Review on Seismic Design and Assessment of High-Rise Structures using various International Codes

Asmita Ravindra Wagh[1] Prof. P. J. Salunke[2] Prof. T. N. Narkhede[3]
[1]M.E. Student [2,3]Assistant Professor
[1,2,3]Department of Civil Engineering
[1,2,3]MGM's College of Engineering and Technology, Navi Mumbai

Abstract— This study focuses on comparison of International standards. An Illustrative study of Seismic design and assessment of a High-Rise Structure using different International Codes is performed. The objective of this study is to investigate the differences caused by the use of different codes in the analysis of a High-Rise building. The parameters such as displacement, base shear, storey drift, time period, axial and shear forces, bending moments are studied to figure out the variations that occur while using different codes. An interest develops to carry out the seismic design of a high rise building using various codes to understand which codal provisions give effective designs to perform good during an earthquake crisis. This paper is intended to compare the design of High rise structure with different International codes. In R.C. buildings, frames are considered as main structural elements, which resist shear, moment and torsion effectively. These frames are subjected to variety of loads, where lateral loads are always predominant. The study of papers published so far helps in understanding the major contributing factors that lead to poor performance of Structures during an earthquake, so as to achieve their adequate safe behaviour under future earthquakes. A comparative analysis can be figured out in terms of Base shear, Displacement, Axial loads, Moments and Displacement.

Key words: Ultra-High Rise Buildings, Building Design Codes

I. Introduction

There is a resurgence of construction of high rise and ultra-high rise buildings around the world. The design of these tall buildings in seismically active regions varies dramatically from region to region whereas rigorous performance-based assessments are required in some countries; many to other countries do not require anything beyond a traditional design based on force reduction factors.

The objective of the research work is to find out the best practice for the seismic design of high-rise buildings anywhere in the world. Best practice for high-rise buildings is not represented by the traditional design codes such as the Uniform Building Code [ICBO, 1997] or its successor, the International Building Code [ICC, 2006]. Whilst these codes are referenced for the design of high-rise buildings in many countries, in part because the UBC still forms the basis for many national building codes. They are not suitable for the design of high-rise buildings for the various reasons.

These codes were developed for application to low and medium-rise buildings [and the framing systems used in those buildings] and not for the modern generation of tall buildings. They permit only a limited number of structural systems for buildings taller than 49m in height, which are not economic for buildings of significantly greater height, and do not include systems that are appropriate for many high rise buildings. Rules appropriate at or below 49m are not necessarily valid at 100 metres or more in height. The use of elastic response analysis with force reduction factors (denoted R in the United States) for strength design is inappropriate for buildings where several modes of vibration contribute significantly to the seismic response along each axis of a building.

A. Introduction to Codal Fundamentals

Structural Engineering is the back bone of Civil Engineering and Infrastructure in any society. It is crucial that all the codes related to structural engineering are based on principles of mechanics, and experimentally verified. They should be logical, rational and efficient, and should be revised as frequently as necessary. Performance based codes need to be introduced at the earliest so that our engineers may compete globally.

Each society has developed its own guidelines on how to construct safe houses/structures in its own ways from times immemorial based on its own experiences with materials, construction practices and nature. Over the last century each code has evolved based on scientific and technical inputs. In India, it is an open fact that there is no fundamental and focused research in structural engineering field including earthquake engineering.

B. Variations in Building Design Codes

All current seismic design codes are based on a prescriptive Force-Based Design approach. Here, a linear elastic analysis is performed and inelastic energy dissipation is considered indirectly, through a response reduction factor (or behaviour factor). This factor, along with other interrelated provisions, governs the seismic design forces and hence the seismic performance of code-designed buildings. Codes also differ significantly in specifying the effective stiffness of RC members, procedures to estimate drift, and allowable limits on drift. However, different national codes vary significantly on account of various specifications which govern the design force level. The response reduction factor, as considered in the design codes, depends on the ductility and over strength of the structure.

Building codes define different ductility classes and specify corresponding response reduction factors based on the structural material, configuration and detailing. Another important issue, which governs the design and expected seismic performance of a building, is control of drift. Drift is recognized as an important control parameter by all the codes; however, they differ regarding the effective stiffness of RC members.

Also, the procedures to estimate drift and the allowable limits on drift also vary considerably. Different codes differ not only with respect to the design base shear but also employ different load and material factors (or strength reduction factors) for the design of members, and hence, the actually provided strength in different codes does not follow the same pattern as the design base shear. This has a direct effect on the expected performance of buildings designed using different codes.

