PERFORMANCE BASED SEISMIC DESIGN FOR REGULAR AND IRREGULAR STRUCTURES USING E-TABS

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Abstract— Performance-based design is a modern approach to seismic engineering, in which the design aim is to deliver a structure capable of meeting certain predictable performance objectives under different levels of earthquake motions. The performance-based design approach enables us to design new structures more efficiently and to assess existing structures more realistically. Performance based design precisely evaluates how building is likely to perform in given possible earthquake threat. This is an iterative process, begins with choice of performance objective followed by preliminary design, and evaluation whether the design meets the performance objective and finally redesign, and reassessment is done. This is a direct displacement method starting from the pre-quantified performance objectives in which plastic hinge design is performed to detail the frame members and connections to achieve the intended yield mechanism and behaviour. The objective of the present project is to carry out a detailed three-dimensional seismic analysis of G+10 reinforced concrete structures. An analytical study is to be made to find response of regular and irregular structures by linear and nonlinear methods. It is proposed to perform Equivalent Static Analysis and Pushover Analysis for regular and irregular structures, as well, using ETABS software. Analysis is to be carried out to arrive at various quantities like time period, storey displacement, storey drift, base shear, torsion, pushover curves, performance points and plastic hinges formation. The results thus obtained are to be interpreted. A comparative study between response of regular structures and that of irregular structures is to be done.

Index Terms—Earthquake threat, Direct displacement method, Seismic analysis, Pushover curves, regular and irregular structures

I. INTRODUCTION

Earthquakes have the potential for causing the greatest damages, among all the natural hazards. Since earthquake forces are random in nature & unpredictable, need of some sophisticated methods to analyse our structures for these forces. Performance based design can relate to a new dimension in the seismic design philosophy. We need to carefully understand and model the earthquake forces to study the actual behaviour of structure so that structure faces a controlled damage [9].

In recent years, the term Performance Based Design is being used as a popular buzzword in the field of earthquake engineering, with the structural engineer taking keen interest in its concepts due to its potential benefits in assessment, design and better understanding of structural behaviour during strong ground motions. The basic idea of Performance Based Design is to conceive structures that perform desirably during various loading scenarios. Furthermore, this notion permits the owners and designers to select personalized performance goals for the design of different structures. However, there is a need to emphasise that some minimum level or minimum acceptable criteria are required to be fulfilled by all structures [24].

In this newly developed performance-based seismic design approach, nonlinear analysis procedures become important in identifying the patterns and levels of damage to assess a structure's inelastic behaviour and to understand the modes of failure of the structure during severe seismic events. Pushover analysis is a simplified, nonlinear static procedure in which a predefined pattern of earthquake loads is applied incrementally to framework structures until a plastic collapse mechanism is reached. This analysis method generally adopts a lumped-plasticity approach that tracks the spread of inelasticity through the formation of nonlinear plastic hinges at the frame element's ends during the incremental loading process. In general, the determination of the satisfactory performance response that fulfils both the system level response and element level response, requires a highly iterative trial-and-error design procedure even with the aid of today's engineering computer software. Static pushover analysis is an attempt by the structural engineering profession to evaluate the real strength of the structure and it promises to be a useful and effective tool for performance-based design. It has been recognized that the inter-storey drift performance of a multi-storey building is an important measure of structural and non-structural damage of the building under various levels of earthquake motion [22].

In performance-based design, inter-storey drift performance has become a principal design consideration. The system performance levels of a multi-storey building are evaluated based on the inter-storey drift values along the height of the building under different levels of earthquake motion [23]. Current research developments in seismic structural behaviour indicate that the most suitable approach of achieving the performance objectives is by performing a damage-controlled design. The most important is to perform an evaluation process easy to be applied but that gets the main features that considerably influence the performance objective. Various recommendations are made to implement this ideology into the design procedure. The non-linear static procedures, (pushover analysis) which is the topic of this work, fulfils this purpose, regardless its limitations. Some results obtained by using different methodologies namely the ones described by the ATC-40, FEMA-273, FEMA-440 and FEMA 445 codes are presented in this study.

Performance-based earthquake engineering, for the purposes of this paper, encompasses the full range of engineering functions--design, evaluation, loss estimation, code-writing, post-earthquake reconnaissance and data gathering, and research assumes that the performance of a given structure, for a given ground motion, can be predicted with an acceptable accuracy and known reliability. Although this paper concentrates on buildings, performance-based earthquake engineering can be applied to bridges, other lifelines, or even green-field sites. Performance-based earthquake engineering is intended to be more general than performance-based codes which are only one product of performance-based earthquake engineering, or performance-based design which only covers a narrow design function.

In the last ten years, particularly due to damage from the Kobe earthquakes, interest has grown worldwide in performance-based earthquake engineering techniques. Unfortunately, due to a lack of uniform definitions and standards, the work in various countries is not coordinated and seldom transportable, despite bilateral workshops and other cooperative efforts. Despite the great interest in performance-based earthquake engineering, there is a lack of appreciation of the powerful and wide-ranging effects that a fully developed performance-based earthquake engineering system would have on the field.

The most development has occurred in performance-based codes, where a history of conceptual development exists by other disciplines. However, this work has never been considered in systematic context within the rich and varied field of earthquake engineering. There is also a common misunderstanding that a performance-based code consists merely of the provision of various performance standards that can be chosen by an owner, rather than a systematic application of performance-based earthquake engineering at several different levels in code development and application.

It is envisioned that performance-based earthquake engineering, using a common and interchangeable platform of performance descriptions and prediction, can be applied:

- to refine simplified code design;
- to provide a valid option to code design at various performance levels;
- to improve evaluation and retrofit of existing buildings;
- to improve and refine regional loss estimation;
- to improve the applicability of post-earthquake reconnaissance, and

- to improve the efficiency of earthquake engineering research

The performance-based seismic design process explicitly evaluates how a building is likely to perform, given the potential hazard it is likely to experience, considering uncertainties inherent in the quantification of potential hazard and uncertainties in assessment of the actual building response. In performance-based design, identifying and assessing the performance or more performance objectives. Each performance objective is a statement of the acceptable risk of incurring specific levels of damage, and the consequential losses that occur because of this damage, at a specified level of seismic hazard [3]. Losses can be associated with structural damage, non-structural damage, or both. They can be expressed in the form of casualties, direct economic costs, and downtime (time out of service), resulting from damage [3]. capability of a building is an integral part of the design process, and guides the many design decisions that must be made. It is an iterative process that begins with the selection of performance objectives, followed by the development of a preliminary design, an assessment as to whether the design meets the performance objectives, and finally redesign and reassessment, if required, until the desired performance level is achieved.

