EFFECT OF THE LATERAL FORCE ON THE SPECIAL MOMENT RESISTING FRAME STRUCTURE IN THE VARIOUS TYPES OF SOIL TYPE ACCORDING TO IS 1893 PART-1:2016: A REVIEW

Rishikesh Tiwari[1], Mr. Ushendra Kumar[2]

[1]*Master of Technology, Civil Engineering, Lucknow Institute of Technology, Lucknow, India*
[2]*Head of Department, Department of Civil Engineering, Lucknow Institute of Technology, Lucknow, India*

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Abstract - *Special Moment Resisting Frame (SMRF) structures play a critical role in mitigating seismic forces in regions prone to earthquakes. Understanding the effect of lateral forces on SMRFs is essential for ensuring their structural integrity and safety. This review paper explores the impact of lateral forces on SMRF structures across various soil types, as specified by IS 1893 Part-1:2016. Soil type significantly influences the behavior of structures during seismic events, making it imperative to comprehend its interaction with lateral forces. Through an extensive literature review, this paper examines the response of SMRF structures to lateral forces in different soil conditions, considering factors such as soil stiffness, damping characteristics, and foundation design. Additionally, the paper evaluates the seismic performance criteria outlined in IS 1893 Part-1:2016 concerning SMRF structures and soil types. By synthesizing existing research findings, this review aims to provide insights into optimizing the design and performance of SMRF structures under lateral forces in diverse soil environments, ultimately contributing to enhanced seismic resilience in structural engineering practices.*

Key Words: Seismic effects, Masonry walls, Reinforced concrete structures, Openings, Structural positioning, Seismic behavior, Structural dynamics.

1.HISTORY

The concept of using moment resisting frames in building construction traces back to the early 20th century, primarily as a response to the devastating earthquakes that highlighted the vulnerability of traditional building designs. However, it was not until the latter half of the 20th century that the development of Special Moment Resisting Frames (SMRFs) emerged as a significant advancement in seismic-resistant structural engineering. In the 1960s and 1970s, pioneering research and experimentation in structural engineering, particularly in earthquake-prone regions like California, led to the refinement of moment resisting frame systems. Engineers and researchers sought to create structural designs capable of efficiently dissipating seismic energy while maintaining structural integrity during earthquakes.

The term "Special Moment Resisting Frame" was formalized in the seismic design provisions of the United States in the 1970s and 1980s. These frames were specifically engineered to resist lateral forces generated by seismic events, utilizing the ductility of steel and reinforced concrete to absorb and redistribute energy. Throughout the latter part of the 20th century and into the 21st century, advancements in computational modeling, material science, and seismic analysis techniques further enhanced the design and performance of SMRF structures. This period saw the refinement of design codes and standards, such as the American Society of Civil Engineers (ASCE) standards and the International Building Code (IBC), which provided comprehensive guidelines for the design and construction of SMRFs to withstand seismic forces. The history of SMRF structures is intertwined with significant seismic events and the lessons learned from their impact on built environments. As earthquakes continue to pose a threat to communities worldwide, ongoing research and innovation in structural engineering ensure that SMRFs evolve to meet the challenges of seismic resilience in the built environment. Today, SMRFs remain a cornerstone of seismic-resistant construction, providing safety and stability in regions prone to earthquakes.

2.INTRODUCTION

A Reinforced Concrete (RC) frame structure is a stalwart configuration employed in construction projects worldwide. It comprises an interplay of columns, beams, slabs, and other reinforced concrete elements meticulously engineered to bear loads efficiently while ensuring structural integrity. Columns, standing as vertical supports, transmit the weight from beams and slabs to the foundation, boasting enhanced strength and flexibility through embedded steel reinforcement. Beams, in turn, horizontally traverse between columns, evenly distributing loads and fortifying the structure against bending and shear forces. These components converge with slabs, forming the framework for floors, roofs, or ceilings, with reinforcement imbuing them with resilience against structural strains. Joints, critical nexus points, facilitate load transfer and are meticulously designed to withstand lateral forces such as wind or seismic activity. Foundations, the bedrock of stability, anchor the structure to the underlying terrain, often constructed with reinforced concrete footings or piles to mitigate settlement and ensure even load distribution. Within this framework, the strategic placement and detailing of reinforcement steel synergize with concrete, imparting tensile strength and ductility, thus reinforcing the structure's durability and performance under diverse conditions. In essence, RC frame structures epitomize a harmonious blend of strength, adaptability, and reliability, offering a robust solution for a myriad of architectural endeavors.

