storeyed RC frame building which was designed in according with IS 456:2000 and IS 1893:2002 using pushover method (ATC 40). The seismic response of the building was carried out in terms of performance point. Gradually increasing lateral loads were applied on the building. The cracks, plastic hinges formed and breakdown of individual structural components corresponding to the loads were recorded. They found that base shear at the performance point is more than the design base shear of the building [3].

S. C. Pednekar, H. S. Chore and S. B. Patil (2015) studied the effect of increase in number of storey on seismic responses by performing pushover analysis. Reinforced concrete structures of G+4, G+5 and G+ 6 storey have been modeled and analyzed using CSi ETABS 9.7.4 software. They comparedseismic response of the structure's in terms of base shear, time period, and displacement. They concluded that when the number of storeys increases, base shear and spectral acceleration decreases, whereas displacement, time period, and spectral displacement increases. It was observed that majority of the hinges fall within the life safety performance level, i.e., most of the hinges had moderate damage to the structural elements, but there was still residual strength and stiffness in all storeys, indicating that there will likely be no local collapse at this level of earthquake [4].

Dimpleben P. Sonwane and Dr. Kiran B. Ladhane (2015) carried out pushover analysis of SMRF RC frame building designed according to IS 456:2000 by modifying reinforcement in beams and columns. It was found that by increasing reinforcement in column it results in significant reduction in the maximum roof displacement. Decrease in roof displacement was found to be maximum in interior columns than corner and mid-face columns. It was also observed that by increasing reinforcement at first floor level had significant impact on base shear at other storeys. They concluded that adding a shear wall to an asymmetrical building reduces base shear and roof displacement dramatically. Performance-based seismic design done based on pushover analysis at various seismic intensities meets the acceptance criteria for immediate occupancy and life safety limit states [5].

Achyut S. Naphade, Prof. G. R. Patil (2015) studied vulnerability of G+10 symmetrical RCC building with soft storey at ground level using pushover method. The building's performance was examined at the second, fifth, and eighth floors, ground floor as a soft storey as well as by retrofitting the building with shear wall. They found that maximum yielding occurred at the soft storey where maximum plastic hinges form despite the increasing base force. It is concluded that in high-rise buildings, soft storey is safer at higher levels [6].

Dubal R.A, Vasanwala S.A and Modhera C.D (2015)carried out pushover analysis of a 10 storied column discontinued RC frame building. Nonlinear Time History Analysis and Nonlinear Static Analysis were used to examine the situation.They found that this technique provides proper lateral force distribution which is dependent on nonlinear behaviour and material stiffness properties, which was not been addressed by any previous methods. They obtained identical performance points for all the cases [7].

Dilip J. Chaudhari and Gopal O. Dhoot (2016) investigated life safety performance of a four storey RC frame building in zone-4 using pushover method. The building was modelled and designed in accordance with IS 456:2000. Multi-level seismic hazards were incorporated in performance-based design which resulted in improved performance and lower life-cycle costs. They concluded that performance-based seismic design is a reliable methodology for seismic retrofitting of existing buildings to meet required performance goals [8].

2.2 Pushover Analysis of Hybrid Structures with and without Infill Wall

N.R.Vineetha, Arun Menon, RavindraGettu (2012)investigated the seismic behaviour of a hybrid RC-masonry building with infill wall completed in 1959-61. They found that modelling connection between RC frame and masonry wall is a critical issue in structural modelling [9].

Nivedita N. Raut& Swati D. Ambadkar (2013) investigated seismic performance of masonry infill panels in RC frames and potential seismic damage of the frame under strong ground motions using pushover analysis. They observed that seismic performance of RC frame was adversely and significantly affected due to masonry infill panels in the frame are discontinued in the ground storey [10].

S. Majumder, H.A. Khan and R. P. Nanda (2017) investigated performance of the opened first storey symmetrical (G+3) RC frame building located in seismic Zone-V, constructed with and without masonry infill using pushover method.The analysis was varied out using methods FEMA-273 & ATC-40.The modelling for infill was done as an "Equivalent diagonal strut".It was concluded that infill panels increase the stiffness of the structure. It was found that as opening percentage increases, lateral stiffness of infilled frames decreases. It was also observed that there is a marginal reduction in earthquake force carrying capacity due to the fundamental natural periods being longer [11].