Performance-based design begins with the selection of design criteria stated in the form of one

II. REVIEW OF LITERATURE

Performance-based seismic design can be viewed as a process of system conception followed by an assessment procedure in which the performance of the structural system is evaluated and improved as needed to satisfy stated performance objectives. The PBSD is a rapidly growing idea that is present in all guidelines in USA like Vision 2000 (SEAOC, 1995), ATC40(ATC, 1996), FEMA273, FEMA440 and FEMA, 445. This PBSD of buildings has been practiced since early in the twentieth century, England, New Zealand, and Australia had performance-based building codes in place for decades. The International Code Council (ICC) in the United States had a performance code available for voluntary adoption since 2001 (ICC, 2001). Literature survey that has been carried out for the present work is summarised as below.

Mr. Chetan Ingal, et al[05] (2017) In this project work the research has carried out on performance based seismic design of multi-storey (G+5) RCC building. The buildings are designed as per IS code (IS 1893 (Part 1): 2002, IS 456: 2000) for zone 5, 4 and 3 for Maximum Considered Earthquake (MCE) and Design based Earthquake (DBE) and a nonlinear static analysis is carried out using auto plastic hinges. The Capacity Spectrum, Storey Displacement, Storey Drift, Demand Spectrum and Performance point of the building was found using the analysis carried out in ETABS 2015.

W.Y. Kam, et al[6] (2017) This research paper challenges some of the fundamental concepts in performance-based seismic assessments in the context of international and New Zealand research. Their present research focus on a performance-based seismic assessment on ascertaining of building behaviour and the governing inelastic mechanism such that informed decision can be made of the implied seismic risk and required seismic strengthening.

Andrea Benedetti, et al[07] (2016) The research group is involved in the development of new analytical models and in the implementation of original computer programs for the nonlinear static and dynamic analysis of reinforced concrete (RC) structures. The pushover analysis, that is a non-linear static analysis performed by applying lateral forces gradually increasing up to collapse, may provide an alternative both to conventional linear methods and to more complex methods based on non-linear dynamic analyses..

Bhave Priyanka, et al [8] (2016) The authors carried out research on reinforced concrete (RC) framed structures located in zones of high seismicity in India. They highlighted about the general/main cause of failure of multi-storey reinforced concrete frames during seismic motion is the sway mechanism.

Rajkuwar Dubal, et al[9] (2015) Presented a research which gives a comparison between Performance based Seismic design and conventional design method (using I.S 1893; 2002) for irregular RC building frames (10 storey) and evaluates performance using pushover and Time Historey analysis. They concluded Time period is one of the effective means to check the reliability of PBSD method.

Ashish R. Akhare, et al[10] (2015) In this work, they did experimentation on buildings with plan irregularity using Standard pushover analysis and Modal pushover analysis. They also checked the accuracy for both the methods. Non-linear time history analysis is also carried out. For their present study, building models of (G+6) storey regular and irregular buildings of 'L' shaped, 'C' shaped and 'T' shaped are generated by a computer program ETABs (version 9.7.3).

Dileshwar Rana, et al[11] (2015) This research work showed the performance & behaviour of regular & vertical geometric irregular RCC framed structure under seismic motion. Five types of building geometry are considered in this project work: one regular frame & four irregular frames. A comparative study is made between all these building configurations height wise and bay wise. All building frames are modelled & analysed in software Staad.Pro V8i. Various seismic responses like shear force, bending moment, storey drift, storey displacement, etc. are obtained.

Saba Bano, et al[12] (2015) This research paper presents an overview of the current state of knowledge about literature on Performance based seismic design method. The Performance-based earthquake engineering (PBEE) comprises the design, evaluation, and construction of structures performing during design earthquakes and extreme earthquakes to the desires / needs of owners, user, society and environment

Rekha Shinde, et al[13] (2014) The authors did the research work and presented a detailed 3-dimensional seismic analysis and capacity-based design of G+3, G+8 & G+15 storied three bay reinforced concrete frame.

Alok Madan, et al [14] (2014) These authors presented a plastic design procedure based on the energy balance concept for PBD of multi-storey multi-bay masonry infilled reinforced concrete (R/C) frames subjected to near-field earthquakes. They proposed energy-based plastic design procedure was implemented for trial performance based seismic design of representative masonry infilled reinforced concrete frames with various practically relevant distributions of masonry infill panels over the frame elevation. Nonlinear dynamic analyses of the trial PBD of masonry infilled R/C frames was performed under the action of near-field earthquake ground motions. The results of non-linear dynamic analyses demonstrated that the proposed energy method is effective for performance-based design of masonry infilled R/C frames under near-field as well as far-field earthquakes.

S S Gehlot, et al [15] (2014) This research paper discusses the procedure to upgrade a seismic deficient unsymmetrical reinforced concrete building and to examine the seismic performance of the upgraded building for desired performance levels. Seismic RC symmetrical building has been considered in this paper and up-gradation of this

Apurba Monda, et al16] (2013)The authors in this research focused on estimating the actual values of 'response reduction/modification factor' (R) for realistic RC moment frame buildings designed and detailed following the Indian standards. They primarily emphasised on a component-wise computation of R. They further considered the performance-based limits at both member and structure levels, and at a detailed modelling of the RC section behaviour, and the effects of various analysis and design considerations on R.

Bhruguli Gandhi, et al [17] (2012) They presented the PBD as the extension of limit-state design to cover the complex range of issues such as excessive displacement, rotation, damages, functionality etc. The authors came with a view PBD can be performed on new as well as existing bridges. The performance of such bridges in the event of earthquake can be evaluated using predictive analysis. This research presents related aspects of performance based seismic design of new bridges. Nonlinear static pushover analysis is used to determine the capacity of section during earthquake loading. Both ordinary and important bridges are designed as per PBD approach considering different seismic parameters like zone factor and soil types and various design parameters like base shear, base moments, % of reinforcement in the pier etc. are determined and comparison is made in the form of charts and Tables.

R. Peres, et al[18] (2012)They aim of the authors is to assess the performance for two types of structures which are torsionally restrained and torsionally unrestrained. They examined the accuracy of the different Nonlinear Static Procedures, through comparison of the results with those obtained from nonlinear dynamic time-historey analysis. In their study two plan-irregular steel structures were assessed in terms of seismic performance through the application of a group of nonlinear static procedures (N2 and Extended N2 methods, CSM with the features of FEMA440 and ACSM) with the purpose of testing these procedures effectiveness when compared with the nonlinear time-historey analysis results.

