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Pushover Analysis of RC Structures with Infill Walls Using Equivalent Strut Approach- A Literature Review

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Abstract—

RC Buildings are very ordinary type of construction in India. Analytically while modelling the structure, we design only structural members which transmit the load like beams, columns, slabs and footings, where walls are not considered while designing and their impact on the structural response is neglected. Their impact is shown in the global behaviour of RC frames subjected to seismic loads. So it is very important to study the behaviour of infill on the RC bare frames. The presence of infill results in increase in the structural stiffness; it also increases natural frequency of vibration which depends on seismic spectrum. In addition to that, it also decreases the storey drift demands and increases the storey lateral forces. This study presents a pushover analysis using E-tabs for reinforced concrete (RC) frames. The main purpose is to study the effect of the infill on failure patterns of the RC frames. The Finite Element Method (FEM) model considered an RC frame with in-filled wall with its variation in thickness using equivalent strut method. The objective of this paper is to understand the performance of the building with varying structural parameters and compare performance of infill Structures with the structures without infill in different seismic zones.

Keywords: Reinforced concrete frames, Infill, Time period, Stiffness, Base shear, Pushover Analysis.

1.1 Introduction -

The RC (reinforced concrete) frame structures provided with masonry infill walls are the most common type of structures used for multi-storey constructions in many countries. In this type of structures, the exterior masonry walls and the interior partitions are considered as non-structural elements, and usually, the structural interaction between the frame and infill is ignored in the seismic design/assessment especially in the past.

Earthquake can cause greatest damages to humanity among all the natural hazards. Since earthquake forces are unpredictable and random in nature, proper analysis of the structures must be ensured to withstand such loads. The recent developments in the performance-based engineering design have brought the non-linear static (NSP) or pushover analysis to the forefront. It has replaced the conventional analysis procedures due to its simplicity and proved to be a useful and effective tool for assessing the real strength of structures.

Pushover analysis can be either force controlled or displacement controlled. The pushover analysis can provide significant perception and understanding about the weak links in the structure. Etabs V18 can perform static or dynamic, linear or nonlinear analysis of structural systems. To perform pushover analyses in Etabs V18, users can create and apply hinge properties. Etabs V18 is fully equipped with US, Canadian and International Design standards and codes like ACI concrete code, AISC building codes and AASHTO specifications. These integrated design code features can easily generate wind, wave and seismic loads with comprehensive automatic steel and concrete design checks. Pushover analysis is a static non-linear technique in which the magnitude of the structural loading is incremented in the lateral direction of the structure according to a certain pre-defined pattern.

Generally, it is assumed that the behaviour of the structure is controlled by its fundamental mode and the predefined pattern is expressed in terms of either story shear or fundamental mode shape. FEMA-273 and its successor FEMA-356 describe about the non-linear static procedure (NSP) or pushover analysis and its uses in the structural engineering field. It is recommended as a standard tool for estimating seismic demands for buildings. In Etabs V18, a frame element is modelled as a line element having linearly elastic properties and nonlinear force-displacement characteristics of individual frame elements are modelled as hinges represented by a series of straight line segments. There are three types of hinge properties in Etabs V18. They are default hinge properties, user-defined hinge properties and generated hinge properties. Studies show that user defined hinge model gives better results than default hinge model. Moment-curvature relationship is used to model plastic hinge behaviour in non-linear analysis. The seismic performance of a structure can be evaluated in terms of pushover curve, plastic hinge formation etc. The maximum base shear capacity of structure can be obtained from base shear versus roof displacement curve.

1.2 Infill Walls

The infill wall is the supported wall that closes the perimeter of a building constructed with a three-dimensional framework structure (generally made of steel or reinforced concrete). Therefore, the structural frame ensures the bearing function, whereas the infill wall serves to separate inner and outer space, filling up the boxes of the outer frames. The infill wall has the unique static function to bear its own weight. The infill wall is an external vertical opaque type of closure. With respect to other categories of wall, the infill wall differs from the partition that serves to separate two interior spaces, yet also non-load bearing, and from the load bearing wall. The latter performs the same functions of the infill wall, hygro-thermically and acoustically, but performs static functions too.