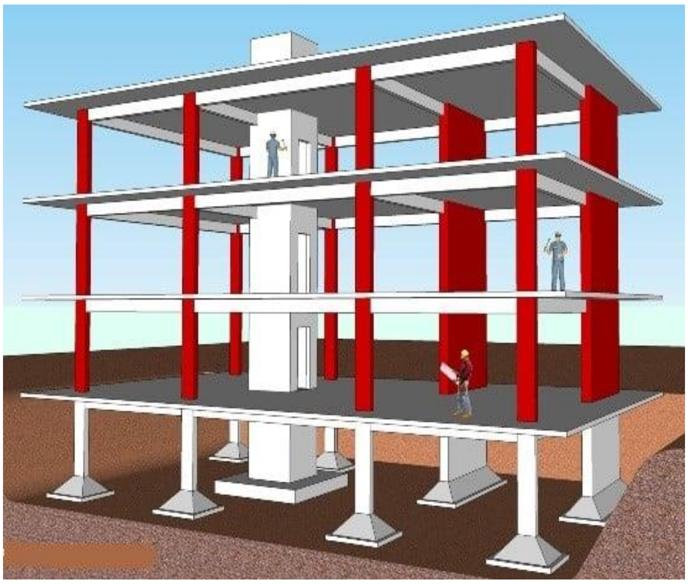

Figure-1: RC Frame Structure.

3.SMRF and OMRF

Special Moment Resisting Frames (SMRF) and Ordinary Moment Resisting Frames (OMRF) represent two distinct approaches to addressing lateral loads in building structures. SMRFs are meticulously engineered to withstand seismic forces, characterized by enhanced ductility, robust connections, and adherence to stringent design standards. These frames prioritize resilience, incorporating specialized detailing and reinforcement to ensure the structure can undergo significant deformations while maintaining stability. Conversely, OMRFs follow more conventional design practices, offering lateral load resistance suitable for regions with lower seismic activity or less stringent seismic design requirements. While OMRFs may be more cost-effective and simpler to construct, they typically exhibit lower levels of ductility and may not withstand severe seismic events as effectively as SMRFs. The choice between SMRFs and OMRFs depends on factors such as seismic risk, building codes, and project budget, with SMRFs offering unparalleled seismic performance and safety, albeit at a higher construction cost, while OMRFs provide a balance between cost-effectiveness and structural adequacy in less seismically active regions.

4. SOIL AN DITS TYPE ACCORDING TO IS 1893 Part-1:2016

IS 1893 Part 1:2016 is a code published by the Bureau of Indian Standards (BIS) that pertains to criteria for earthquake resistant design of structures. While it doesn't specifically classify soil types, it does provide guidelines for assessing soil properties and their impact on structural design. Soil types are typically classified based on their engineering properties such as cohesion, angle of internal friction, permeability, etc., which are crucial for seismic design considerations. For seismic design purposes, soils are broadly categorized into different classes based on their characteristics. These classifications are often based on the seismic hazard they pose and their response during an earthquake. Some common soil types considered in seismic design codes include:

Soft Soil: Soft soil typically includes loose sands, silts, and clays with poor engineering properties. Soft soils have low shear strength and can undergo significant settlement or liquefaction during an earthquake, leading to amplified ground motion. Structures founded on soft soil may experience higher accelerations and displacements during seismic events. Special foundation systems, such as deep piles or ground improvement techniques, may be required to mitigate the effects of soft soil on structures.

Medium Soil: Medium soil includes soils with moderate stiffness and strength, such as moderately dense sands or silty sands. These soils have better engineering properties compared to soft soil but may still experience some amplification of ground motion during earthquakes. The response of structures founded on medium soil is generally less severe compared to soft soil, but still requires careful consideration in seismic design. Foundation design for structures on medium soil may involve a combination of shallow and deep foundation elements, depending on site-specific conditions.

Hard Soil: Hard soil includes soils with high stiffness and strength, such as dense sands, gravels, or rock. These soils have excellent bearing capacity and minimal settlement, offering favorable conditions for structural support. Structures founded on hard soil typically experience minimal amplification of ground motion during earthquakes. Foundation design for structures on hard soil may involve relatively simple shallow foundation systems, although consideration of site-specific seismic hazards is still necessary.