Mrugesh D. Shah[19] (2011) In the present research work two typical new R.C.C. buildings were taken for analysis: G+4 and G+10 to cover the broader spectrum of low rise & high-rise building construction. Different modelling issues were incorporated through nine models for G+4 building and G+10 building where bare frame (without infill), having infill as membrane, replacing infill as equivalent strut in previous model. A comparative study made for bare frame (without infill), having infill as membrane, replacing infill as equivalent strut.

Dalal Sejal P, et al [20] (2011) The author here discussed about the Performance based seismic design as an elastic design methodology done on the probable performance of the building under different ground motions. The derivative of the PBSD method, known as the Performance based plastic design (PBPD) method that has been widely recognised as an ideal method for use in the future practice of seismic design has also been reviewed and discussed.

Vipul Prakash [21] (2004) has gives the prospects for Performance Based Engineering (PBE) in India. He lists the pre-requisites that made the emergence of PBE possible in California, compares the situation in India and discusses the tasks and difficulties for implementing PBE in India. In India, the criteria for earthquake resistant design of structures are given in IS 1893, published by the Bureau of Indian Standards (BIS). IS 1893-2002 reduced the number of seismic zones to four by merging zone I with zone II.

Xiao-Kang ZOU, et al [22] (2004) In their paper they presented an effective computer-based technique that incorporates pushover analysis together with numerical optimization procedures to automate the pushover drift performance design of reinforced concrete (RC) buildings. In their study, steel reinforcement ratios are taken as design variables during the design optimization process.

Bo-Quan LIU, et al [23] (2004) They summarised the current structure seismic design method is force-based, and played an important role in building seismic design, which also have some shortcomings. He also summarised about the PBSD theory stemmed from displacement-based seismic design(DBSD) which is supposed by Moehle, in Berkley University in California.

R. BENTO, et al [24] (2004) Their research aims at evaluating and comparing the response of two reinforced concrete building systems using different methodologies namely the ones described by the ATC-40 and the FEMA-273 and by the EC8 (Eurocode 8) design code using nonlinear static procedures, with described acceptance criteria. Some results are also compared with the nonlinear dynamic analysis.

Katsuhiko YAMAWAKI, et al[25] (2000) Apart of their the authors summarised about the developed a performance-based design methodology in which various aspects of seismic performances in buildings are clearly defined. A “seismic performance menu” has also been prepared to provide common bases for designers in determining design seismic performances of each specific building.

William T HOLMES [26] (2000) Their research encompasses the full range of engineering functions--design, evaluation, loss estimation, code-writing, post-earthquake reconnaissance and data gathering, and assumes that the performance of a given structure, for a given ground motion, can be predicted with an acceptable accuracy and known reliability. Although this research concentrates on buildings, performance-based earthquake engineering can be applied to bridges, other lifelines, or even green-field sites.

M J N PRIESTLEY [27] (2000) Presented the research about three techniques – the capacity spectrum approach, the N2 method and direct displacement-based design which have been now matured to the stage where seismic assessment of existing structures, or design of new structures can be carried out to ensure that deformation-based criteria are met. They outlined and compared the three methods and discussed them in the context of traditional force-based seismic design and earlier design approaches which contained some elements of performance-based design. Factors defining different performance states also discussed, including the need, not yet achieved, to include residual displacement as a key performance limit **JACK P. MOEHLE** [28] (1996) Did research on PBSD theory and stated that Performance based seismic design criteria, performance objectives developed by various individuals and organisations are evolving around displacement-based design concepts, which use expected displacement response of a structure to gauge performance. Limitations of these criteria should be recognised, and some probabilistic approaches should be developed and applied to deal with the uncertainties in estimating demands and capacities. He concluded Displacement based seismic design criteria are simple and direct in representing design parameters that relate to performance.

III. MODELLING AND ANALYSIS

In the current work, the study is conducted on eight buildings i.e., two regular and six irregular models with different shapes and varying projections are shown in the figs.1 to 8 For comparative study, the above regular and irregular configurations are considered with distinct floors of G+10. The area of 256 m^2 is continued same for all the configurations Two different types of material grades i.e. M30 and M40 with varying sections, and M40 with bracings, M40 with infill walls is taken into the study.

The structures are analysed using finite element software ETABS. Equivalent static analysis and pushover analysis is used for the seismic analysis. Comparison of parameters like time period maximum storey displacement, base shear, storey drifts, torsion, performance points and formation of hinges is done from analysis. The differences in the results for the models of RCC frame with change of material grade, with bracings and with infill walls are taken for comparative study and will be tabulated. The seismic effect is considered along the x direction and y direction of the model plan to note the differences of irregularities in the structure. This seismic effect is given out by Equivalent Static Analysis and Pushover Analysis. The results of all the above parameters are taken from finite element software ETABS and Tables are formulated, graphs are plotted for easy comparison of analysis. Tables and graph results obtained are presented in chapter 4 to compare and to determine the structural performance.

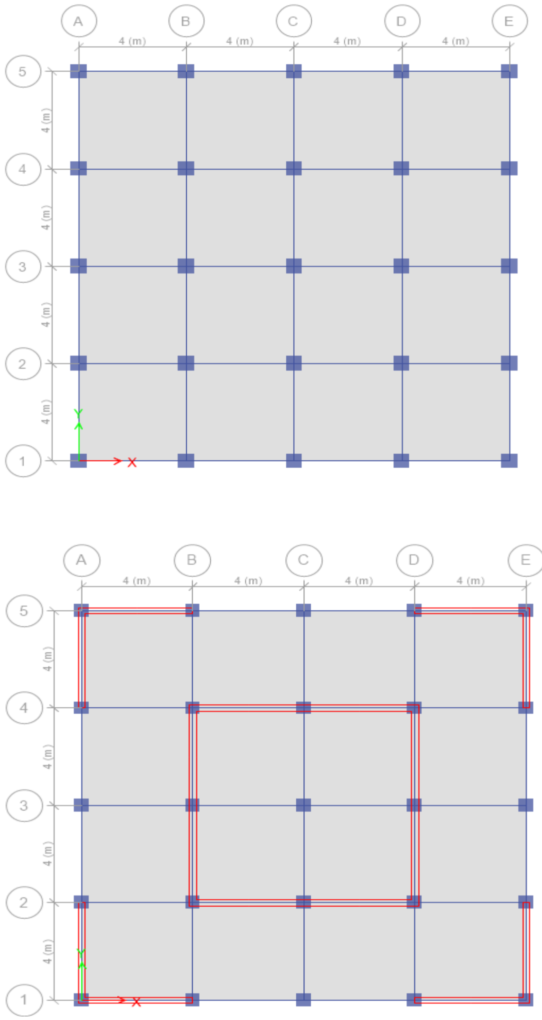

Fig.1 Plan of regular structure R1 representing bare frame and frame with bracings and infill walls

