Scientific Journal Impact Factor (SJIF): 1.711
International Journal of Modern Trends in Engineering and Research
ISSN (ONLINE) : 2349 - 9745
ISSN (PRINT) : 2393 - 8161

PERFORMANCE BASED SEISMIC DESIGN OF STRUCTURES – A REVIEW

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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.

Keywords—Performance based seismic design, Performance-based earthquake engineering

I. 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.

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. This is the role of PBSD (Freeman et al., 2004).

II. ADVANTAGES 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 lifesafe 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 six key issues [37]:

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.

III. 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 performancebased 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).

S Monish et al. (2015) [1] in their paper present that 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 re-entrant 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.

Massimiliano Ferraioli (2015) [2] studied that most published studies on inelastic earthquake response of non-symmetric buildings are based on simplified inelastic, highly idealized models, while general conclusions regarding the inelastic torsional response of multi-storey building are still lacking. This paper aims to provide a useful contribution in the study of the torsional response of real irregular buildings. To this aim, the manuscript reports the comprehensive study on the seismic vulnerability of an irregular RC building: the hospital building of Avezzano (L'Aquila Italy). For this multi-story building, which is irregular in both plan and elevation, the application of nonlinear static evaluation procedures is by no means straightforward. The study proposes a nonlinear static procedure based on pushover analysis under the multimodal distribution of lateral loads and a capacity spectrum method. This pushover procedure accounts for mass distribution, higher modes contribution and mode-shapes correlation. Furthermore, due to its non-iterative feature, it avoids problems of non-convergence and multiple solutions of the conventional capacity spectrum method. Applied to a real case study, the procedure is used to investigate, in a 3D plan irregular building, the sensitivity of torsional inelastic response to lateral force distribution, higher modes contribution, accidental eccentricity and controlled point for monitoring the target displacement.

Dubal R.A et al. (2015) [3] 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.

Arvind. S. Khedkar (2014) [4]explain in his paper that 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.

Volume 02, Issue 10, [October – 2015] ISSN (Online):2349–9745 ; ISSN (Print):2393-8161

Rajkuwar Dubal et.al. (2014),[5] presented that 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.

Q. Xue et al. (2013) [6] presented that methodology of performance-based seismic design and evaluation has been studiedfor 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.
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 2Dstructural 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 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 existingcomputer program for performance-based seismic evaluation.

Dr. Suchita Hirde and Ms. Dhanshri Bhoite (2013) [7] in this study the effect of modeling of infill walls on the performance of multi storey reinforced concrete frame building was observed and concluded that lateral load resisting mechanism of the masonry infill frame is essentially different from the bare frame. The bare frame acts primarily as MRF (moment resisting frame) with the formation of plastic hinges at the joints under lateral loads.

Onur Merter and Taner Ucar (2013) [8] in this study six and ten-story RC frame structures were analyzed using linear and nonlinear dynamic analyses. Turkish seismic design code was used for primary design, RC frame structures performed by using seven ground motions recorded at different sites of soil at Turkey and concluded that inter story drift ratios obtained from nonlinear time history analyses are generally larger in upper stories.

Kavita Golghate, Vijay Baradiya And Amit Sharma (2013) [9] in this study a four storey building in seismic zone IV was designed and constructed using IS-456:1978 and the revised code IS-1893:2000 provisions. They carried out pushover analysis, for default hinge and user defined hinge properties, which is available in some of the programs which are based on the guidelines of FEMA-356 and ATC-40. This study was aimed to evaluate the zone –IV selected RC building for non linear static analysis. Pushover analysis shows the plastic hinges, pushover curves, capacity spectrum, and performance level of the building and concluded that to explore the nonlinear behavior of the buildings. The results obtained in terms of demand of pushover, plastic hinges, capacity spectrum and the real behavior of structures. Hinges were developed in the beams and columns showing the three stages immediate occupancy, Life safety, Collapse prevention. The hinges in the column limited the damage.

Ms. Nivedita N. Raut & Ms. Swati D.Ambadkar (2013) [10] studied pushover analysis under strong ground motion , effect of the layout of masonry infill panels was investigated over the elevation of masonry infilled RC frames on the seismic performance and potential seismic damage of the frame based on realistic and efficient computational models and compared base shear vs. displacement in bare frame, infill wall frame and ground. It was seen that displacement was more than other two frames at roof level in bare frame and at ground floor in weak story displacement was more than other two frames. Less hinges were formed in column than beam.
Mr. A. Vijay and Mr. K.Vijayakumar (2013) [11] studied the performance based design of steel building frame work , focused on a computer based pushover analysis technique which was subjected to earthquake loading. 2D frames were modeled for solid and hollow sections, for various stories with constant bay width and storey height which was analyzed and concluded that;

1. When the no. of storey decreases corresponding base shear increases and also when the no. of stories increases corresponding displacement increases.
2. Drift to height ratio is limited to thirty five stories.
3. Comparing the results of solid and hollow sections base shear vs. displacement curve indicates that the hollow sections are far better than solid ones.