5.PURPOSE OF SPECIAL MOMENT RESISTING FRAME

Special moment resisting frames (SMRFs) serve a critical purpose in structural engineering, primarily designed to withstand lateral forces, notably those induced by seismic activity. Their primary objective is to ensure the safety and integrity of buildings in regions prone to earthquakes. By offering enhanced seismic resistance, SMRFs minimize structural drift during seismic events, crucially safeguarding against damage and ensuring stability. These frames establish a clear load path for lateral forces, efficiently redirecting them through the structure and reducing the risk of failure. Moreover, SMRFs provide architectural flexibility, allowing for expansive open spaces and fewer interior columns, while still meeting stringent seismic design requirements. They are instrumental in ensuring code compliance in seismic regions, where building regulations mandate the integration of seismic-resistant elements. Despite potentially higher initial costs, the long-term benefits of SMRFs in terms of safety, resilience, and cost-effectiveness underscore their indispensable role in structural design and construction practices.

6.PRINCIPLE OF SMRF

At the core of special moment resisting frames (SMRFs) lies a fundamental principle: the efficient dissipation and resistance of lateral forces, especially those provoked by seismic activity. These frames are meticulously engineered to ensure structural stability and load distribution, embodying principles of ductility, redundancy, stiffness, and strength. Ductility allows SMRFs to deform gradually under stress, absorbing seismic energy and mitigating the risk of sudden failure. Redundancy is incorporated to provide multiple load paths, fortifying the system against single-point failures. The design carefully balances stiffness to control displacement and strength to withstand applied loads without compromising integrity. Crucially, the design of moment-resisting connections between beams and columns is pivotal, demanding meticulous engineering to withstand lateral forces while permitting controlled deformation. Compliance with seismic building codes is essential, dictating minimum standards for structural integrity in high-risk regions. Increasingly, SMRFs are being designed through performance-based approaches, emphasizing specific objectives such as damage limitation and occupant safety. By adhering to these principles, SMRFs stand as stalwart guardians against seismic threats, fortifying structures with resilience and safeguarding lives and property during earthquakes.

7.IMPACT OF EARTHQUAKE ON RC STRUCTURE

The impact of an earthquake on a reinforced concrete (RC) structure can be substantial, potentially leading to various forms of damage and compromise to the building's integrity. Earthquakes exert immense force on structures, inducing movements that can cause structural elements to crack, fracture, or fail entirely. Cracks are a common manifestation, appearing in walls, beams, columns, and other load-bearing components due to the seismic forces. Such cracks, if left unaddressed, can escalate structural weaknesses and compromise safety. Moreover, earthquakes can induce shear and flexural failures in RC structures, especially when the seismic forces surpass the elements' load-bearing capacities. The result can range from localized damage to catastrophic collapse, depending on the severity of the earthquake and the structural robustness. Additionally, pounding damage, where adjacent structures collide due to lateral movements, and foundation damage are significant concerns during seismic events. Non-structural damage to interior elements and contents is also a risk. Mitigating these risks requires adherence to rigorous seismic design standards, meticulous construction practices, and regular maintenance. Retrofitting existing structures for improved seismic resilience is also crucial in earthquake-prone regions.

8.LITERATURE SURVEY

In the present review paper, we have delved into the intricacies of the special moment resisting frame of reinforced concrete structures with varying parameters, including but not limited to seismic zone and other significant factors. The crux of each research paper has been succinctly summarized below for your perusal.

Vinay et.al: In this study, the analysis of two types of bracing - OMRF (ordinary moment resisting frame bracing) and SMRF (special moment resisting frame) - was conducted in all seismic zones, taking into account various types of regular and irregular constructions. Both OMRF and SMRF were used at the lintel level. The analytical data led to several important conclusions. Firstly, it was found that buildings with an irregular plaza experienced the highest amount of bending moment, while structures with a standard bare frame had the lowest amount. Additionally, as seismic activity increases in intensity, so does the rate at which bending moment rises. It was also discovered that SMRF is more effective than OMRF because it minimizes moments, reducing the area of steel required. In fact, SMRF was found to be more effective than any other type of bracing analyzed in this study. Upon analyzing graphs from all seismic zones, it became clear that a bare frame is the best option for construction followed by stepped construction as a second-best option. Plaza construction is essential for achieving stability during earthquakes. When compared to OMRF structures, SMRF ones provide greater degrees of information in their respective diagrams. Thus, choosing the appropriate type of bracing and construction style is crucial for ensuring structural stability during seismic events.

