International Journal of Engineering Sciences & Research Technology

(A Peer Reviewed Online Journal)
Impact Factor: 5.164

IJESRT

RESEARCHERID
THOMSON REUTERS

[Shristi *et al.*, 9(12): December, 2020]
ICTM Value: 3.00

ISSN: 2277-9655
Impact Factor: 5.164
CODEN: IJESS7

IJESRT

INTERNATIONAL JOURNAL OF ENGINEERING SCIENCES & RESEARCH TECHNOLOGY

PERFORMANCE BASED SEISMIC DESIGN OF STRUCTURES – A REVIEW

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DOI: https://doi.org/10.29121/ijesrt.v9.i12.2020.9

ABSTRACT

This paper presents an overview of the current state of knowledge with regard to literature on Performance based seismic design method. 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. The general promise of performance based design is to produce engineered structures with predictable performance during future earthquakes. Presented in this paper is an updated literature review of the Performance based Seismic design (PBSD) method. Performance based Seismic design is an elastic design methodology done on the probable performance of the building under different ground motions. The derivatives of the PBSD method, known as the Performance based Plastic design (PBPD) and Displacement-based seismic design (DBSD) method that has been widely recognized as an ideal method for use in the future practice of seismic design has also been reviewed.

KEYWORDS: Performance Based Seismic Design , Performance-Based Earthquake Engineering , Performance objectives , Seismic Evaluation , . STAAD PRO, ETABES, SAP

1. INTRODUCTION

The disastrous damage and life losses incurred by earthquakes in the last decade around the world have increased public attention and concern of how to reduce potential seismic risk. Earthquake engineering practice is undergoing fundamental changes triggered by a variety of reasons. In addition to the increasing knowledge to earthquake ground motion and structural response and the realization from recent earthquake in different parts of the world that monetary damage can surpass expectations by a large amount, the most important reasons for these changes are that facts that present code design procedures cannot be rationalized sufficiently to satisfy the desires of the engineers, owners and society. Since the initial development of building code provisions for earthquake resistance, the primary intent of code criteria has been to protect life safety by providing reasonable assurance that buildings would not collapse in anticipated levels of shaking.

The usual code method of design is aimed at achieving the specified limit states which are stipulated in the code namely the strength criteria / ultimate limit state and the serviceability limit states. Following the 1989 Loma Prieta and 1994 Northridge earthquakes, structural engineers in the United States began development of structural design procedures that changed emphasis from strength to performance. The resulting criteria and methodologies came to be known as “performance-based design.” Interest in these procedures has spread throughout the international earthquake engineering community.

PBSD is a modern designing concept of seismic resistant structure. Performance-based design is a more general design philosophy in which the design criteria are expressed in terms of achieving stated performance objectives when the structure is subjected to stated levels of seismic hazard. Since, 1994 Northridge earthquake and other earthquakes around the world during the end of the 20th century were an eye-opener for the use of PBSD. Performance- based design (PBD) is a more general design philosophy which aims at achieving multiple performance objectives when the structure is subjected to stated levels of earthquake ground motion.

ISSN: 2277-9655
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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. The general promise of performance based design is to produce engineered structures with predictable performance during future earthquakes. These days efficient method of assessing the capacity and demand of structures are developed. Moreover, due to advancement in research and test facilities, rapid development of structural analysis and design software, PBD is becoming more popular and efficient tool of design over the usual code methods. The purpose of performance-Based Seismic Design (PBSD) is to give a realistic assessment of how a structure will perform when subjected to either particular or generalized earthquake ground motion. While the code design provides a pseudo-capacity to resist a prescribed lateral force, this force level is substantially less than that to which a building may be subjected during a postulated major earthquake. It is assumed that the structure will be able to withstand the major earthquake ground motion by components yielding into the inelastic range, absorbing energy, and acting in a ductile manner as well as by a multitude of other actions and effects.

2. NEED OF THE STUDY OF PERFORMANCE BASED SEISMIC DESIGN-

PBSD is a systematic methodology for design of structures whose performance under seismic loads is predefined based on needs of the stakeholder. In simple words, it requires that a building be designed to meet specific performance objectives under the action of the frequent or the rarer seismic events that it may experience in its lifetime. So, a building with a lifetime of 50 years may be required to sustain no damages under a frequent, "50 % in 50 years" event, e.g., one that has a probability of 50% of being exceeded in the next 50 years. At the same time it should be able to remain repairable, despite sustaining some damage, during a "10% in 50 years" event and remain stable and life safe for rare events of "2% in 50 years", although, subsequently, it may have to be demolished. The advantages of PBSD over the methodologies used in the current seismic design code are summarized as the following key issues :-

1. Multi-level seismic hazards are considered with an emphasis on the transparency of performance objectives.
2. Building performance is guaranteed through limited inelastic deformation in addition to strength and ductility.
3. Seismic design is oriented by performance objectives interpreted by engineering parameters as performance Criteria.
4. An analytical method through which the structural behavior, particularly the nonlinear behavior is rationally Obtained.
5. The building will meet the prescribed performance objectives reliably with accepted confidence.
6. The design will ensure the minimum life-cycle cost.
7. To provide structure with higher lateral strength to resist seismic load.
8. To study the consequences of earthquakes by considering safety, economy and sustainability in seismic design of building.
9. To minimize the time involve in tedious work of manual design through adoption of computer Aided design.
10. To provide scope and platform to building construction industry so that life span of building design can be enhanced and their durability can be insured.
11. To study previous research works pertaining to the performance based seismic analysis of the building with soft storey.
12. Assess the potential seismic performance of existing structures and estimate potential losses in the event of a Seismic Event.