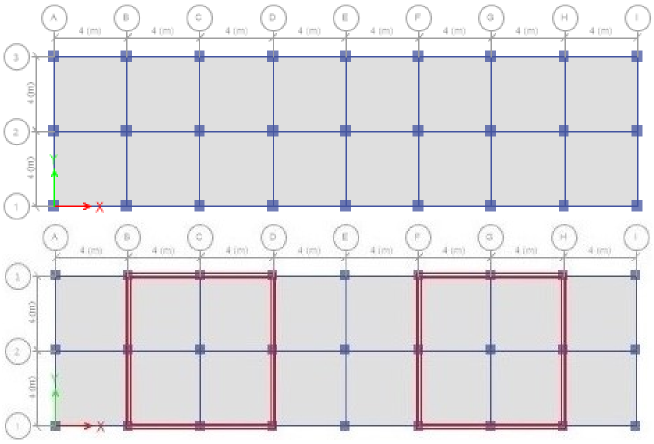

Fig.2 Plan of regular structure R2 representing bare frame and frame with bracings and infill walls

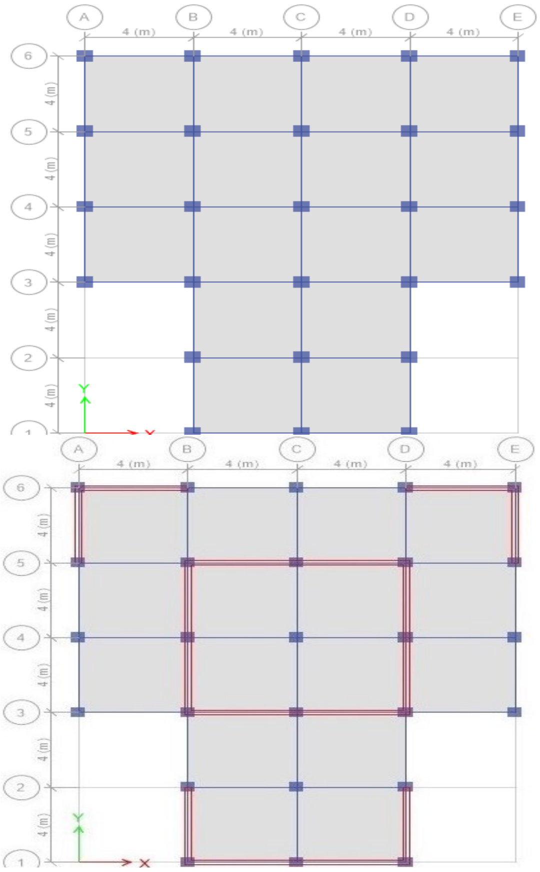

Fig. 3 Plan of irregular structure T1 representing bare frame and frame with bracings and infill walls

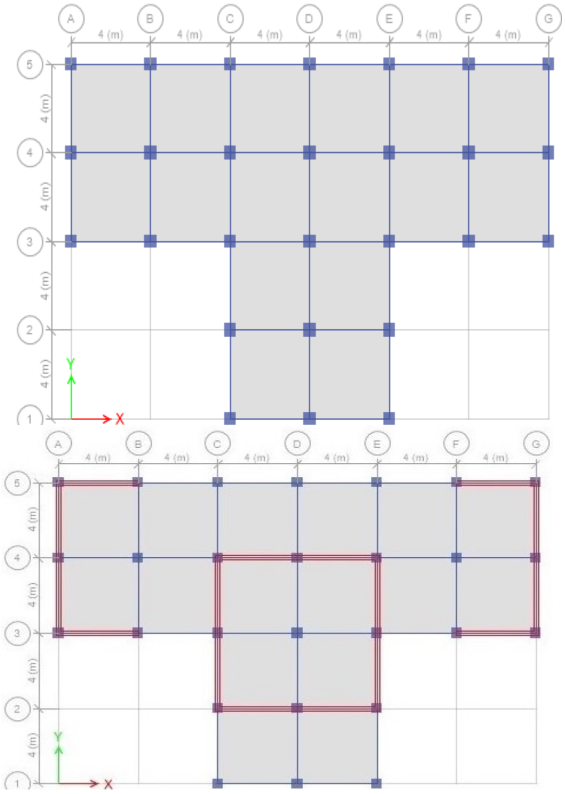

Fig. 4 Plan of irregular structureT2 representing bare frame and frame with bracings and infill walls

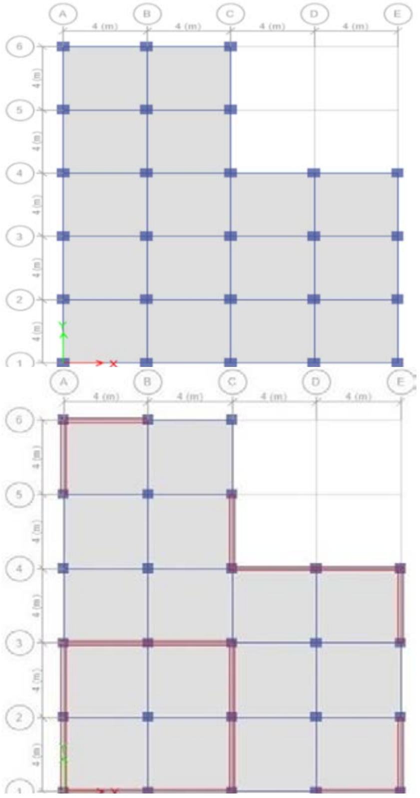

Fig. 5 Plan of irregular structureL1 representing bare frame and frame with bracings and infill walls

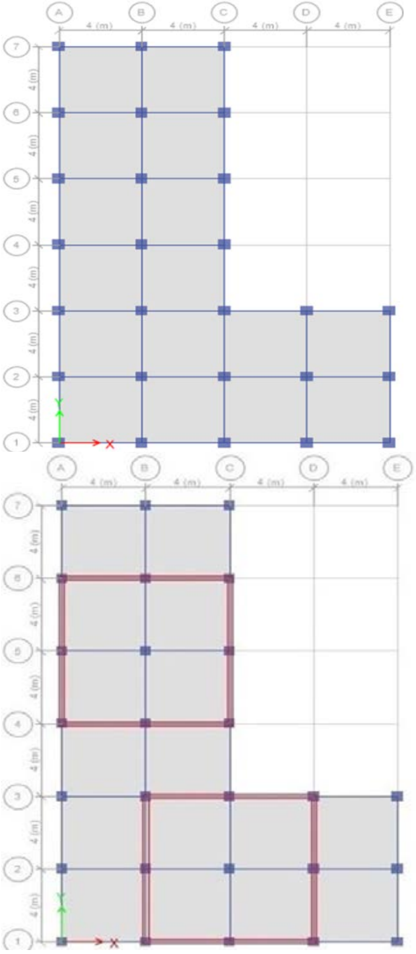

Fig. 6 Plan of irregular structure L2 representing bare frame and frame with bracings and infill walls