Prasad, Rama: Based on the research conducted by RSA, it was found that the shear power of the tale decreased over time in all three stories. The first story had the highest shear power, while the popular narrative had the lowest. Additionally, mass sporadic structure outlines were shown to be able to withstand larger base shear compared to corresponding standard structure outlines. This was confirmed by RSM analysis, which revealed that the control structure had more base shear than the unexpected firmness structure. Interestingly, the unexpected firmness structure had larger entomb story floats despite having less base shear. Furthermore, when looking at specific hubs during time history examination of mathematics sporadic working, it was discovered that relocations were more significant in these structures compared to ordinary structures for upper stories. However, as we move towards lower stories, relocations in both types of structures tend to combine. This phenomenon can be explained by the fact that geometrically uncertain designs have lower rigidity in their upper levels due to their L shape. As a result, when difficulty is lowered and more tales are removed from the top spot in rankings, there is a greater tendency for relocations to occur. In summary, this study highlights important findings regarding structural stability and its relation to design complexity and geometry.

Abhay et.al: When an OMRF structure is being considered, it's important to note that the axial load placed on column C1 (which is located at the corner) is significantly less than that of an SMRF. However, both systems distribute axial load in the same manner across column C2. Additionally, an OMRF system experiences a maximum shear force on the floor beam that is about 20-25% lower than that of an SMRF system. On the other hand, SMRF systems have between 15-20% less torsion in their structure when compared to OMRF systems. Furthermore, each floor in an SMRF system carries a bending moment that is 25-30% lower than its counterpart in an OMRF system. It's worth noting that OMRF systems are more common. When comparing drift caused by the two systems, it's apparent that drift from SMRF systems is approximately 40% less significant than drift from OMRF systems. The lateral force distribution on each floor occurs linearly for both types of structures; however, the SMRF system displays a lower level of attraction of lateral force due to this linear distribution. Finally, it's important to mention that when compared to the base shear of an OMRF system, the base shear of an SMRF system is approximately 40% less significant.

Prakash, Kadali: When it comes to comparing combined footing and pad form footing, it is clear that combined footing shows a significant advantage. Specifically, it has been found that combined footing has 23% fewer occurrences of uneven pressures when compared to rectangle footing resulting from pad form footing. This difference can be attributed to the fact that pad form footing distributes the highest amount of axial force when compared to other scenarios, while combined footing displays the least amount of this force. As a result, combined footing provides the greatest support response possible and is considered the finest and most suitable alternative for distributing weight to the soil. It has been observed that deflection values are largest in pad form footings and lowest in oval-shaped circumstances. Therefore, it can be concluded that deflection resulting from this condition will be minimal and oval-shaped footings will come in as a close second in terms of their prominence. In particular, the deflection in an oval shape is only around 13% total. Cost-effectiveness is an important consideration when choosing between different types of footings. Based on quantity estimation and rate analysis performed according to S.O.R., it has been determined that combined footing is the most cost-effective option for these conditions. In contrast, circular footings are more expensive and challenging to construct than either rectangular or oval-shaped options. Therefore, if you are looking for a reliable and economical solution for your foundation needs, combined footing may be your best bet!

Ambika, Prerana: In order to determine the response reduction factor for each of the ten distinct types of reinforced concrete (RC) structures, a non-linear static analysis is utilized. The Response Reduction Factors obtained from this analysis are then studied further and compared with various structural aspects of the buildings. After conducting necessary analyses and interpreting the data appropriately, several conclusions can be drawn from the study. It was found that structures lacking floating columns have a base shear value that is greater than those with floating columns. Additionally, bringing a floating column up to the top floor of a building causes an increase in the base shear value of the entire structure. However, this impact is dependent on soil conditions, as buildings with floating columns at ground level can only be constructed in circumstances where medium soil conditions are present rather than harder soil conditions. When comparing displacement values between structures with and without floating columns, it was discovered that there is only a slight difference between them. Furthermore, both Ordinary Moment Resisting Frames (OMRF) and Special Moment Resisting Frames (SMRF) exhibit lower values in hard soil conditions compared to medium soil conditions. This trend holds true for both structures with and without floating columns.