1.3 NON-LINEAR STATIC ANALYSIS (PUSHOVER METHOD)

In elastic analysis, there were procedures for the seismic evaluation and design of upgrades of structure as well as design of new construction. The generic process of inelastic analysis is similar to conventional linear procedure in that the engineer develops a model of the structure in which is then subjected to a representation of the anticipated seismic ground motion. The coefficient method is fundamentally a displacement modification procedure that is presented in FEMA -356. The coefficient method of displacement modification from FEMA- 356: - The coefficient method is the primary non-linear static procedure presented in FEMA-356. This approach modifies the linear elastic response of the equivalent SDOF system.

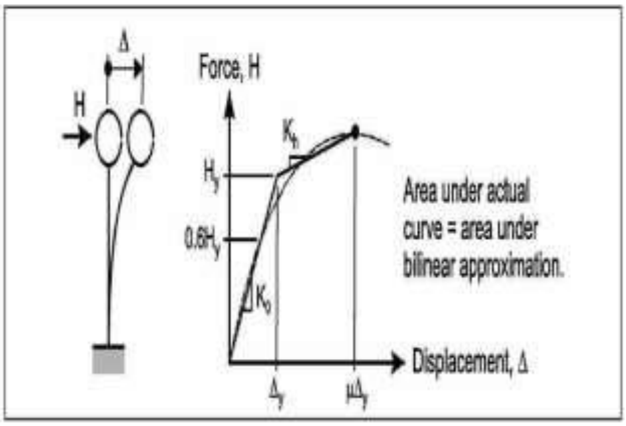

Figure: Bilinear approximation of push-over curve

The peak elastic spectral displacement is directly related to the spectral acceleration by the relation.

Sd= (Teff) 2/4π2xSa

Where, Sd = spectral displacement. Sa = spectral acceleration. Teff = effective time period depends upon the relative stiffness of structure.

The NSP may be used for any structure and any Rehabilitation Objective, with the following exceptions and limitations. • The NSP should not be used for structures in which higher mode effects are significant, unless an LDP evaluation is also performed. To determine if higher modes are significant, a modal response spectrum analysis should be performed for the structure using sufficient modes to capture 90% mass participation, and a second response spectrum analysis should be performed considering only the first mode participation. Higher mode effects should be considered significant if the shear in any story calculated from the modal analysis considering all modes required obtaining 90% mass participation exceeds 130% of the corresponding story shear resulting from the analysis considering only the first mode response. When an LDP is performed to supplement an NSP for a structure with significant higher mode effects, the acceptance criteria values for deformation controlled actions (m values).

This method aims to produce structures with predictable seismic performance. The three key elements of this method are:

1) Capacity: It is a representation of the structures ability to resist the seismic demand.

2) Demand: It is a representation of the earthquake ground motion.

3) Performance: It is an intersection point of capacity spectrum and demand spectrum.

The performances levels as per FEMA, ATC 40 are:

- Immediate occupancy IO: damage is relatively limited; the structure retains a significant portion of its original stiffness and most if not all its strength.
- Life safety 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.

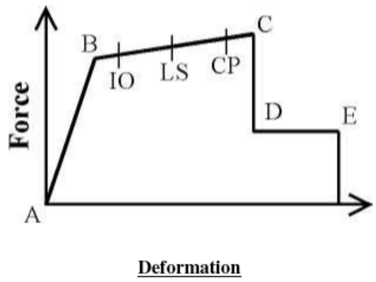

Fig. 2: Deformation

Target Displacement

The fundamental question in the execution of the pushover analysis is the magnitude of the target displacement at which seismic performance evaluation of the structure is to be performed. The target displacement serves as an estimate of the global displacement of the structure is expected to experience in a design earthquake.