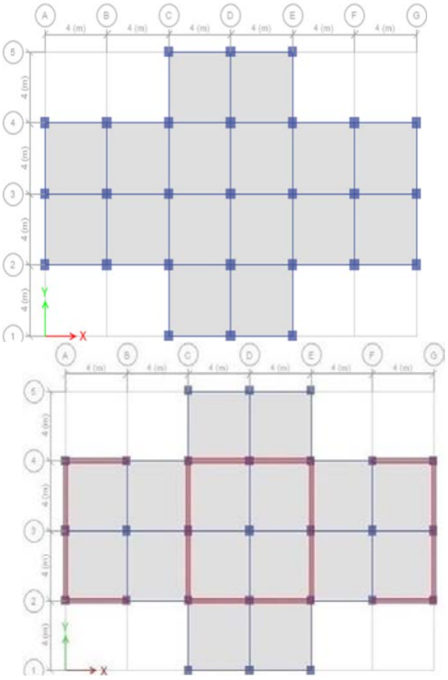

Fig. 7 Plan of irregular structure P1 representing bare frame and frame with bracings and infill walls

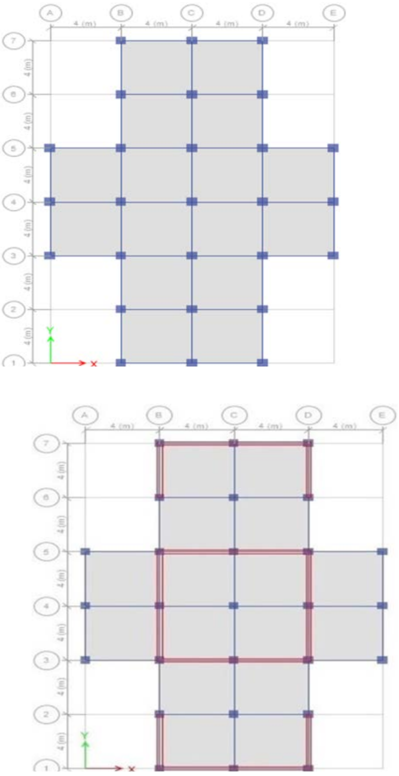

Fig. 8 Plan of irregular structure P2 representing bare frame and frame with bracings and infill walls

IV. RESULTS AND DISCUSSIONS

The main objective of performance based seismic design of buildings is to get out of wide-ranging disastrous damage and to limit the structural damages caused, to the performance limit of the building. For this purpose, Non-linear static pushover analysis is used to evaluate the actual strength of the structure and it pledge to be a suitable and effective tool for performance-based design.

The analysis is has been done on eight building which consisting of two regular and six irregular buildings with various varying projection ratios as shown in Table 3.2 of chapter 3. Plans denoting bare frame and frames with positioning of bracings and infill walls with highlighted red area has been shown in section 3.3 and the detail parameters considered are also given in chapter 3.

These models are subjected to seismic analysis by using Equivalent Static Analysis and Pushover Analysis which has been done, using a finite element software called ETABS. In this study, for all the considered parameter for distinct concrete frames time period, base shear, maximum displacement, base shear, storey drifts, torsions, performance points and formation of hinges are studied. The results of storey drift are taken with respect to each floor of the model is also studied. The differences in the results for the models of RCC frame with change of material grade, with bracings and with infill walls by variation in projection ratio are taken for comparative study and tabulated. The results of all the above parameters are taken from finite element software ETABS and tables are formulated, graphs are plotted for easy comparison of analysis. Tables and graph results obtained are presented here and compared to determine the structural performance.

Initially analysis was done for M30 grade concrete with conservative sections. In later trial, reduced sections resulted in failure of the structure and M40 grade was hence chosen. Effect of bracings and geometry was studied for structures with reduced sections with M40 grade concrete.

Fig.9 & 10 shows the time period in sec for all structures in X and Y directions

Fig.11 & 12 shows the maximum displacements in mm for all structures in X and Y directions

Fig.13 & 14 shows the Base Shear in kN for all structures in X and Y directions

Figs.15-18 shows the Storey Drft in kN for all structures in X and Y directions

Fig.19 & 20 shows the Torsional moments in kNm for all structures in X and Y directions