3. PUSHOVER ANALYSIS-

In the push over analysis method, earthquake load is applied on the model in an incremental basis. As the loads are increased, the building undergoes yielding at a few locations. Every time such yielding takes place, the structural properties are modified approximately to reflect the yielding. The analysis is continued till the structure collapses, or the building reaches certain level of lateral displacement. The material nonlinearities are assigned as hinges; M3 flexural hinges for beams and PMM flexural hinges for columns. Then each lateral load pattern is applied.

ISSN: 2277-9655
Impact Factor: 5.164
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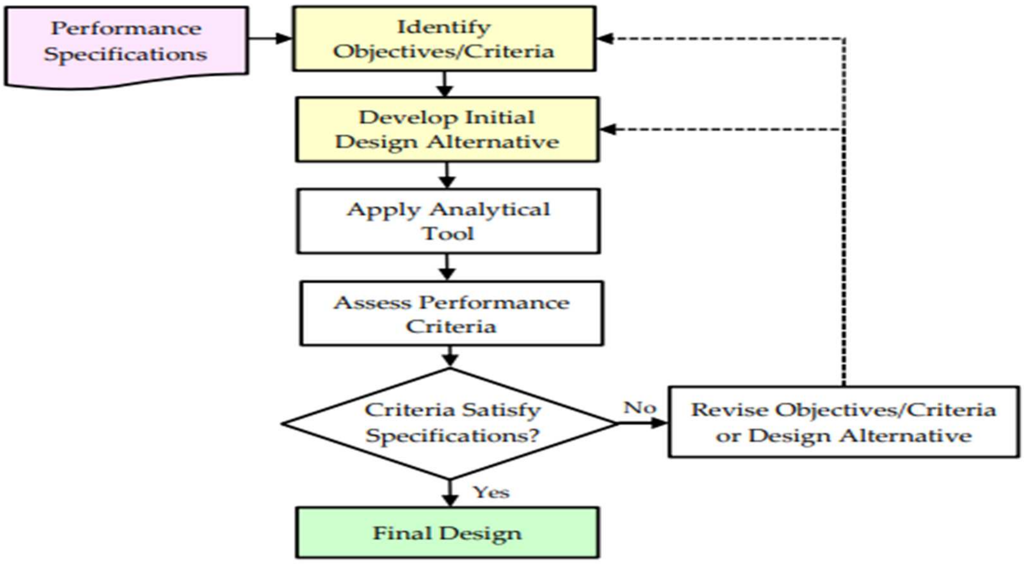

Figure 1. Typical performance-based analysis (PBA) process.

4. PERFORMANCE BASED SEISMIC DESIGN-

Performance-based seismic design 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. As graphically presented in Fig. 3, the nonlinear static analysis procedure requires determination of three primary elements: capacity, demand and performance. The capacity spectrum can be obtained through the pushover analysis, which is generally produced based on the first mode response of the structure assuming that the fundamental mode of vi- Performance based seismic design using nonlinear pushover analysis 655 bration is the predominant response of the structure. This pushover capacity curve approximates how a structure behaves beyond the elastic limit under seismic loadings. The demand spectrum curve is normally estimated by reducing the standard elastic 5% damped design spectrum by the spectral reduction method. The intersection of the pushover capacity and demand spectrum curves defines the "performance point" as shown in Fig. 3 :-

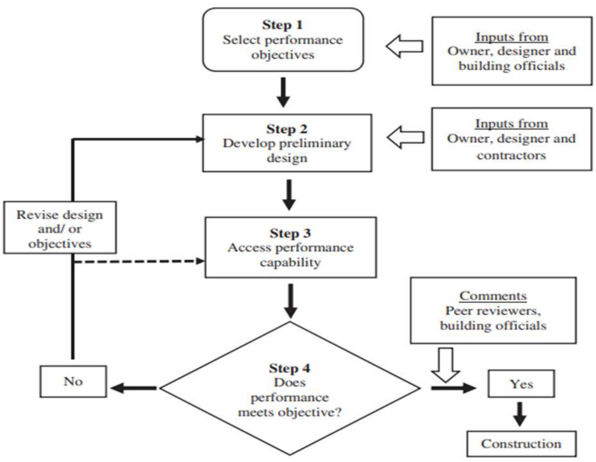

Figure. 2: - PBSD flow diagram

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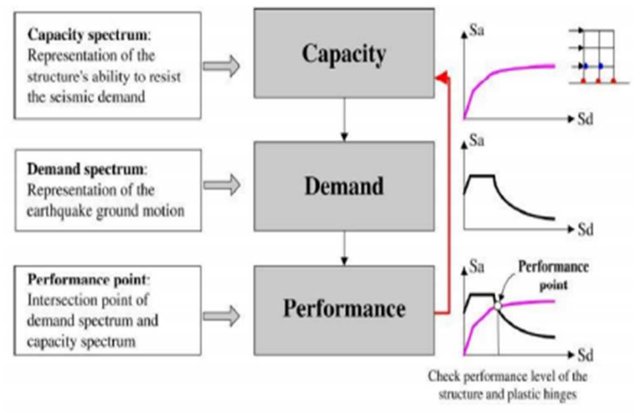

Figure. 3: - Non-Linear Analysis Procedure

At the performance point, the resulting responses of the building should then be checked using certain acceptability criteria. When the responses of a structure do not meet the targeted performance level, the structure needs to be resized the design process repeated until a solution for the desired performance level is reached. In general, the determination of the satisfactory performance response that fulfills both system level response and element level response requires a highly iterative trial-and-error design procedure even the aid of today's engineering computer software.The performance target can be a specified limit on and response parameter such as stress, strains, displacements, accelerations, etc.