Use of Pushover Results

Pushover analysis has been the preferred method for seismic performance evaluation of structures by the major rehabilitation guidelines and codes because it is 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 provides information on many response characteristics that cannot be obtained from an elastic static or elastic dynamic analysis. These are;

- Estimates of inter story 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).

Pushover analysis also exposes 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.

Limitations of Pushover Analysis

Although pushover analysis has advantages over elastic analysis procedures, underlying assumptions, the accuracy of pushover predictions and limitations of current pushover procedures must be identified.

There are many unsolved issues that need to be addressed through more research and development. Examples of the important issues that need to be investigated are:

- Incorporation of torsional effects (due to mass, stiffness and strength irregularities).
- 3-D problems (orthogonality effects, direction of loading, semi-rigid diaphragms, etc)
- Use of site-specific spectra.
- Cumulative damage issues.
- Most importantly, the consideration of higher mode effects once a local mechanism has formed.

Safety Evaluation of Reinforced Concrete Buildings

Safety against collapse of reinforced concrete is usually defined in terms of its ductility ratios. The design of reinforced concrete structures is performed by using resistance smaller than the one required for the system to remain elastic under intense ground shaking. Then, the seismic codes implicitly cause structural damages during strong earthquake motions and the design relies on the capacity of the structures to undergo large inelastic deformations and to dissipate energy without collapse.

Seismic Vulnerability

The vulnerability of a building subjected to an earthquake is dependent on seismic deficiency of that building relative to a required performance objective. The seismic deficiency is defined as a condition that will prevent a building from meeting the required performance objective. Thus, a building evaluated to provide full occupancy immediately after an event may have significantly more deficiencies than the same building evaluated to prevent collapse.

Stiffness:

A building is made up of both rigid and flexible elements. For example, beams and columns may be more flexible than stiff concrete walls or panels. Less rigid building elements have a greater capacity to absorb several cycles of ground motion before failure, in contrast to stiff elements, which may fail abruptly and shatter suddenly during an earthquake. Earthquake forces automatically focus on the stiffer, rigid elements of a building.

2. LITERATURE REVIEW

Many methods have been proposed for achieving the optimum performance of structures subjected to earthquake excitation. The use of non linear static analysis for analyzing the structure is the best technique. Many papers have been published related with non linear static analysis. Some of them are discussed below.

Vojko Kilar & peter fajfar (1997) Simple Push-Over Analysis Of Asymmetric Buildings" Faculty of Civil and Geodetic Engineering, University of Ljubljana Jamova 2, 1000 Ljubljana, Slovenia - Simple method for the non-linear static analysis of complex building structures subjected to monotonically increasing horizontal loading (push-over analysis) is presented. The method is designed to be a part of new methodologies for the seismic design and evaluation of structures. It is based on the extension of a pseudo-three-dimensional mathematical model of a building structure into the non-linear range. The structure consists of planar microelements. For each planar microelement, a simple bilinear or multi linear base shear–top displacement relationship is assumed. By a step-by-step analysis an approximate relationship between the global base shear and top displacement is computed. During the analysis the development of plastic hinges throughout the building can be monitored. The method has been implemented into a prototype computer program. In the paper the mathematical model, the base shear–top displacement relationships for different types of microelements, and the step-by-step computational procedure are described. The method has been applied for the analysis of a symmetric and an asymmetric variant of a seven-storey reinforced concrete frame–wall building, as well as for the analysis of a complex asymmetric 21-storey reinforced concrete wall building.

Murty, C.V.R et al 2000 - Beneficial influence of masonry infills on seismic performance of RC frame buildings, Proceedings, 12th World Conference on Earthquake Engineering, New Zealand, Paper No.1790 - study, a 3-story R/C frame structure with different amount of masonry infill walls is considered to investigate the effect of infill walls on earthquake response of these type of structures. The diagonal strut approach is adopted for modelling masonry infill walls.