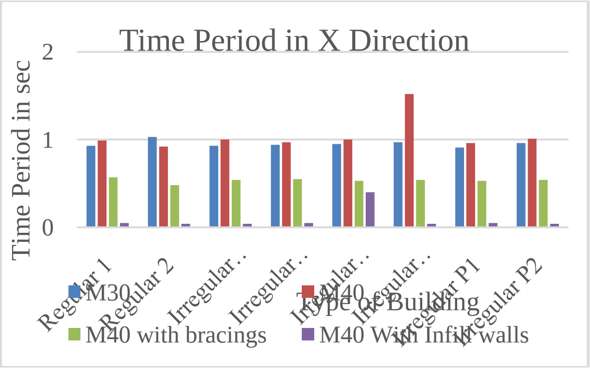

Fig. 9 Time period in sec for all structures in X direction

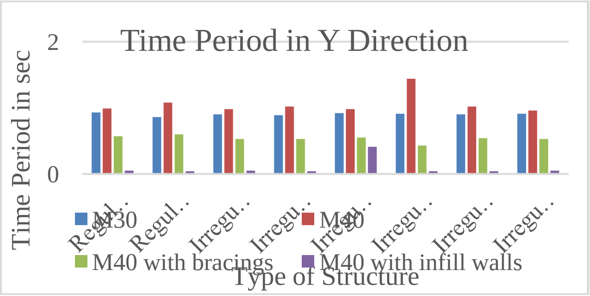

Fig. 10 Time period in sec for all structures in Y direction

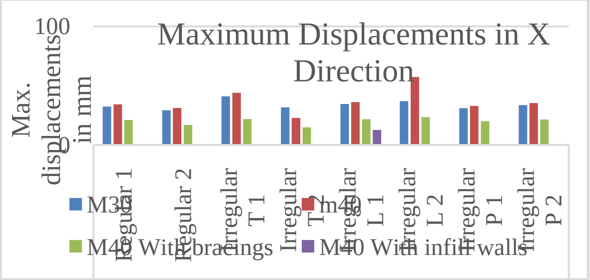

Fig. 11 Maximum displacements in mm for all structures in X direction

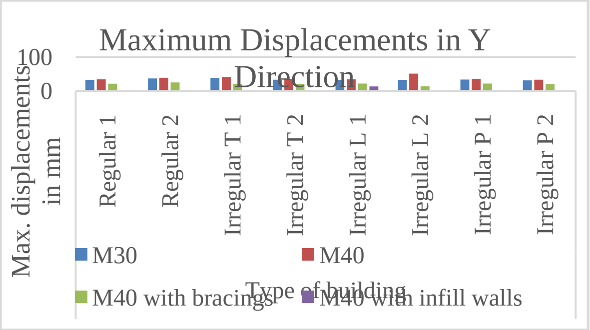

Fig. 12 Maximum displacements in mm for all structures in Y direction

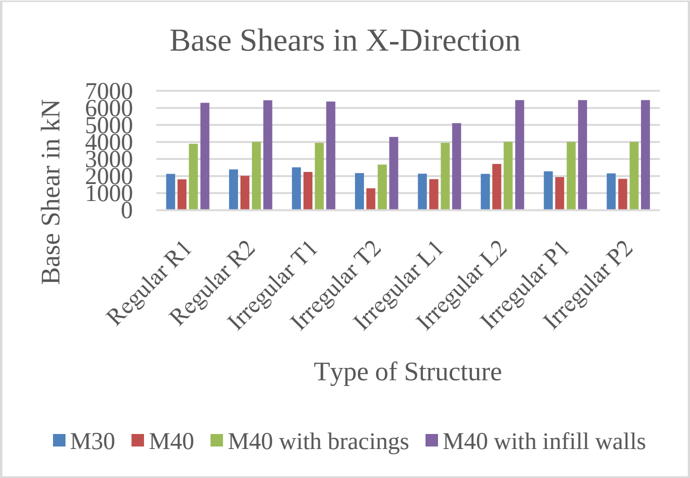

Fig. 13 Base Shear in kN for all structures in X direction

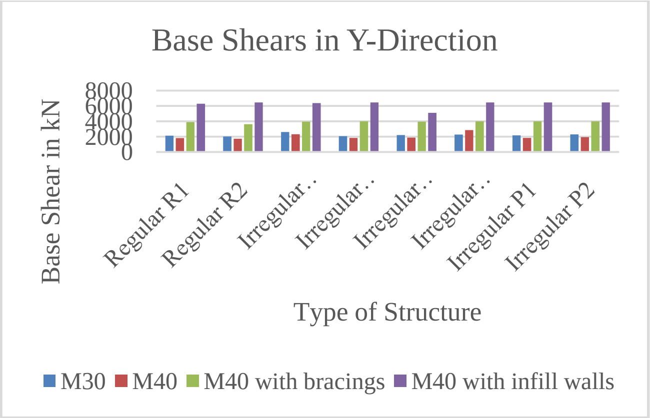

Fig. 14 Base Shear in kN for all structures in Y direction

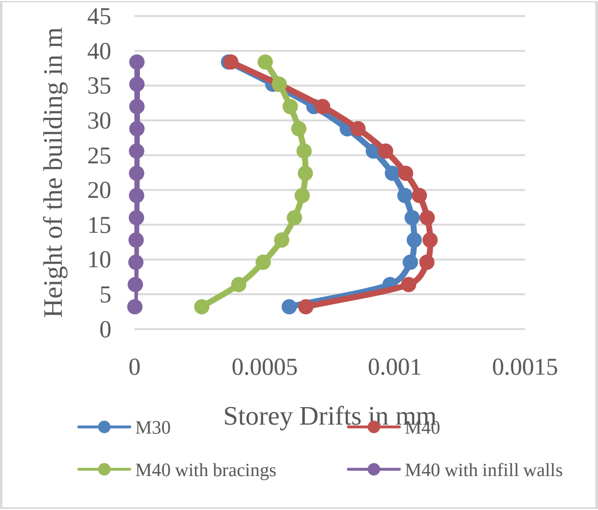

Fig. 15 Storey Drifts in mm for regular structures in X direction

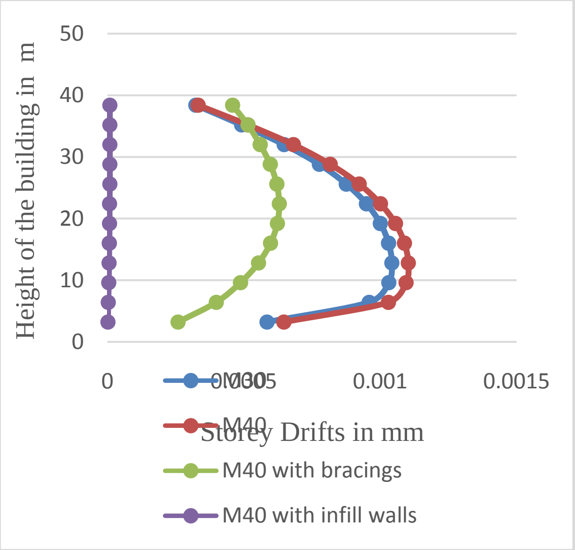

Fig. 16 Storey Drifts in mm for regular structures in Y direction

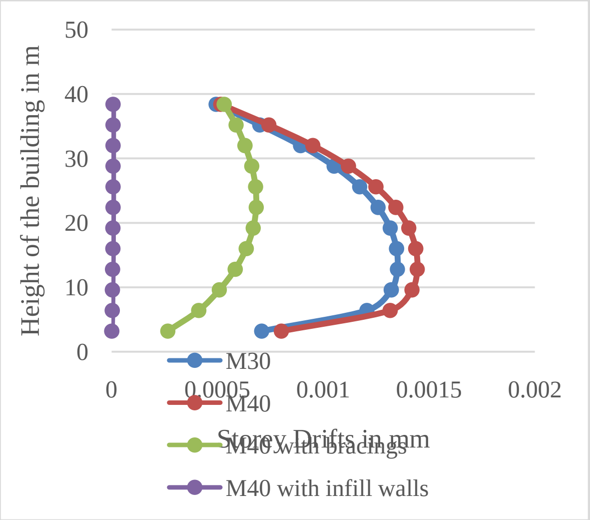

Fig. 17 Storey Drifts in mm for irregular structures in X direction

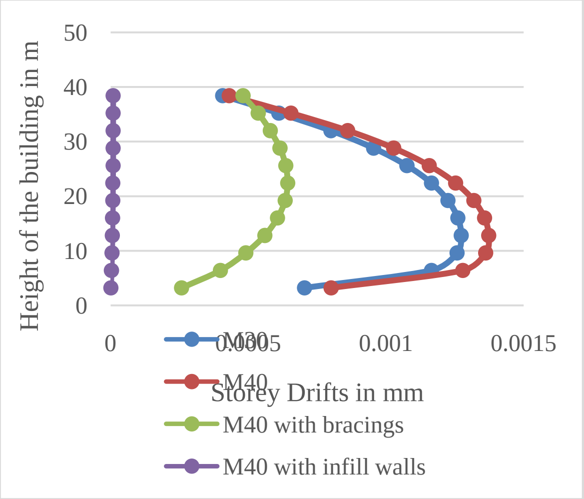

Fig. 18 Storey Drifts in mm for irregular structures in Y direction

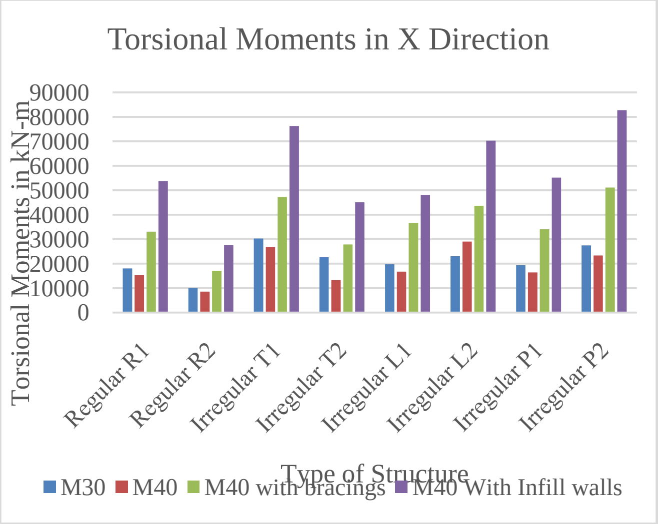

Fig. 19 Torsional moments in kNm for all structures in X direction

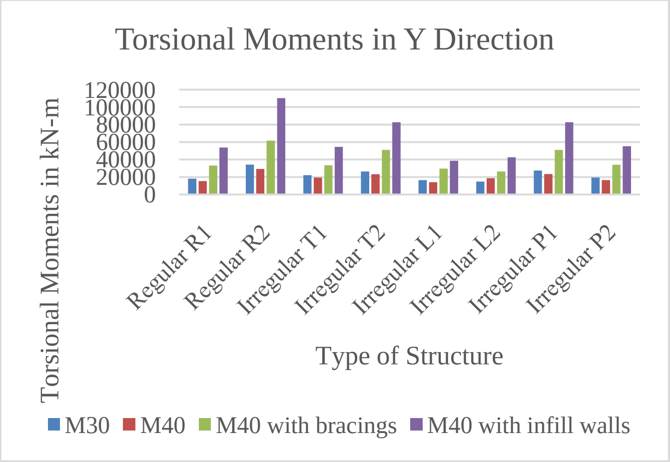

Fig. 20 Torsional moments in kNm for all structures in Y direction

V. CONCLUSIONS

Both Equivalent Linear static and Performance Based Non-linear analyses have been carried out using E-tabs which a powerful tool, with a focus on seismic response of both regular and irregular structures. The study includes the analyses of square, L-shaped and T-shaped buildings. The actual response of the structure in terms of time period, base shear, storey displacement, storey drift, torsional moments and performance points are determined. After the investigation the following conclusions are arrived at.

1. Inclusion of bracings and infill walls results in decrease of the time period of the structure. In other words, rigidity of the structure is enhanced by provision of infill walls and bracings. As compared to the original structure the reduction in Time period is in the order of 48% and

45% in the X and Y directions respectively when infill walls are provided. Addition of bracings resulted in decrease of Time period by 83% and 98% in the principal directions when compared to those of the original structure.
2. The structures were analysed for monitored roof displacement of 4% of the total height. By static analysis, the decrease in maximum storey displacements along the principal axes is 49% and 50% if bracings are introduced and 83% and 95% if infill walls are provided. By Pushover analysis, the reduction in maximum storey displacements along the principal axes is 54% and 69% if bracings are introduced and 96% and 97% if infill walls are provided. The trend of change in base shear is opposite in static analysis and pushover analysis. The probable reason is that there is no provision in the static method to include the enhanced rigidity because of inclusion of infill walls and bracings, rather only the increase in dead weight and inertia forces are considered. The displacements obtained by Pushover analysis satisfy the various performance levels and ranges. i.e. Immediate occupancy, Life safety and Collapse Prevention.