5. LITERATURE REVIEW

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 Performance Based Seismic Design is a rapidly growing idea that is present in all guidelines in all recent guidelines in USA like Vision 2000 (SEAOC, 1995), ATC40(ATC, 1996), FEMA273 (FEMA, 1997), and SAC/FEMA350 (FEMA, 2000a). 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).

Shashi Shankar(1), Mohd. Tauseef Husain(2), 2020 - In this work, Performance based seismic design of a G+20 storied symmetrical building structure has been done by evaluating their performance using Non-linear pushover- analysis. Reinforcements of various structural elements of the structure i.e. the beams & the columns increased with different combinations & their effect on the performance on the structure was studied. The design of reinforcements done in ETABS & further Non-Linear analysis was carried out using SAP2000 Non-linear software tool. The primary objective of this work is to study the seismic response of RC framed building using Performance based seismic engineering. The effect of earthquake force on multi-level building, having height (G+20) with the help of Non-linear pushover- analysis, for various different sets of reinforcements at different levels has been investigated.

Nayer A. El-Esnawy (1), Bahaa E. H. Mahmoud (2), Ahmed G. Fouad (3), 2020 - Due to architectural needs, the geometrical irregularities in buildings, either in plan or elevation, have become among the common challenges that face structural engineers nowadays. Irregularities in elevation are usually associated by the presence of setbacks in the building. In this paper, the seismic responses of several R/C multi-storey moment-resisting frame buildings with single symmetrical setback are examined and evaluated via pushover analysis, which is a non-linear static analysis technique used to estimate the seismic capacity of buildings for design purposes. Four pushover analysis methods are applied for different vertical configurations of setbacks: the mass proportional uniform pushover analysis, the mass proportional triangular pushover analysis, the method of modal combinations, and the improved upper bound method. Also, the nonlinear time-history analysis using seven scaled earthquakes is applied to determine the mean values and standard deviations for the seismic responses. The results of the inter-story drifts for damage and the base shear for strength determined by the

ISSN: 2277-9655
Impact Factor: 5.164
CODEN: IJESS7

pushover analysis methods are compared with the mean results determined by the nonlinear time-history analysis. This comparative study with the nonlinear time-history analysis shows that the improved upper bound pushover method is the most suitable to estimate damage based on inter story drifts for R/C multi-storey moment-resisting frame buildings with setbacks, whereas the mass proportional uniform pushover method is better for estimating the base shear capacities of buildings.

Mohd. Zameeruddin (1), Keshav K. Sangle (2),2020- The performance-based seismic design has two primary concerns: (a) appropriate quantification of the uncertainties associated with the performance evaluation process, and (b) satisfactory characterization of the associated structural damage for direct incorporation into the design or performance evaluation methodology. This study attempts to address these primary concerns by evaluating the performance of reinforced concrete frame using nonlinear static procedures. For this, fifteen-moment resisting frames designed following the guidelines of Indian seismic codes were subjected to different lateral load patterns. The seismic performance is investigated in terms of fundamental periods, roof displacements, inter story drift ratio, base shear, and modification factor and was compared with various performance limits. The obtained results showed disagreement with Indian seismic code provisions, especially, towards the fundamental time period, upper and lower bound values of base shear drift ratio and modification factor.

M A Zubritskiy(1), O Y Ushakov(2) , L S Sabitov(3), 2019 - The article presents experimental research and comparison of two seismic evaluation methods: nonlinear static procedure (NSP) / pushover analysis (PoA) and nonlinear time history analysis. It is established that nonlinear static procedure is good enough for prediction of plastic hinges localization, but difference between methods results is more than 15 % with a lack of seismic resistance.

Said M. Easa (4) and Wai Yeung Yan (5), 2019 – Traditional design approaches in civil engineering mainly focus on codes/guidelines related to building an infrastructure, while performance-based analysis (PBA), an emerging new reality around the world, focuses on the performance of the end product. Professional organizations, academicians, and the industry have made significant contributions in formulating PBA in various civil engineering fields, where practical guidelines and principles have been adopted in infrastructure analysis. This paper presents a critical review of PBA applications in three civil engineering fields: transportation, environmental, and structural engineering. The applications are grouped into a wide array of civil engineering areas, including highway transportation, pavement design and management, air transportation, water-structures design and operation, landfill design, building architectural design for evacuation, urban energy design, building earthquake-based design, building wind-based design, and bridge design and management. A total of 187 publications on PBA were reviewed and details on 122 application papers (from 23 countries/regions) are presented. The review consists of vertical and horizontal scans of PBA applications. In the vertical scan, the applications in each civil engineering area are summarized in tabular format that shows the system element modeled, analysis objective, performance criteria, analytical tool, and specifications/codes. The horizontal scan (discussion and lessons learned) addresses the following aspects of PBA: (1) the wide array of analytical tools used, (2) the broad functional and process-related areas, (3) the advantages, challenges, and opportunities, and (4) potential future applications. It is hoped that the state-of-the-art review presented in this paper will help researchers/practitioners quickly find useful information about PBA and promote its development in their respective fields.

Mrs. Sonal S. Ambhaikar (1), Mr. Satyajit D. Patil(2), Mrs. Rajbansi S Kognole(3) ,2018 - Performance based design explicitly evaluate 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 act building response. It is an iterative process that begins with selection of performance objective, followed by the development of a preliminary design assessment as to whether or not the design meets the performance objective and finally redesign and reassessment if required until the desired performance level is achieved. In present study two R.C. buildings, one rectangular and one square in plan are analyzed using pushover analysis and redesigning by changing the reinforcement in columns. The pushover analysis is carried out using Etabs 2015. A Six storied buildings are considered to be located in Zone IV with Hard soil strata.