A. S. Moghdam and W. K. Tso (2000) "Pushover analysis For Asymmetric and Set-Back Multi-Story Buildings", 12WCEE 2000, 1093 - a response spectrum based pushover procedure to obtain seismic response estimates of three types of building systems that were asymmetrical was studied. The procedure included some of the 3-D effects caused by the response of torsion. The main features of the procedure were the use of elastic response spectrum analysis of the building to obtain the target displacements and the load distributions used in the pushover analyses.

Moreno Rosangel et al. (2004) Influence of masonry infill walls on the seismic behaviour of multi-storeys waffle slabs RC buildings, Proceedings of the 13th World Conference on Earthquake Engineering, Vancouver BC (Canada) - in this review, the wall is damaged by earthquake reaction of the RCC slab of the building. They have analyzed the 3, 5, and 6 storey which is located in Barcelona, and the Spain. The spectra is capable of reaching the method of push over, they are also having the steps to carry by curves. It is provides the lesser breakage.

R. Bento (2004)) Non-linear static procedure in performance seismic design 13th world conference on Earthquake engineering Aug 1-6 2004 - the performance of a structural system can be evaluated resorting to non-linear static analysis. This involves the estimation of the structural strength and deformation demands and the comparison with the available capacities at desired performance levels. This paper aims at evaluating and comparing the response of two reinforced concrete building systems by the use of different methodologies namely the ones described by the ATC-40 and the FEMA-273 and by the EC8 (Euro code 8) design code using nonlinear static procedures, with described acceptance criteria. Some results are also compared with the nonlinear dynamic analysis. The methodologies are applied to a 4 and 8 storey frames system, both designed as per the Euro codes in the context of Performance Based Seismic Design procedures.

ÖZTÜRK Mehmet Selim et al. (2005) Effects of masonry infill walls on the seismic performance of buildings. Middle East Technical University, Ankara Turkey - This paper showing the behaviour of hollow masonry infill's wall of the horizontal behaviour and by testing the RC frame. For the necessity of two different structures are taken for the study purpose. As an in filled structure 3 and 6 storey building are constructed. The testes are conducted for the column, infill wall for the overall of the storey. The influence of each study is calculated by storey drift k and comparison of each study.

T Hasegawa (2008) "Seismic response prediction of steel frames utilizing plastic strain energy obtained from pushover analysis". The 14th World Conference on Earthquake Engineering October 12-17, Beijing, China - A series of earthquake response analyses of these example frames was carried out, and was compared to the results of the proposed method. From the results of the earthquake response analysis, it was found that the maximum inter-story drift and the cumulative ductility demands of members obtained from the proposed method could approximately catch the tendency of results of the earthquake response analysis From the results of the earthquake response analysis, maximum inter-story drift of the proposed method could approximately catch the results of the earthquake response analysis, and the cumulative ductility demands (h) of members obtained from the proposed method could approximately catch the tendency of results of the earthquake response analysis. But the prediction values (h) of panel zones in the frames, and the prediction values of ends of beam connecting to outside columns became smaller than those of the earthquake response analysis.

Ajay D Goudar (2012) "Sensitivity of Pushover analysis to design parameter an analytical investigation" International Journal of advance structure and geotechnical engineering Oct 2012 - the static pushover analysis is becoming a popular tool for seismic performance evaluation of existing and new structures. The existing building can become seismically deficient since seismic design code requirements are constantly upgraded and advancement in engineering knowledge. Further, Indian buildings built over past two decades are seismically deficient because of lack of awareness regarding seismic behavior of structures. The widespread damage especially to RC buildings during earthquakes around the world generated great demand for developing a simple yet efficiently accurate new method known as “pushover analysis” for seismic evaluation. The expectation is that the “non-linear static analysis” popularly known as “pushover analysis” will provide adequate information on seismic demands imposed by the design ground motion on the structural system and its components and consumes very less time compared to non-linear dynamic analysis.