Interestingly, it was also found that the response reduction factor (designated by R) is lower for structures with floating columns than those without them. The difference between these two types of structures' R-values highlights this discrepancy clearly. Additionally, when comparing R-values of floating columns on upper levels versus those on ground level, it was discovered that upper levels exhibit much greater values than their ground-level counterparts. Both OMRF and SMRF have higher R-values in hard soil conditions compared to medium soil conditions. In conclusion, this study provides valuable insight into how various structural aspects impact RC buildings' response reduction factors under different soil conditions.

Prasad, Adi: After conducting extensive analysis on altered soil conditions while keeping all seismic parameters the same, several conclusions can be drawn. It is important to note that this analysis was performed prior to modifying the soil conditions. One of the most significant findings was that the base shear value of soft soil is substantially higher than both soft and hard soil. Additionally, the tale drift value in soft soil is considerably greater than in both soft and hard soil. As a result, model M1 with soft soil has the highest storey displacement value, while model M2 with hard soil has the lowest storey displacement value. This is due to the fact that as the stiffness property of the soil stratum decreases, so does the storey displacement value. This correlation between stiffness property and storey displacement can be attributed to a decrease in stiffness causing an increase in storey displacement.

Valsson: The isolation of the base is a highly promising and innovative approach that has the potential to safeguard various structures from the detrimental effects of seismic activity. This technique can be applied to diverse structures such as buildings, bridges, airport terminals, nuclear power plants, and other types of infrastructure. In comparison to fixed-base models, base-isolated models exhibit significantly lower levels of variation in the maximum displacement of their stories. It has been observed that as the number of stories within a structure increases, the variation in maximum displacement becomes increasingly significant. One of the most crucial aspects of base isolation is that it results in a stiffer movement for superstructures. This stiffness reduces the relative story displacement and story drift of structural elements, which leads to a decrease in internal forces exerted by beams and columns. The lateral weights applied to stories are also reduced, thereby slowing down accelerations provided to them. Consequently, the total quantity of inertia forces generated is ultimately reduced.

When a building is base-isolated, both story overturning moment and story shear are decreased. This reduction causes the superstructure above the isolation plane to become more rigid and stiff. Based on this evidence, it can be concluded that isolated buildings located in earthquake-prone areas may benefit significantly from such an approach as it enhances their performance efficacy.

Battacharya, Dutta: It is of utmost importance that the seismic risk is thoroughly evaluated and taken into consideration prior to the construction of any major or tall structures. This should go without saying, as failure to do so could result in grave consequences. In order to better understand the implications of such an analysis, a study was conducted on three distinct structures. The findings revealed that while BSF provides designers with a higher level of safety, its implementation can be quite costly. According to International Standard 1893 (IS:1893), storey drift is permitted in all systems as long as it falls within acceptable parameters (Part 1). However, when compared to OMRCF, SMRCF proved to be much more effective. Specifically, SMRCF produced 18.5% more steel due to its larger production capacity, resulting in a decrease of 66.12% in overall storey drift. Despite the cost factor, BSF remains the most reliable option for protecting against lateral loading and extending the service life of frame designs beyond that of other alternatives. It is therefore imperative that designers take these factors into account when constructing large-scale buildings.

The shrinking of the zone signifies an increase in the likelihood of earthquakes. In such a scenario, structures constructed with BSF or SMRF that have shear walls installed are deemed the most appropriate option. The use of lateral bracing in BSF structures minimizes the strain on columns. The Response Reduction Factor plays a crucial role in determining cost differences. OMRCF and SMRCF may experience storey drifts, but BSF has the lowest value. To further improve building performance, earthquake-resistant construction methods like base isolation and shear walls can be incorporated into the design and construction process.

Saad et.al: Based on the investigation conducted, it has been found that the safety of a structure is better ensured when it is built using a Special RC Moment Resisting Frame (SMRF) rather than an Ordinary RC Moment Resisting Frame (OMRF). However, it should be noted that the SMRF requires more reinforcement to be installed as compared to the OMRF. Interestingly, both the SMRF and OMRF have been found to have high rise building displacement values within permissible limits. The percentage of steel used in SMRF is higher due to more tie members near joints as compared to the ordinary moment resisting frame structure. Additionally, the results indicate that an SMRF structure with smaller dimensions can withstand greater lateral force than an OMRF structure. When comparing structures built in different seismic zones, it was observed that an SMRF in zone II exhibits less displacement than an OMRF in zone III. Similarly, there is less displacement in an SMRF in zone III as compared to an OMRF in zone IV and less displacement in an SMRF in zone IV as compared to an OMRF in zone V. These findings highlight the importance of considering the type of moment resisting frame structure used for construction based on seismic zone and necessary reinforcement requirements for ensuring maximum safety and structural integrity.