Mohammed Ismaeil, 2018- The infrastructure, existing in Sudan, is mostly not structured or designed to resist seismic forces accordingly. The study investigated the seismic damage of a 5 storey existing reinforced concrete building in Khartoum, Sudan. Three performance levels were considered in the study, which included immediate occupancy, life safety, and collapse prevention. The gravity push was carried out using force control method and lateral push with displacement control, using SAP2000. Pushover analysis produces push curve, consisting of capacity spectrum, demand spectrum, and performance point. It showed the performance level of building components along with maximum base shear carrying capacity. It has been observed that demand curve intersected the capacity curve between the points B and C at the X direction that is life safety level; and between the points B and C at the Y direction that is life safety and collapse prevention level. Therefore, some building elements are needed to be strengthened.

Samir A.B. Jabbar Al-jassim (1), Mohanned Abdul Husssain (2),2018 – Engineers in Basrah city in the south of Iraq like the engineers in many other cities in the world were not consider seismic forces in the design of the city buildings. It was believed that Basrah is not prone to earthquakes. Recent seismological studies showed that the city is near to an active fault with a high damage intensity in addition, the alluvial thick layer of the city soil is susceptible to liquefaction during an earthquakes. Hence the seismic evaluation of the existing buildings gains an increased attention and become a public demand. In this work a nonlinear static analysis (Pushover analysis) based on ATC40 capacity spectrum method is employed to analyze an existing G+5 stories reinforced concrete building. The building is analyzed in three cases, (regular, irregular in plan and irregular in height). The seismic coefficients of the design earthquake used in the analysis are based on the UBC97 code. Results showed that the building in all its three cases is over designed and its performance during the design earthquake is a little beyond its elastic limit. All plastic hinges developed in the building are in performance level less than immediate occupancy. Also the building showed a weak beam strong column behavior. Thus the building expected to be safe during any earthquake less or equal to the design one.

Wen Cheng Liao (1), Yu Heng Chiang Hsieh (2), C. Subhash Goel (3), 2017 – Seismic evaluation and collapse prediction of structures mostly includes determination of story displacement demands, and member forces and deformations for certain hazard levels. A few methods have been developed in the decades, such as modal pushover analysis (MPA), FEMA 440, and capacity spectrum. In general, non-linear pushover analyses are applied in these methods. This paper presents a seismic evaluation and collapse prediction method based on energy balance concept. In this method, the design base shear for any given hazard level can be obtained by associating the work necessary to push the structure to the design target drift with the energy needed in a structure of an equivalent SDOF oscillator. This work energy equation can be further applied to estimate responses of existing structures under certain earthquake excitations. In this procedure, an energy-displacement plot (ے (□can be converted with the force-displacement curve (capacity) of the structure obtained by static pushover analysis. This curve is then overlaid over the energy demand plot (E_d) for the specified hazard level to determine the ultimate displacement demand. This method can be also used to obtain the collapse margin ratio (CMR) without cumbersome time-history analyses, such as incremental dynamic analysis (IDA). The drift estimations and collapse predictions of two 20-story RC moment frame structures by applying this energy balance concept were in good agreement with those obtained from inelastic dynamic analyses and IDA using a set of representative ground motion records.

E. Budak (1), H. Sucuoğlu (2), 2017 – The need for tall buildings are steadily increasing all over the world, in parallel to the need for new living spaces in large cities. Improvements in technological equipment, material science and analysis methods have opened opportunities to construct new life areas by rising along the vertical direction instead of horizontal. Unlike regular buildings, tall buildings are peculiar due to their specific architectural properties and building configurations. On the other hand, most of these buildings are located in the regions of high seismicity. The behavior of tall buildings under seismic effects is crucial since the contribution of higher mode effects is significant on their dynamic behavior. Seismic response of tall buildings under the effect of seismic loading is one of the most sophisticated problems in earthquake engineering. High strength materials and innovative structural systems are generally employed to resist the unique challenges introduced by these structures in the regions of high seismicity. In this study, the behavior of tall buildings under seismic loading is summarized first by utilizing the performance based seismic design (PBSD) approach since current prescriptive seismic codes are too restrictive and inadequate to understand the anticipated behavior of tall buildings and pursue a reasonable design. Considering all these facts, several institutions and building officials have recently proposed and published alternative consensus guidelines, which are based on performance based design concepts. In this study, all of these issues are addressed. PBSD is commonly conducted by performing nonlinear dynamic analysis (NDA) for tall buildings. PBSD approach is quite sophisticated and a time consuming process, from creating nonlinear modelling to the interpretation of results. However, there are also variety of uncertainties from modelling of the component to the selection of ground motions, and to the definition of performance target levels. This study especially focusses on nonlinear modeling of reinforced concrete shear walls. Finally, a reinforced concrete unsymmetrical-plan tall building with 34 stories is designed in Istanbul according to the Turkish Seismic Code. For both service and maximum earthquake levels, nonlinear time history analysis is employed by using a suite of ground motions for checking the results in compliance with the determined target performance levels. The results have indicated that satisfactory seismic performance can be obtained through the use of performance based seismic design procedures.