Mohammad H. Jinya 2014 - Analysis of RC Frame with and Without Masonry Infill Wall with Different Stiffness with Outer Central Opening”, Volume: 03 Issue: 06| Jun-2014, eISSN: 2319-1163 | pISSN: 2321-7308, IJRET investigated the seismic response of reinforced concrete (RC) frame building considering the effect of modelling masonry infill (MI) walls. The seismic behaviour of a residential 6-storey RC frame building, considering and ignoring the effect of masonry, is numerically investigated using response spectrum (RS) analysis. The considered herein building is designed as a moment resisting frame (MRF) system following the Egyptian code (EC) requirements.

Mr. A Vijay (2014) “Performance of Steel Frame by Pushover Analysis for Solid and Hollow Sections”, International Journal of Engineering Research and Development, vol. 8, issue 7, pp 05-12, , September 2014 - The research concentrates on a computer based push-over analysis technique for performance-based design of steel building frame works subjected to earthquake loading. Through the use of a plasticity-factor that measures the degree of plasticization, the standard elastic and geometric stiffness matrices for frame elements (beams, columns, etc.) are progressively modified to account for nonlinear elastic–plastic behavior under constant gravity loads and incrementally increasing lateral loads. The analysis is performed for two steel frameworks of solid and hollow members. This investigation aims to analyze the difference in structural behavior between hollow and solid frames. The technique adopted in this research is based on the conventional displacement method of elastic analysis.

Chidananda HR, Raghu 2015 “Analysis of RC Framed Structures with Central and Partial Openings in Masonry Infill Wall Using Diagonal Strut Method”, Volume: 04 Issue: 04 | Apr-2015, IJRET - studied 4, 8 and 12 storey buildings with their number of bays increasing from 3 to 6 were modelled as bare and infilled frame. Equivalent Static Analysis (ESA), Response Spectrum Analysis (RSA) and non-linear static Pushover analysis were performed on all structures. Base shear capacity for both ESA and RSA were compared for bare and infilled frame.

Parlobh S Gaikwad (2015) “Dynamic analysis of G+9 Structure” International Journal of Current Engineering and Technology E-ISSN 2277 – 4106 Vol 5 No 2 April 2015 - The important objective of earthquake engineers is to design and build a structure in such a way that damage to the structure and its structural component during the earthquake is minimize. The paper aims towards the dynamic analysis of RCC and Steel building with unsymmetrical configuration. For the analysis purpose models of G +9 stories of RCC and Steel with unsymmetrical floor plan is consider. The analysis is by carried by using F.E based software E TABS. Various parameter such as lateral force, base shear, story drift, story shear can be determined .For dynamic analysis time history method or response spectra method is used. Dynamic analysis should be performed for symmetrical as well as unsymmetrical building. Dynamic analysis can be in the form of full nonlinear dynamic time history analysis. If the RCC and Steel building are unsymmetrical, Torsional effect will be produce in both the building and thus are compared with each other to determine the efficient building under the effect of torsion.

Narendra A. Kaple, V.D. Gajbhiye, S.D. Malkhede,” Seismic Analysis Of RC Frame Structure With And Without Masonry Infill Walls”, ISSN: 2348 – 8352, (ICEEOT) – 2016 analyzed two models of tall structures with different symmetric and asymmetric plan geometries are analysed by linear static method and designed for the same. The analysis results are shown in terms of storey shear, storey drift and storey displacement in all the two models.

Mircea Bârnaure, Ana-Maria Ghiţă, “SEISMIC PERFORMANCE OF MASONRY-INFILLED RC FRAMES”, Urbanism. Arhitectură. Construction • Vol. 7 • Nr. 3 • 2016 presents a study about the effect of masonry infill walls on the behaviour of framed buildings, in seismic areas. The study was done for a building that will be built in Bucharest, Romania. In this case, the building will have 6 stories. The bays are narrow, because of the architecture requirements. The structure is composed of concrete frames.