3. The base shear is the greatest along the longest side of the irregular buildings as compared to rest of the sides. By Equivalent static analysis the base shear in both principal axes increased by about 94% and 200% with the provision of bracings and infill walls respectively. By Pushover analysis the base shear decreased by about 18% & 10% in X and Y axes respectively with the inclusion of bracings. The base shear with the addition of infill walls decreased by about 207% & 210% in X and Y axes respectively.
4. The storey drifts are of higher magnitude in third to eighth floors. The same pattern is noticed in both regular and irregular buildings. The storey drifts are higher in L and T shaped buildings as compared to those of regular or square shaped buildings. Irregular buildings are more prone pounding with adjacent buildings. Moreover, they are susceptible to damage of non-structural elements when subjected to lateral loads.
5. For structures M40 with bracings an increment of 94% and 100% has occurred in x and y directions. By Equivalent static analysis the torsional moments in both principal axes increased by about 100% and 200% with the provision of bracings and infill walls respectively. By Pushover analysis the torsional moments increased by about 3.5% & 7% in X and Y axes respectively with the inclusion of bracings. The torsional moments with the addition of infill walls increased by about 120% & 182% in X and Y axes respectively.
6. It is evident from the results that shape of the building and aspect ratio affect the torsional moments and irregular buildings are subjected to higher torsional moments. Hence, torsion is a critical parameter in the seismic design of irregular buildings.
7. For both regular and irregular buildings modal pushover analysis is used to evaluate the performance, where the first and second mode response of the structure based on the assumption that the fundamental mode of vibration is the predominant response of the structure. The total performance level for all building models has started between IO-CP (Immediate occupancy to collapse prevention). The hinge position and location has been determined and it is noted that maximum number of hinges commence to form in A-IO range onwards. In columns and beams the plastic hinges formed are within immediate occupancy and life safety. This agrees that the performance based seismic design obtained by above process satisfies the acceptance criteria for immediate occupancy and life safety limit states.