Further, the other provisions of codes also indirectly govern the seismic performance. In the era of globalization, there is a need for convergence of design methodologies to result in buildings with uniform risk of suffering a certain level of damage or collapse. A first step in this direction is to compare the expected seismic performance of buildings designed using the provisions of different codes.

C. Introduction to Seismic Design Codes

Ground vibrations during earthquakes cause forces and deformations in structures. Structures need to be designed to withstand such forces and deformations. Seismic codes help to improve the behaviour of the structures so that they may withstand the earthquake effects without significant loss of life and property. Countries around the world have procedures outlined in seismic codes to help design engineers in the designing, detailing, constructing and planning of structures. An earthquake-resistant building must have four virtues in it, namely:

– Good Structural Configuration: Its size, shape and structural system carrying loads are such that they ensure a direct and smooth flow of inertia forces to the ground.
– Lateral Strength: The maximum lateral (horizontal) force that it can resist is such that the damage induced in it does not result in collapse.
– Adequate Stiffness: Its lateral load resisting system is such that the earthquake-induced deformations in it do not damage its contents under low-to-moderate shaking.
– Good Ductility: Its capacity to undergo large deformations under severe earthquake shaking even after yielding is improved by favourable design and detailing strategies.

Seismic codes cover all these above mentioned aspects. Seismic design deals with the yielding and inelastic behaviour of structural element which are detailed to exhibit such behaviour during earthquake. The structure is designed with sufficient strength to behave elastically during earthquake. Seismic design of a multi-storeyed RC building is to withstand the ground motion caused during the earthquake. In order to design an earthquake resistant structure an Engineer must have a good knowledge about various seismic design codes.

II. LITERATURE REVIEW

In order to design an earthquake resistant structure an Engineer must have a sound knowledge about various seismic design codes. Many researchers have worked and contributed their efforts for the study of different design codes. The papers published by these researches give more information about the static and dynamic analysis done on various types of structures. The researchers have used various countries codes to evaluate the seismic performance of the structure. This report gives an overview of the study and research from some of the International journals published around the world. In the following section, a summary of the articles and papers found in the literature, about the design and seismic codal provisions and comparison of international code provisions, is highlighted.

A. Review of Literature

In October 2015, Pamela Jennifer J P and Jegidha K J have studied the literatures of various researches. This paper presents that the main objective of seismic design of multi-storeyed RC building is to withstand the ground motion caused during the earthquake. This states that in order to design an earthquake resistant structure, an Engineer must have a good knowledge about various seismic design codes.

The research work gives more information about the static and dynamic analysis performed on various types of structures. The researchers have used various countries codes to evaluate the seismic performance of the structure. The important parameters such as displacement, base shear, storey drift, time period, axial and shear force bending moment were studied. From these researches, an interest arises to do seismic design of multi-storeyed building using various codes to understand which Codal provisions give very effective design to withstand during the earthquake. The paper gives a review on performance of buildings towards seismic load for various designs. The review explains the need of improvement in codes resulting in improving the performance of structures while an earthquake.

In June 2015, S. Karthiga et al. have done a comparative study of the design and analysis of a building to check which was the most economical. The purpose of this research work is to design the structures in the best possible way to take into account the effects of seismic forces and thereby aiming for an adequate structural response. Different international seismic codes differ significantly in various parameters. In this paper, analysis and design of a G+10 building for seismic forces is performed using four international building standards- IS1893, Euro code 8, ASCE7-10 and the British Codes. A comparative study between the design and the seismic performance of the building is done.

The results obtained show that the Indian standards give the highest value of base shear and the British standards give the minimum value. The displacement results obtained from Euro code are the maximum and that obtained for Indian Standards are the minimum.

In the year 2014, F. Atique and Z. Wadud have carried out a comparison of the provisions of wind & earthquake analysis between the existing BNBC – 1993 and proposed BNBC – 2012. The objective of this paper is to identify the changes in design and analysis of structures in order to update the code on a regular basis. As it is a necessity to keep pace with the advancement of technology.

Comparisons in inter story drifts, maximum reinforcement required for column designs are done. All these comparisons have eventually helped in providing effective guidelines to the engineers for the most economical designs. A detailed study regarding the lateral loads has been performed.

Base shear increases with the number of stories in both the codes. While the change in base shear with number of stories is uniform and linear according to BNBC-1993, it gives significant changes in the initial stories of BNBC-2012.

Change in base shear as a % of dead load is negligible in BNBC -1993 whereas in BNBC-2013, it is much higher and significant.

Maximum story displacement is greater in BNBC-2012 due to higher base shear. From the graphs, it is stated that maximum reinforcement is required for corner columns and minimum for internal columns; thus concluding that BNBC-2012 is more economical than BNBC-1993 for design purpose.