Khonaboina Sandeep Kumar, J.S.R. Prasad, VenuMalagavelli (2019) evaluated performance of the G + 5 and G + 9 RC structures located in seismic zone IV with and without infill walls using nonlinear static pushover analysis. The structure was designed in accordance with IS 1893(Part 1): 2002. Infill walls were simulated as struts according to FEMA-356. Significant changes were not observed in hinge development for the considered buildings as compared to bare frame of same height. The model with an infill wall exhibits less displacement at the top floor [12].

2.3 Pushover Analysis of Steel Framed Building

Fadzli M. Nazri, Pang Yew Ken (2014)investigated the static and dynamic responses on MSRF steel structures using pushover analysis. The drift of MRSF after seismic excitation using SAP was investigated.Models are subjected to nonlinear static analysis in the form of uniform and triangular distributions.They obtained that uniform loading leads in larger base shear in steel frames than triangular loading. Three and six stories have a smaller proportion of collapse hinges than the 9-story steel frame. It was observed that the higher the base shear, the higher the collapse hinge formation[13].

Prince Kaley and Mirza AamirBaig (2017)analyzed the performance of each frame and the influence of various types of bracings on a typical G+9 steel frame building using pushover method. Bracings of different types such as single diagonal, X, V, and Inverted V bracing were used in the analysis. The deformed forms, hinge results, lateral displacements, modal period, and frequency of building frames with and without bracings were compared. They observed that the damage was more severe in structures without bracing than in structures with bracing. It was also observed that in the case of braced steel framework, the lateral displacement is greatly reduced [14].

A.A. Vasilopoulos, G.S. Kamaris (2020) presented a rational and efficient seismic design method for regular space steel frames using pushover analysis. They calculated strengths according to Euro codes 3. The design begins with assumed member sections, proceeds with PA-assisted deformation and damage checks at three performance levels, and concludes with member size adjustments. As a result, it can adequately capture the structure's and individual members' limit states of displacements, strength, stability, and damage, obviating.The need for separate member capacity assessments using Euro code 3's interaction equations or Euro code 8's behaviour factor q. The PA method produced member sizes that were similar to those produced by the EC3/EC8, implying that the PA method is more rational and efficient alternative to the EC3/EC8 design process [15].

2.4 Pushover Analysis Steel and Steel-Concrete Composite Frame Structure

SudarshanBhutekar, Mohammed Ishtiyaque (2018) Evaluated the performances of G+15 steel and RCC-steel composite framing structures when exposed to the same lateral loading in seismic zone-5. The approach of nonlinear static pushover analysis is used. It Examines how the steel frame structure can prove to be much more economical and durable than concrete composite frames. It was obtained that the base shear of a composite frame structure is greater than that of a steel frame structure because steel has a lower self-weight. Due to the composite structure's lower ductility than steel, plastic hinges form early in the deformation process. In terms of seismic performance, steel structures outperform concrete composite frame constructions. Furthermore, when the two constructions are compared, the steel structure withstands the forces for a longer amount of time than the composite structure. They concluded from the comparative analysis that steel structures are more feasible in seismic excitation since they have shown superior to composite structures in every outcome parameter included in the study [16].

Raut et al. (2019) pushover analysis was carried for the G+12 RCC and Steel framed structures located in Zone IV. They observed that the time required for a steel frame construction is longer than for an RCC structure due to the increased flexibility of steel. G+12 steel and RCC frame structures have time periods of 5.92sec and 2.13sec, respectively. The development of the first hinge occurs at a displacement value of 134.46mm in the case of steel and 31.80mm in the case of RCC. At the first hinge formation, RCC has a higher base shear than steel frame structures [17].

III. CONCLUSION

As per the available research done in the past, researchers had focussed on using pushover analysis for precise evaluation of strength of both existing and new structures for given seismic loadings. After reviewing the above literature on pushover analysis of reinforced concrete structures,mixed farmed structures with and without infill wall, steel framed building we can conclude that:

- Researchers had studied performance based design using different codes around the world, found the results of plastic hinges, performance points of buildings, and accordingly evaluated the performance of existing as well as proposed Structure efficiency during an earthquake activity. Pushover analysis gives an appropriate indication of possible location of plastic hinges in the structure.

- By considering infill masonry walls in design of RC structures by equivalent strut method gives significant better results as compared to bare frame structure. In addition, pushover analysis gives non-linear performance of R.C.C. structure with and without masonry wall for seismic loading. So designing concrete structures without infill walls needs additional measures because of generation of soft story phenomena.
- Pushover analysis can be consistently used to estimate the limit states of steel frames while limit state estimations from incremental dynamic analysis requires carefully selected ground motions with considerations of important parameters. Also using different bracing systems on steel structures significantly increases the performance of the structure.

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