Trupanshu Patel, Jasmin Gadhiya , Aditya Bhatt “Effect of floating column on RCC building with and without infill wall subjected seismic force” International Journal of Engineering Trends and Technology (IJETT) – Volume 47 Number 4 May 2017 - In the present work author is to study the behaviour of G+3 buildings having floating columns. In the recent studies based on structural element floating columns building, which have most on contracted on the higher zones and very some amount of works is available for lower seismic zones Also to be obtain the various effects of mass variations and infill walls on behaviour of normal and floating column building, some portion of typical floor has been provided with higher mass compare to the various other portions and different building models analysed with and without provisions of infill walls. Analytical study is done on SAP 2000.

Hakan Dilmac, Hakan Ulutas, Hamide Tekeli and Fuat Demir, “The investigation of seismic performance of existing RC buildings with and without infill walls” International Journal of Advanced Research in Science, Engineering and Technology, Vol. 22, No. 5 (2018) - This paper investigates the effects of infill walls on seismic performance of the existing structure of residential building by considering requirements of the Turkish Earthquake Code (TEC). Seismic performance levels of residential RC buildings with and without masonry walls in high-hazard zones were find according to the nonlinear procedure given in the code. Pushover curves were obtained by considering the effect of masonry infill walls on seismic performance of RC buildings. The analysis results are going shows that the infill masonry walls beneficially affected to the rigidity, roof displacements and seismic performance of the building.

Shobha Ramachandra, Vinod Balekatte Ramakrishna1, Vasantha , Vivek Vedant (2020) - IOP Conf. Series: Materials Science and Engineering 955 (2020) - This study is conducted to investigate, analyze and compare the response of RCC structure i.e., with masonry infill and without masonry infill, subjected to earthquake loading. The analysis is conducted on a G+5 structure with the loading condition given in Indian Standard IS1893:2002 codal provisions incorporating ETABS software. The analysis is studied under the categories like pushover curve, storey displacement, storey shear at base, and storey drift. Results obtained from the analysis of structure with and without infill masonry walls shows that all the parameter discussed above, except storey shear, have a significant reduction for structure with infill wall which would result in over estimation of seismic influence on structure that could considerably optimize the seismic behaviour and sustainable impact of building on the environment.

S. VIJAYALAKSHMI, J. SAIBABA (2022) - EXPERIMENTAL STUDY ON ANALYSIS OF RCC STRUCTURE WITH OR WITH OUT INFILL DIFFERENT SEISMIC ZONES – Journal of Engineering Sciences, Vol. 13, Issue 06, June / 2022 ISSN NO: 0377-9254 - In this study, 3D analytical model of G+10 multi-storey building has been generated for different buildings models and analyzed using structural analysis tool 'E-TABS'. In the analytical building model, all of the significant components are included that affect the mass, strength, and stiffness of the structure. As part of the research, seismic analysis using linear dynamic (response spectrum technique) and nonlinear static (pushover) procedures will be used to assess the capacity, demand, and performance level of the model under consideration. The ductility coefficients of structures are assessed using numerical findings for the following seismic demands, which take the inelastic behaviour of the building into consideration.

3. CONCLUSION

Many guidelines are reviewed for linear, non-linear analysis and the seismic evaluations of the structures are also discussed. Most of the researchers have reviewed that the buildings were assumed to be placed in various zones of India and carried out the investigation on the non-linear analysis (pushover analysis) and compared the performance of the building components, maximum base shear capacity and displacement of the structures located in the various zones. Many papers considered different amount of masonry infill walls to investigate the effect of infill walls on earthquake in response to the structures. SAP2000, ETABS and IDARC-2D software's were mainly used to find out the seismic evaluation and performance of the structures. All these studies require further research not based on assumptions, but in real terms it is essential to consider existing RC structures under seismic evaluation.

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