In September 2013, a major comparison study has been done by G. V. S. Sivaprasad and S. Adiseshu to investigate the seismic behaviour of the structure i.e. OMRF (Ordinary moment resisting frame) & SMRF (Special R C moment Resisting frame). In this research work, comparative analysis between the frames is executed by using only Indian codes (IS 1893:2002, IS 456: 2000). Also, the design of alternate shear wall in a structural frame and its orientation, which gives better results for the OMRF & SMRF structure constructed in a particular region, has been performed. This work gives the development of a new method and analysis of shear wall framing system and a new model to compare the safety of the structure and cost effectiveness of the structure for a lateral loading system for a tall & high rise structures.

The behaviour of OMRF & SMRF structures was studied under seismic loads. The lateral loads, dead loads, live load are considered for structural design as per IS standards. However, comparative analysis between different codes for the different frames can be done as a further development. Analysis of shear wall was done using a four noded plate element giving stress contour which in turn gives better results to design a structure. On comparing with OMRF, the SMRF structure has less story drift so that the structure can resist seismic loads more than the OMRF. The min % percentage and spacing of the lateral ties at beam column joint is different for OMRF & SMRF structure, thus the lateral deflections that are coming from is less.

In February 2013, Pravin Ashok Shirule et al. have presented a comparative study on Reinforced Concrete structural walls and moment resisting frames building by using response spectrum method. Further, the design spectra by Indian Standard Code IS 1893-2002 (part I), Uniform Building Code and Euro Code 8 are considered for comparison. The researchers in this paper have investigated the differences caused by the use of different codes in the dynamic analysis of a multistoried RC building. A comparison between the building with and without shear walls is also executed.

In the year 2013, Luca Zanaica et al., the Working Group 7 of International Association for Bridge & Structural Engineering) have carried out a comparative evaluation of seismic design standards among some international, European and American codes. The objective of this study was to identify the discrepancies and similarities among these codes. The various parameters studied are the criteria for the analysis of conventional (residential and commercial) buildings, design and detailing of RC buildings, concepts of recurrence periods for establishing the seismic input; seismic zonation and shape of the design response spectra.

A comparison between following codes was executed; ASCE/SEI – 7/10, Euro code 8 – EN1998-1:2004, Italian Code, Romanian Code & Brazilian Code. The obtained results compared lead to some important conclusions that are as follows:

Displacements and Forces obtained with Euro code and Italian Code are inferior to the ones obtained with other codes.

The recurrence periods for Euro code and Brazilian Code are both 475 years, while for Italian Code 50 years (DLS) and 475 years (LPLS), Romanian Code and ASCE-7 code are 100 years and 2475 years respectively. The design accelerations are 0.025g – 0.15g for Brazilian, 0.025g – 0.3g for Italian, 0.08g – 0.32g for Romanian and 0.024g – 0.8g for ASCE – 7 codes.

The spectral shapes are governed by a single parameter i.e. Peak Ground Acceleration in all other codes except for Euro code 8 and ASCE – 7 codes. In Euro code 8, two different spectral types associated with magnitude are analyzed while in the ASCE -7 three basic parameters are required for defining the spectral shape.

In the year 2012, Vijay Namdev Khose et al. have done a detailed analysis and comparison of a ductile RC frame building. The comparison has taken into account various important factors as; different ductility classes, corresponding response reduction factors, reinforcement detailing provisions, and seismic performance of the building. All these factors have been compared using four major design codes, viz. ASCE7 (United States), EN1998-1 (Europe), NZS 1170.5 (New Zealand) and IS 1893 (India). Further the comparison is extended to the provisions of different codes regarding effective stiffness of RC members, procedure to estimate drift, and allowable drift limits.

The study also presents the classification of ductility classes, control of drift factor, story drift limits, design base shears & effective stiffness of the RC members in the following four major codes.

In the year 2011, ICSECM have presented a comparative study of four major national seismic design codes that are; the American code (ASCE7-05 2006), Euro code 8 (EN1998-1 2004), New Zealand Standard (NZS1170.5 2004) and Indian code (IS1893-Part1 2002). The research analyses the applicability of displacement spectra derived from code specified design spectra, to displacement-based design. The issues examined in the study include seismic hazard, site classification, design response spectra.

The codes define the design seismic hazard in terms of an idealized acceleration response spectra, that is scaled to the desired hazard level by using Peak Ground Acceleration (PGA) or spectral ordinates corresponding to different periods (usually at 0.2 sec and 1 sec). Specification of design displacement spectra is an important feature highlighted in this research.