Sofyan. Y.Ahmed (2013) [12] investigated a ten storey five bay reinforced concrete frame (2D beams and columns system) subjected to seismic hazard of the Mosul city Iraq. Plastic hinge was used to represent the failure mode in the beams and columns and conclusion drawn from the study that most of the hinges were formed in beams.

Wei Li and Li Qing-Ning (2012) [13] Performance-based seismic design (PBSD) has been widely recognized as an ideal method for use in the future practice of seismic design. This paper summarizes the advantages and disadvantages of the current seismic design code in China. Suggesting the tall building structures beyond the code specification (TBBC), applying PBSD method due to its many advantages of PBSD and aiming TBBC characteristics, a PBSD flowchart is presented and the proposed code is described. Structural seismic performance objectives, performance levels and the main method to implementation of PBSD have been presented. Site feasibility requirements, conceptual design scopes and basic rules have been proposed. Performance objective-oriented procedures for preliminary design and seismic performance evaluation have been presented. Suggestions on seismic performance criteria and the evaluation of new TBBC have been made. In order to verify the feasibility of PBSD for application of TBBC, a typical case study has also been conducted. It is believed that PBSD methodology will bring a new era to engineering practices with increased confidence in, and reliability on, seismic performance and safety.

R. Peres et al. (2012) [14] in recent years, Nonlinear Static Procedures (NSPs) became a powerful tool for seismic performance evaluation. Several seismic design/assessment Guidelines have recommended this type of procedure as design/evaluation technique. The aim of this work is to assess the performance of these procedures applied to a set of 1-storey steel structures with plan irregularities. To investigate the torsional phenomenon, two types of structures were considered, namely torsionally restrained and torsionally unrestrained.
The NSPs evaluated were the original N2 method recommended in Euro code 8 (CEN, 2004), the Extended N2 method developed by Fajfar et al. (2005), the Capacity Spectrum Method (CSM) specified in ATC40 (ATC, 1996) with the improvements presented in FEMA 440 Report (ATC, 2005) and the Adaptive Capacity Spectrum Method (ACSM) proposed by Pinho et al. (2007). The accuracy of the different Nonlinear Static Procedures was examined through comparison of the results with those obtained from nonlinear dynamic time-history analysis.

K. Rama Raju, A. Cinitha And Nagesh R. Iyer (2012) [15] studied Pushover Analysis for a typical 6-storey office building designed for 4-types of load cases, considered 3-revisions of the Indian codes that are IS:1893 and IS:456. Stress–strain (nonlinear) curves for confined concrete and user defined hinge properties as per CEN Eurocode 8 were used in this study and concluded that the model with user defined hinge was more successful in capturing the hinging mechanism.

Wen-Cheng Liao and Subhash C. Goel (2012) [16] 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.

Gomase O.P, Bakre S.V (2011) [17] studied the seismic response of multistory building which was supported on base isolation, under real earthquake TH (time history) motion, and they concluded that seismic effects can be reduced by seismic base isolation technique by lengthening the natural period of vibration of a structure via use of rubber isolation pads between the columns and the foundation.

P. Poluraju, and P. V. S. Nageswara Rao (2011) [18] studied the performance of reinforced concrete frames using the pushover analysis, they concluded that the behavior of properly detailed reinforced concrete frame building is adequate as indicated by the intersection of the demand and capacity curves and the distribution of hinges in the columns and the beams. Hinges were mostly developed in the beams and few in the columns but with limited damage.

Dalal Sejal P , Vasanwala S. A. and Desai A. K. (2011) [19] observed that for various other different types of structures more research work is needed, especially for development of PBPD (Performance Based Plastic Design) method.

N. Choopool and V. Boonyapinyo (2011) [20] investigated the seismic performance for nine-story reinforced concrete moment resisting frames under seismic loadings with various ductilities by the nonlinear static analyses and nonlinear dynamic analysis in Bangkok according to the newly proposed seismic specifications of Thailand (DPT 1302-52).

Mansour Bagheri and Mahmoud Miri (2010) [21] was discussed future seismic design needs based on defined multiple performance objectives and earthquake hazard levels and they observed the benefits of performance based seismic design which is the possibility of achieving a predictable seismic performance of structure with a very uniform risk.

Qiang Xue, Chia-Wei Wu et al (2007) [22] summarized the development of the seismic design draft code for buildings in Taiwan using performance-based seismic design methodology and case studied following the guidelines in the paper. They presented the design of a reinforced concrete building by using the draft code.

Vipul Prakash (2004) [23] 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.

IV. CONCLUSION

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.

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