Mr. Chetan Ingale(1), Prof. M.R.Nalamwar(2) , 2017 - Every Civil Engineering structure or building is inimitable in nature unlike other engineering products which are constructed in a massive scale using the same technique repeatedly. The present Project is an attempt to understand Performance Based Design Approach. The performance-based seismic design approach enables us to design new structures more efficiently and to assess existing structures more realistically. The promise of performance based seismic engineering is to construct structures with expected seismic performance. Performance based seismic design precisely evaluates how building is likely to perform in given possible earthquake threat. In performance based design identifying and assessing performance capacity of structure in an important part of design process, and guide the many decisions that must be made. Present study based on performance based seismic design and non-linear analysis of multi-storey RCC building. Performance based seismic design is an iterative process, begins with choice of performance objective followed by preliminary design, an evaluation whether or not the design meets the performance objective and finally redesign and reassessment, until desired performance level is achieved. In this project work we have carried out performance based seismic design of multi-storey (G+5) RCC building. Once design is complete, non-linear analysis is carried out to study seismic performance of building and found out whether selected objective is satisfied or not. In this work (G+5) RCC building is 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. After the building is designed it is imported to ETABS platform in order to carry out Pushover Analysis. The Displacement controlled Pushover Analysis was carried out and the Pushover Curve were obtained for the building as per guidelines mentioned in ATC 40. 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. These results were compared for each zone from which we can find out how the building will perform in different zones. From the Performance point it was found that the Building designed as per Indian standards was found to be well above Life safety performance level considering Designed Based Earthquake.

Peter Fajfar (1) ,2017 – The analysis of structures is a fundamental part of seismic design and assessment. It began more than a 100 years ago, when static analysis with lateral loads of about 10% of the weight of the structure was adopted in seismic regulations. For a long time seismic loads of this size remained in the majority of seismic codes worldwide. In the course of time, more advanced analysis procedures were implemented, taking into account the dynamics and nonlinear response of structures. In the future methods with explicit probabilistic considerations may be adopted as an option. In this paper, the development of seismic provisions as related to analysis is summarized, the present state is discussed, and possible further developments are envisaged.

Dona Mary Daniel(1), Shemin T. John(2), 2016 - In this study the seismic response of a ten storied reinforced concrete building is analysed by displacement controlled pushover analysis. It is assumed to be located in seismic zone 3. The building frame is simulated and analysed using the structural analysis and design software SAP2000. In non-linear analysis, moment-curvature relationship is used to model plastic hinge behaviour. Thus it was developed for modelling the user defined hinges for beam and column sections. Moment (M) and interactive P-M hinges were assigned to the both ends of beam and column sections respectively. The lateral forces were obtained as per IS 1893 (Part1):2002 and applied to the building. Top node displacement is

ISSN: 2277-9655
Impact Factor: 5.164
CODEN: IJESS7

incremented step by step up to the limiting displacement to obtain the pushover curve and the sequence of formation of plastic hinges and failure of beams and columns were recorded. The analysis results including the pushover curve and hinge formation are discussed. The maximum base shear capacity was found to be higher than the design base shear and hinges were formed in beams prior to columns.

Dilip J. Chaudhari(1), Gopal O. Dhoot(2), 2016 – In past two decades earthquake disasters in the world have shown that significant damage occurred even when the buildings were designed as per the conventional earthquake-resistant design philosophy (force-based approach) exposing the inability of the codes to ensure minimum performance of the structures under design earthquake. The performance based seismic design (PBSD), evaluates how the buildings are likely to perform under a design earthquake. As compared to force-based approach, PBSD provides a methodology for assessing the seismic performance of a building, ensuring life safety and minimum economic losses. The non-linear static procedures also known as pushover analysis are used to analyze the performance of structure under lateral loads. Pushover analysis gives pattern of the plastic hinge formations in structural members along with other structural parameters which directly show the performance of member after an earthquake event. In this paper, a four-storey RC building is modelled and designed as per IS 456:2000 and analyzed for life safety performance level in SAP2000 v17. Analysis is carried out as per ATC 40 to find out storey drift, pushover curve, capacity spectrum curve, performance point and plastic hinges as per FEMA 273 in SAP2000 v17. From the analysis, it is checked that the performance level of the building is as per the assumption.

Nilesh M. Kashid, Pune, Maharashtra, 2016 – During the last few decades, earthquake engineering has undergone significant development. Initially, structures were designed without considering seismic loading. Later, it was observed that the structures designed for some lateral loads like wind etc. performed significantly well than those designed for gravity loading only. Hence, the importance of considering earthquake forces in the design process is realized and seismic resistant design became a practice. Further with the advent of time history analysis and better understanding of seismic response. The importance of ductility of structure is realized in resisting even higher seismic loads than the designed loads. The design base shear force is reduced by introducing a response reduction factor to consider an inelastic displacement capacity of ductile structure in dissipating the energy. Further, with more understanding of structural behaviour at micro-level or element level, the concept of "capacity design" was introduced and this forced to decide the required performance of the structure right at the design stage itself. Today, the seismic design codes of various countries are being revised to decide performance criteria of the buildings that will suit the existing design and construction practices in the respective countries. In this paper, an attempt has been made to develop a possible method of seismic analysis that can be incorporated in the existing Indian Seismic Code I.S.: 1893-2002. For the purpose, some of the key features the existing methodology followed by Federal Emergency Management Agency (FEMA) of United States of America is made use of.