Many significant variations in the aforementioned code provisions are observed highlighting the fact that provisions of IS 1893 are not up to the state-of-the-art.

NZS 1170.5 provides a more refined site classification. It differentiates soils based on low-amplitude period and depth of soil, also unlike other considered codes.

Only ASCE 7 considers the effect of ground motion amplitude on soil amplification.

Corner period between constant-velocity and constant-acceleration is one of the important parameter governing the construction of displacement spectra. Codes vary significantly on this issue. ASCE 7 provisions on corner period appear to be more realistic as compared to other codes. Euro code 8 and NZS 1170.5 specify constant values of corner period. IS 1893 does not specify any displacement-controlled range and hence corner period.

These wide differences in code based spectra leads to an urgent need to review and revise the code design spectra, to obtain reliable estimates of displacement for displacement based design.

In this paper, Dr. S. V. Itti et al. have carried out a detailed comparison of the Indian Code (IS) and International Building Codes (IBC) with respect to the seismic design and analysis of Ordinary RC moment resisting frame (OMRF), Intermediate RC moment-resisting frame (IMRF) and Special RC moment-resting frame (SMRF). This paper investigates the variations in the results obtained using the two codes, for the parameters of design base shear, lateral loads, drifts and area of steel for structural members for all RC buildings in both the codes. Specific provisions for design of seismic resistant reinforced members are presented in detail. Various provisions of Indian and International Buildings Codes for earthquake analysis are identified.

The objective of this work is to highlight the main contributing factors which lead to poor performance during the earthquake and make necessary recommendations to be taken into account in designing the multi-storeyed reinforced concrete buildings in order to achieve an adequate safe behaviour under future earthquakes.

B. Summary of Literature

The building designed using Euro code performs better in comparison to Indian standard (IS1893:2002) and American (ATC40 and FEMA440) codes. Frames with shear wall perform better with increase in the base shear when compared to the frames without shear wall. Shear wall performs better to lateral displacement as well. The ductility of SMRF buildings is more than the OMRF buildings.

The analysis and design of the G+10 building concludes that the Euro standards serve to be the most economical design and the Indian Standards are the least economical. The pushover analysis results state that the Indian standards have the maximum shear value. From the displacement values it is seen that Indian Standards undergo minimum displacement thus stating that building designed according to the Indian standards are more rigid and it attracts more seismic forces.

It is observed that the seismic base shear varies significantly between the existing BNBC- 1993 and the proposed BNBC-2012. Also, huge differences in maximum lateral displacements with varying number of stories are obtained. The change in base shear with number of stories is uniform and linear according to BNBC-1993, whereas it gives significant changes in the initial stories of BNBC-2012.

The SMRF system was found cost effective and resisting to tall and high rise structures. SMRF gives more safety to designers to design the structure, being a bit cost effective to the builders who construct the tall and high rise buildings. In both the system of analysis of OMRF & SMRF, the storey drift is within permissible limits as per IS (1893 part1, clause no 7.11.1). The structure is found to be safe when subjected to seismic loads in SMRF resisting the lateral loads thereby increasing the life of the structure.

The base shear using IS code is higher in all the three buildings, when compared to that of with other codes which leads to overestimate of overturning moments in the building and hence heavier structural members. Analysis of the asymmetrical building, suggested that it is better to provide shear wall to the asymmetrical building. It helps in prevention of the building from damage and collapse, increases the strength of the building along with decreases in the displacement and storey drift of the building. For the buildings, UBC code gives the maximum and IS gives the minimum displacement values.

There is a necessity that the structural design and detailing should provide enough ductility for energy dissipation in the non-linear range. There should be a general agreement in all the considered codes on the desired main characteristics of a seismic resistant structure namely; simplicity, symmetry, regularity, redundancies, et al.

The research suggests that different codes differ with respect to design base shear, different load and material factors for the design of members resulting in various different patterns of strength actually provided in different codes, thus directly affecting the performance of the building designed with the mentioned four codes. Except for IS: 1893 (India), the other three codes take into account the Total (inelastic) displacement whereas Indian code considers the elastic displacement. Two major points highlighted in this paper are that all other three codes except NZS 1170.5 (New Zealand) combines the effect of over strength and ductility in a single response reduction factor. NZS 1170.5 considers the effect of over strength through a structural performance.

The major drawback with the design earthquake levels/ seismic hazard level is that some codes are clear about the return period or exceedence rate, but all the existing codes are vague about the intended performance objectives. Also the effect of local soil strata is an important issue that is being dealt by various codes by classifying the sites into different cases and providing site amplification factors to scale the design spectra.