REFERENCES

[1] FEMA 273. “NEHRP Guidelines for the Seismic Rehabilitation of Buildings.” Washington, D.C., USA: Building Seismic Safety Council for the Federal Emergency Management Agency, October 1997.

[2] FEMA 440. “NEHRP Improvement of Nonlinear Static Seismic Analysis Procedures.” Washington, D.C., USA: Department of Homeland Security for the Federal Emergency Management Agency, June 2005.

[3] FEMA 445. “Next-Generation Performance-Based Seismic Design Guidelines Program Plan for New and Existing Buildings.” Washington, D.C., USA: Department of Homeland Security for the Federal Emergency Management Agency, August 2006.

[4] Dr. Vinod Hosur, “Earthquake resistant design of structures”, Wiley India Private Limited

[5] Mr. Chetan Ingale1, M.R. Nalamwar, “Performance Based Seismic Design of RCC Building”, International Research Journal of Engineering and Technology (IRJET) Volume: 04 Issue: 10 | Oct -2017.

[6] W.Y. Kam and R. Jury, “Performance-Based Seismic Assessment: Simplified Methods and Collapse Indicators”, 16th World Conference on Earthquake Engineering, 16WCEE 2017 Santiago Chile, January 9th to 13th 2017 Paper No 854.

[7] Andrea Benedetti, Pier Paolo Diotallevi, Giada Gasparini, Luca Landi, Stefano Silvestri, Tomaso Trombetti, Marco Savoia, “Non-linear analysis of rc structures, performance based seismic design and displacement-based design approaches”, structures – earthquake engineering (2016)

[8]Bhave Priyanka, Banarase Mayur “Analysis and Capacity Based Earthquake Resistance Design of Multy Bay Multy Storeyed Residential Building” (2016) Int. Journal of Engineering Research and Applications, ISSN: 2248-9622, Vol. 6, Issue 4, (Part - 5), pp.78-84

[9] Rajkuwar Dubal, Sandip Vasanwala, Chetan Modhera (2015), “Innovative study of Performance Based Seismic Design Method for RCM R Frames with Vertical Geometric Irregularity” (IOSR-JMCE), PP 09-14.

[10] Ashish R. Akhare, Abhijeet A. “Maske Performance Based Seismic Design of R.C.C. Buildings with Plan Irregularity” (2015) Journal of Civil Engineering and Environmental Technology Print ISSN: 2349-8404; Volume 2, Number 10; pp. 1-6.

[11] Dileshwar Rana1, Juned Raheem, “Seismic Analysis of Regular & Vertical Geometric Irregular RCC Framed Building”, International Research Journal of Engineering and Technology (IRJET) Volume: 02 Issue: 04 | July-2015.

[12] Saba Bano, T. Naqvi, M. Anwar, “Performance Based Seismic Design of Structures – A Review”, International Journal of Modern Trends in Engineering and Research (IJMTER) Volume 02, Issue 10, [October – 2015]

[13] Rekha Shinde, Mukesh Shinde, “Performance Based Seismic Analysis of a Building with Soft Storey”, IJIRST –International Journal for Innovative Research in Science & Technology| Volume 1 | Issue 3 | August 2014

[14] Alok Madan, Arshad K. “Hashmi Performance Based Design of Masonry Infilled Reinforced Concrete Frames for Near-Field Earthquakes Using Energy Methods”, World Academy of Science, Engineering and Technology International Journal of Civil and Environmental Engineering Vol:8, No:6, 2014

[15] S S Gehlot and Ravi K Sharma, “Application of Performance Based Design to Upgrade Unsymmetrical RC Building”, International Journal of Structural and /civil Engineering research.

[16] Apurba Mondal, Siddhartha Ghosh, G.R. Reddy, “Performance-based evaluation of the response reduction factor for ductile RC frames”, ELSEVIER, Engineering Structures 56 (2013) 1808–1819

[17] Bhruguli Gandhi, Dr.B.J. Shah, “Performance Based Seismic Design of Reinforced Concrete Bridges”, International Journal of Engineering Research & Technology (IJERT) ISSN: 2278-0181 Vol. 1 Issue 5, July - 2012

[18] R. Peres, R. Bento, “Performance Based Seismic Design and Assessment of Irregular Steel Structures”, 15th World Conference on Earthquake Engineering, LISBOA 2012.

[19] Mrugesh D., “Performance based analysis of r.c.c. frames”, National Conference on Recent Trends in Engineering & Technology. (2011).

[20] Dalal Sejal P , Vasanwala S A, Desai A K, “Performance based seismic design of structure”.International journal of civil and structural engineeirg Volume 1, No4, 2011

[21] Vipul Prakash, “Whither Performance-Based Engineering in India?”, ISET Journal of Earthquake Technology, Paper No. 447, Vol. 41, No. 1, March 2004, pp. 201-222.

[22] Xiao-Kang ZOU and Chun-Man CHAN, “Seismic Drift Performance-Based Design Optimization of Reinforced Concrete Buildings”, (2004) 13th World Conference on Earthquake Engineering Vancouver, B.C., Canada. Paper No. 223.

[23] Bo-quan LIU1, Ming LIU and Ying-bin LI, “Research and Development of Performance-Based Seismic Design Theory”, (2004) 13th World Conference on Earthquake Engineering Vancouver, B.C., Canada. Paper No. 2457

[24] R. BENTO, S. FALCÃO, F. RODRIGUES, “Non-Linear Static Procedures in Performance Based Seismic Design”, (2004) 13th World Conference on Earthquake Engineering Vancouver, B.C., Canada. Paper No. 2522

[10] [25] Katsuhiko Yamawaki, Haruyuki Kitamura, Yasuhiro Tsuneki, Nobuyuki Mori and Satoru Fukai, “Introduction of a Performance-Based Design”, 12WCEE (2000) Paper No.1511.

[26] William T Holmes, “A Vision for a Complete Performance-Based Earthquake Engineering System”, 12WCEE (2000) Paper No. 8386.

[27] M J N Priestley, “Performance Based Seismic Design” (2000), 12WCEE, Paper No. 2381.

[28] Jack P Moehle, “Displacement-Based Seismic Design Criteria”,(1996) Eleventh world conference on Earthquake Engineering. ISBN 008 042822 3 Paper No.2125