Rajan L. Wankhade(1), Amarsinh B. Landage(2), 2016- Analysis and design of building structures subjected to earthquake forces is complex task as earthquake forces are random in nature & unpredictable. In performance based analysis and design estimation of proper response parameters of structure is priorly considered to evaluate its performance. In the present work performance based analysis and design of building frames with earthquake loading is carried out. The performance of the structure considering potential hazards and uncertainties in assessment of the actual building responses are studied. Performance objectives are selected in performance based analysis and design followed by the development of a preliminary design. Further redesign and reassessment are carried out until the desired performance levels are achieved. Buildings frames are analyzed and redesigned by improving the reinforcement of various components of building frames. Multi storied building frames are analyzed enhancing the reinforcement of structural members in different combination as well as at different storey levels. The results of the analysis and design performed to meet required performance are presented in terms of displacement and forces.

Dubal R.A , 2015 - A performance-based seismic design (PBSD) method is aimed at controlling the structural damage based on precise estimations of proper response parameters. PBSD method evaluates the performance of a building frame for any seismic hazard, the building may experience. Use of this method for vertical irregular building is verified with comparison of conventional method. Vertical irregular frame is subjected to failures due to stiffness and strength reduction. This paper deals with application of performance based seismic design method for vertical irregular RC building frames (10 storied). Performance evaluation of conventional frames designed by conventional code method is compared with performance based seismic designed frames. The evaluation is carried out by Nonlinear Time History Analysis and Nonlinear Static analysis. The vertical irregular frames considered for study are with column discontinuity.

Saba Bano (1), T. Naqvi (2), M. Anwar (3), 2015- This paper presents an overview of the current state of knowledge with regard to literature on Performance based seismic design method. 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. The general promise of performance based design is to produce engineered structures with predictable performance during future earthquakes.

S Monish (1), S Karuna (2), 2015 – Earthquakes are known as one of the most unpredictable and devastating of all natural disasters, however the unpredictable nature of occurrence of these earthquakes makes it difficult to prevent loss of human lives and destruction of properties, if the structures are not designed to resist such earthquake forces. In this paper attempt has been made to study two types of plan irregularities namely diaphragm discontinuity and re-entrant corners in the frame structure. These irregularities are created as per clause 7.1 of IS 1893:2002(part1) code. Various irregular models were considered having diaphragm discontinuity and reentrant corners which were analysed using ETABS to determine the seismic response of the building. The models were analysed using static and dynamic methods, parameters considered being displacement, base shear and fundamental natural period. From the present study the model which is most susceptible to failure under very severe seismic zone is found, modelling and analysis is carried out using ETABS.

Arvind. S. Khedkar (1), Rajkuwar. A. Dubal (2), Sandeep. A. Vasanwala (3), 2014 –A performance-based seismic design (PBSD) method is aimed at controlling the structural damage based on precise estimations of proper response parameters. PBSD method evaluates the performance of a building frame for any seismic hazard, the building may experience. This paper gives a comparison between Performance based Seismic design and conventional design method (using I.S 1893; 2002) for irregular RC building frames (10 storeys) and evaluates performance using pushover and Time History analysis.

Rajkuwar Dubal (1), Gole Neha (2), Patil G.R (3), Sandip Vasanwala (4), Chetan Modhera (5), 2014 –A performance-based seismic design (PBSD) method is aimed at controlling the structural damage based on precise estimations of proper response parameters. PBSD method evaluates the performance of a building frame for any seismic hazard, the building may experience. Use of this method for vertical irregular buildings is verified with comparison of conventional method. Soft storey is subjected to failures due to stiffness and strength reduction. This paper deals with application of Performance based seismic design method for soft storey RC building frames (10 storeys). Push over analysis results show significance of PBSD method in frames having soft story at lower floor level compared to higher ones.

Mr. A. Vijay (1), Mr. K.Vijayakumar(2) , 2013 –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 behaviour 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 analyse the difference in structural behaviour between hollow and solid frames. The technique adopted in this research is based on the conventional displacement method of elastic analysis.

Q. Xue et al. (2013) - Presented that methodology of performance-based seismic design and evaluation has been studied for several years. The result has been applied in developing the seismic design draft code in a commissioned research project sponsored by the Architecture and Building Research Institute at Ministry of the Interior. In addition, a generalized numerical method for displacement-based seismic evaluation and direct displacement-based seismic design is also developed. Sensitivity study on the design parameters are carefully carried out to find the optimal setting in order to increase the design efficiency. It has been found that the design procedure based on the yielding displacement estimated through proper empirical formula is more efficient for ordinary buildings because of the resulted non-minimum strength. However, the design demand will have significant deviation when the empirical formula is unsuitable for the target building. Therefore, this study proposes a combined strength-displacement design method and its modified version for the design of Type I ordinary buildings when there is no empirical formula. The application range of these methods is also given.

M. A. Ismaeil , 2013 – A three-stories hospital existing reinforced concrete building in the city of Khartoum-Sudan, subjected to seismic loads ,was analysed .The Sudan is not free from earthquakes , it has experienced many earthquakes during the recent history, and the previous studies on this field demonstrated this argument. This paper is focused on the study of seismic performance of the existing hospital buildings in the Sudan. Plastic hinge is used to represent the failure mode in the beams and columns when the member yields. The pushover analysis was performed on the building using SAP2000 software (Ver.14) [1] and equivalent static method according to UBC 97 [2]. The principles of Performance Based Seismic Engineering are used to govern the analysis, where inelastic structural analysis is combined with the seismic hazard to calculate expected seismic performance of a structure. Base shear versus tip displacement curve of the structure, called pushover curve, is an essential outcomes of pushover analysis. The pushover analysis is carried out in both X and Y directions. Default hinge properties, available in some programs based on the FEMA -356 [3] and Applied Technology Council (ATC-40) [4] guidelines are used for each member. One case study has been chosen for this purpose. The evaluation has proved that the three stories hospital building is seismically safe.