The Base Shear, Lateral Loads and Displacements for OMRF, IMRF and SMRF of IS-1893-2002 Code buildings are higher than that of IBC-2006 Code buildings. Target deflection of the building is achieved at a lower lateral force in SMRF IBC i.e., the concept of lesser force and more deflection is followed. However in OMRF, IMRF and SMRF of Indian Code lateral force applied is higher as a result the deflection on the top of the building exceeds the target deflection. The reinforcement requirement is highest for OMFR (IS) at both left end and right end of the beams and at bottom of the column, whereas the reinforcement required at the beam ends and at bottom of the column is lowest for SMRF (IBC).

C. Limitations in Present State of Codes

From the study of papers presented above, it is observed that the traditional design codes are not suitable for the design of high-rise buildings for various reasons. These codes were initially developed for application to low and medium-rise buildings. The codes permitted only a limited number of structural systems for buildings taller than 49m in height, thus not being economical for buildings of significantly greater height. The guidelines incorporated in these codes are appropriate at or below 49m and are not necessarily valid at 100+m in height. The use of elastic response analysis with force reduction factors (denoted R in the United States) for strength design turns out to be inappropriate for buildings where several modes of vibrations contribute majorly to the seismic response of a building.

Building codes in the United States and other national codes based on these documents permit performance-based design but provide little-to-no specific guidance. The direct application of the standard design procedures in these codes result in poor structural forms, relatively uneconomic structural designs, and to buildings that will not perform well in moderate and severe earthquakes. Over the last several decades, these performance objectives have formed the basis of structural design of innumerable high rise structures around the world, although their performance levels are rarely verified precisely.

III. Conclusions

A state of the different design codes and their reliability based approach for the design and assessment of civil engineering systems is observed. The issues related to the design phase, and its reliability based seismic assessment of the high rise structures is highlighted. Effectively a comparative study can be carried out between the different design codes.

Looking at the recent literature and structural standards, it is possible to try to provide the best practice for the seismic design of high-rise buildings. A comparative study of design and detailing provisions, seismic performance of a building designed for the major international codes could be performed. This approach of comparative study based on the design and seismic analysis of the building will act as a check as to which code serves to be the most economical. The study may also take into account the design displacement response spectra derived from code spectra.

References

[1] Yogendra Singh & Vijay Namdev Khose, Dominik H. Lang, “Comparative Study Of Code Provisions For Ductile RC Frame Buildings” Indian Institute of Technology Roorkee, India, WCEE Lisboa, 2012
[2] S. Karthiga, Hanna Elza Titus, Reetwiz Raj Hazarika & Mohamed Harrish, “Design And Comparison Of A Residential Building (G+10) For Seismic Forces Using The Codes: IS1893, EUROCODE8, ASCE 7-10 And BRITISH Code”, International Journal of Research in Engineering and Technology (IJRET), Volume: 04 Issue: 06, June 2015
[3] Sergio Hampshire De C. Santos, Luca Zanaica, Carmen Bucur, Silvio De Souza Lima, Ana Arai, “Comparative Study Of Codes For Seismic Design Of Structures”, VERSITA, Mathematical Modelling in civil engineering, Volume 9- No. 1, 2013
[4] F. Atique and Z. Wadud, “A Comparison Of Bnbc-93 With Other Building Codes With Respect To Earthquake And Wind Analysis”, Paper No. 1443, International Journal Of Scientific & Technology Research Volume 3, Issue 11, November 2014
[5] “A Comparative Study Of Design Seismic Hazard In Major National Codes”, International Conference on Structural Engineering and Construction Management (ICSECM) 2011
[6] G. V. S. SivaPrasad, S. Adiseshu, “Comparative Study Of OMRF & SMRF Structural System for Tall & High Rise Buildings subjected to Seismic Load”, International Journal of Research in Engineering and Technology (IJRET), Volume: 02 Issue: 09, September 2013
[7] Dr. S.V. Itti, Prof. Abhishek Pathade, Ramesh B. Karadi, “A Comparative Study on Seismic Provisions Made in Indian and International Building Codes for RC Buildings”, Dept. of Civil Engg., KLESCET, Belgaum – 590008 (Karnataka)
[8] Pravin Ashok Shirule, Bharti V. Mahajan, “Response Spectrum Analysis of Asymmetrical Building”, Pratibha: International Journal Of Science, Spirituality, Business And Technology (IJSSBT), Vol. 1, No.2, February 2013
[9] Pamela Jennifer J P, Jegidha K J, “Review on Seismic Design Of Multi-storeyed RC Building Using Various Codes”, International Journal of Innovative Science, Engineering & Technology, (IJISET) Vol. 2 Issue 10, October 2015