K Rama Raju(1), A Cinitha (2), Nagesh R Iyer(3) , 2012 – Assessing the capacity of existing building as per the present codes of practice is an important task in performance-based evaluation. In order to enhance the performance of existing buildings to the present level of ductile design prescribed by present codes and find the retrofit or design a rehabilitation system, there is an urgent need to assess accurately the actual lateral load resistance and the potential failure modes. In this paper, a typical 6-storey reinforced concrete (RC) building frame is designed for four design cases as per the provisions in three revisions of IS: 1893 and IS: 456 and it is analysed using user-defined (UD) nonlinear hinge properties or default-hinge (DF) properties, given in SAP 2000 based on the FEMA-356 and ATC-40 guidelines. An analytical procedure is developed to evaluate the yield, plastic and ultimate rotation capacities of RC elements of the framed buildings and these details are used to define user-defined inelastic effect of hinge for columns as P-M-M and for beams as M3 curves. A simplified three parameter model is used to find the stress–strain curves of RC elements beyond the post yield region of confined concrete. Building performance of structural components in terms of target building performance levels are studied with the nonlinear static analysis. The possible differences in the results of pushover analysis due to default- and user-defined nonlinear component properties at different performance levels of the building are studied.

Wen-Cheng Liao(1), Subhash C. Goel(2), 2012 - studied the application of the performance based plastic design (PBPD) approach to seismic resistant reinforced concrete special moment frames. Four baseline reinforced concrete special moment frames (4, 8, 12 and 20-story) as used in the FEMA P695 were selected for the study and they concluded that the performance based plastic design method is a direct design method which uses previously selected targeted drift and the yield mechanism as a key performance objectives. At present, international and domestic direct displacement-based seismic design approaches include substitute structure DBD/EBD method based on the equivalent-elastic response spectrum and inelastic structural capacity spectrum method involving yield point spectra method and the generalized numerical method. By using graphical, numerical or the combined methods, these methods are basically applicable for the first-mode-dominated regular structures or single-mode dominated irregular ones. Although a few methods considering with the higher-mode effects are available, their applications are limited to 2D structural model. For commonly known irregular structures, particularly high-rise ones, application of the method is limited. Hence, regarding regular or irregular structures with significant higher-mode effects, this study proposes a modified direct displacement-based seismic design method in which the target displacements corresponding to the first three modes of the structural vibration are decomposed. Meanwhile, influence of the mode shapes on the design

ISSN: 2277-9655
Impact Factor: 5.164
CODEN: IJESS7

method for irregular buildings is also discussed. Since the nonlinear dynamic analyses are inherently time-consuming, a simple time-history analysis method is proposed in this study. Comparison among the proposed method, nonlinear static analysis and nonlinear dynamic analysis are made through numerical examples. Finally, the proposed methodology is implemented as new features in the existing computer program for performance-based seismic evaluation.

Gomase O.P (1), Bakre S.V (2), 2011 – The seismic response of multistory building supported on base isolation is investigated under real earthquake time history motion. The force deformation behavior of an isolator is modeled as Bi-linear hysteretic behavior which can be effectively used to model all isolation system in practice. Uniform Building Code (UBC-97) is widely used in design of base isolation systems which contains provision according for near fault effect. In order to investigate the performance of base isolation systems, design according to UBC-97 under near fault earthquake. Non-linear time history analysis of a four storey base isolated building, located at close to an active fault. The isolation system is composed of high damping rubber bearing. Design displacements are estimated using UBC-97 parameter. The building is subjected to 1979 El-Centro, 1995 Kobe and 1994 Northridge earthquakes. The analysis result shows that UBC-97 predicts isolator displacements successfully. Floor acceleration and inter-story drifts of the subject base isolated building are significantly reduced when compared to its fixed base counterpart.

Mrugesh D. Shah, 2011- Performance Based Seismic Engineering is the modern approach to earthquake resistant design. It is limitstates design extended to cover complex range of issues faced by earthquake engineers. 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 modeling issues were incorporated through nine model for G+4 building and G+10 building were; bare frame (without infill), having infill as membrane, replacing infill as a equivalent strut in previous model. All three conditions for 2×2, 3×3, 4×4 bays. Comparative study made for bare frame (without infill), having infill as membrane, replacing infill as a equivalent strut.

Mansour Bagheri (1), Mahmoud Miri (2), 2010 – The design objectives in current building codes address life safety, control damage in minor and moderate earthquakes, and prevent collapse in a major earthquake. However, the actual reliability of the design in achieving the objectives is not known. There is a general agreement among researchers and professionals that future seismic design needs to be based on achieving stated multiple performance objectives. Future seismic design practice will be based on explicit performance criteria that can be quantified, considering multiple performance and hazard levels. There are several challenges to be addressed before procedures for performance based design can be widely accepted. The development in performance based design in seismic engineering will be directed towards the definition of performance objectives, a general design methodology, issues of ground motion modeling, and demand and capacity evaluation.

John W. van de Lindt, M. ASCE (1), Shiling Pei M. ASCE (2), Steven E. Pryor M.ASCE(3), H. Shimizu(4) and H. Isoda(5) ,2010 –: In July 2009, a full-scale midrise light-frame wood apartment building was subjected to a series of earthquakes at the world's largest shake table in Miki, Japan. This article focuses on the test results of that full-scale six-story light-frame wood building. The objectives of the testing program were to 1 demonstrate that the performance-based seismic design procedure developed as part of the NEES Wood project worked on the full-scale building, i.e., validate the design philosophy to the extent one test can and 2 gain a better understanding of how midrise light-frame wood buildings respond, in general, to a major earthquake while providing a landmark data set to the seismic engineering research community. The building consisted of 1,350 m2 14,000 ft2 of living space and had 23 apartment units; approximately one-half one-bedroom units and one-half two-bedroom units. The building was subjected to three earthquakes ranging from seismic intensities corresponding to the 72-year event to the 2,500-year event for Los Angeles. In this paper, the construction of the NEES Wood Capstone Building is explained and the resulting seismic response in terms of base shears, selected wall drifts, global inter story drifts, accelerations, hold-down forces, and roof drifts are presented. Detailed damage inspection was performed following each test and those results are summarized also. The building performed excellently with little damage even following the 2,500-year earthquake. The global drift at roof level was approximately 0.25 m and maximum inter story drifts were approximately 2% for the floor average with individual wall drifts reaching just over 3% in one corner of the building at the fifth story.

ISSN: 2277-9655
Impact Factor: 5.164
CODEN: IJESS7

S. Pei and J. W. van de Lindt(2009)- proposed a probabilistic framework to estimate long-term earthquake-induced economical loss for wood frame structures and demonstrated in this paper. The concept of a damage fragility system which can be used to quantitatively model the uncertainty in the response-damage-loss relationship was developed and applied to wood frame residential building components. Bayesian models were used in the framework in order to incorporate subjective engineering experiences and test data. A simulation procedure was used to implement the loss estimation framework and was investigated with several numerical examples. Specifically, the analyses of two typical wood frame residential structures were examined in order to illustrate the concepts and methods. Such a procedure has not yet been developed for wood frame structures within performance-based seismic design (PBSD) procedures that are under development, thus incorporating economic losses within the PBSD of wood structures is novel. The methods and concepts explained in this paper could provide a viable path towards the design, optimization, and assessment related to long-term earthquake-induced loss for existing wood frame structures and new designs.

Houssam Mohammad Agha (1), Li Yingmin (2), Oday Asal Salih (3) and A'ssim Al-Jbori(4) , 2008 – The basic aim of this study is to investigate the nonlinear performance of a ten story special moment resisting frame (SMRF). The elements are designed based on the 1997 edition of the Uniform Building Code for seismic zone 2A. The global and local nonlinear behaviors of the frame are studied under several earthquake ground motions. For this purpose, an inelastic dynamic analysis is performed using three artificial time histories functions generated using SIMQKE_GR program. Nonlinear Static "Pushover" Analyses using various invariant lateral load patterns was also performed. The seismic performance of the structure is determined on the basis of its damage state under an earthquake ground motion. For this purpose, inelastic dynamic and nonlinear static analyses are used to calculate the damage state "drift profiles and inter-storey drifts". Damage Index from the nonlinear time history analysis is compared with those obtained by pushover analysis procedure. In general, the case study explores variations in the results; it was found that estimates of building response from the nonlinear static analysis are generally insensitive to the pattern of lateral load used to perform the pushover analysis. On the other hand, it was found that building structure's dynamic response characteristics depend strongly on the load path, properties of the structure and the characteristics of the ground motion.

S.R. Satish Kumar (1) and G Venkateswarlu (2), 2008 – The seismic analysis and design of reinforced concrete (RC) frames is still an unresolved issue due to its complex behaviour. Seismic design codes are traditionally based on the force-based approach wherein structures are designed with a certain minimum lateral strength. However, it has been observed that such an approach, which relates to the elastic response, does not produce consistent inelastic response in terms of the amount and distribution of damage in structural elements. In views of the above, the displacement based approach, also known as performance based design (PBD) approach, has been explored in recent times. In this approach, the prime response quantities of interest are the inter-storey drifts and the design process directly attempts to limit these drifts to an acceptable value. However, PBD is still not ready for codification as several issues need to be understood. These include the influence of parameters such as the strength, stiffness, energy dissipation capacity and detailing such as percentage of reinforcement and amount of confining steel on the local and overall damage. In this study, a small portion of the overall problem is studied extensively to arrive at meaningful conclusions which can be used to develop a suitable design approach. Over 700 RC regular frames of two, four and eight storeys, designed and detailed as per the Indian seismic codal provisions, are analyzed by varying the time period, response reduction factor and percentage of longitudinal reinforcement. Non-linear time history analyses for six different earthquake accelerograms are carried out using the Pivot hysteretic model. The response parameters considered are local and global ductility demand, local damage index and inter-storey drift index. Variation in the response parameters with time period, percentage of reinforcement and response reduction factor are presented in graphical form. It is shown that the percentage of reinforcement plays a major role in the seismic performance. Based on the study, a simple design procedure to implement performance based design is suggested.

6. SUMMARY AND DISCUSSION

Several approaches for the PBSD method proposed by researchers have been reviewed in this paper. The main of performance based design to achieve multiple performance objectives when the structure is subjected to stated levels of earthquake ground motion. The general promise of performance based design is to produce engineered structures with predictable performance during future earthquakes. Due to advancement in research and test facilities, rapid development of structural analysis and design software, PBD is becoming more popular and efficient tool of design over the usual code methods.

List of Abbreviations :-

ASCE	-	American Society of Civil Engineers
ATC	-	Applied Technology Council
FEMA	-	Federal Emergency Management Agency
ICBO	-	International Conference of Building Officials
ICC	-	International Code Council
NEHRP	-	National Earthquake Hazard Reduction Program
PBEE	-	Performance Based Earthquake Engineering
PBPD	-	Performance Based Plastic Design
PBSD	-	Performance based Seismic design
DBSD	-	Displacement Based Seismic Design
SEAOC	-	Structural Engineers Association of California
UBC	-	Uniform Building Code.

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