Tabata, Massumi: In the context of MRF structures, an increase in the number of bays for the same storey and seismic zone, height for the same storey and seismic zone, or a change in seismic zone from II to V for the same storey and bay results in an increase in base shear and storey drift. It is financially advisable to use SMRF over OMRF in seismic zones II and III. When comparing MRF structures without shear walls to those with shear walls (Dual system) for the same storey, bays, and seismic zone, base shear and storey drift are greater in bare frame construction as well as frame construction that includes infill walls. The Dual system MRF structure that incorporates a shear wall is more cost-effective than the MRF structure without a shear wall in seismic zones IV and V.

Whan, Jee: According to the results of the pushover analysis, it has been found that the curve has achieved a displacement greater than the displacement of the OMRF structure in both X and Y directions. This holds true regardless of the direction being considered. The SMRF structure can be understood in this way, as its beam-column connection is particularly strong due to this factor. However, upon conducting the pushover analysis, it was discovered that the curve had obtained a displacement less than the intended 840mm displacement in both X and Y directions, leading to a collapsed scenario. This occurred because the curve acquired a displacement lower than planned. As a result, renovations are required for both structures. Additionally, after conducting a response spectrum investigation, it has been revealed that the shear at performance for both OMRF and SMRF structures is lower than that at base level; therefore, retrofitting is necessary to ensure their safety and stability.

9. CONCLUSION

In conclusion, this review paper has provided a comprehensive analysis of the effect of lateral force on special moment resisting frame (SMRF) structures in various soil types according to IS 1893 Part-1:2016. Through a meticulous examination of research studies and design standards, several key insights have emerged. It is evident that the behavior of SMRF structures significantly varies depending on the type of soil they are founded on. Soil characteristics such as stiffness, strength, and liquefaction potential play crucial roles in determining the seismic response of these structures. The seismic design provisions outlined in IS 1893 Part-1:2016 offer valuable guidelines for engineers to ensure the safety and performance of SMRF structures under lateral forces. However, the application of these provisions must be tailored to specific soil conditions to achieve optimal seismic performance. The review underscores the importance of site-specific seismic hazard assessment and soil-structure interaction analysis in the design process. By accounting for local soil conditions and seismic hazards, engineers can enhance the resilience of SMRF structures and mitigate potential risks. In conclusion, while IS 1893 Part-1:2016 provides a robust framework for seismic design, research and development are necessary to refine design methodologies and address the complex interplay between lateral forces and soil dynamics. By continuing to advance our understanding of these factors, engineers can effectively design SMRF structures that withstand seismic events and ensure the safety of occupants and assets.

REFERENCE

1. Sheovinay Rai, Rajiv Banarjee, Tabish Izhar, ―A Comparative Study Of Omrf & Smrf Structural System Using Different Softwares,‖ International Journal of Innovative Research in Advanced Engineering (IJIRAE), ISSN: 2349-2763, Issue 12, Volume 2 (December 2015)

2. P.Ram Prasad, R. Rama Rao, ―Determination Of Moment Resisting Rc Frames Of Response Reduction Factors,‖ International Journal of Advance Research in Science and Engineering (IJARSE), ISSN: 2319-8654, Issue 12, Volume No. 4 (December 2015)

3. Abhyuday Titiksh, Dr. M.K. Gupta, ―A Study of the Various Structural Framing Systems Subjected to Seismic Loads,‖ SSRG International Journal of Civil Engineering (SSRGIJCE) – Volume No. 2, Issue 4 , April 2015

4. Jaya Prakash Kadali, M.K.M.V.Ratnam, Dr.U.RangaRaju, ―Static Analysis of Multistoreyed RC Buildings By Using Pushover Methodology,‖ IJIRST –International Journal for Innovative Research in Science & Technology| Volume 1 | Issue 8 | January 2015 ISSN (online): 2349-6010.

5. Ambika-Chippa, Prerana-Nampalli, ―Analysis and Design of R.C. Moment Resisting Frames with and without Shear Wall for Different Seismic Parameters,‖ IJISET - International Journal of Innovative Science, Engineering & Technology, Vol. 1 Issue 6, August 2014. www.ijiset.com ISSN 2348 – 7968

6. G.V.S.SivaPrasad, S. Adiseshu, ―A Comparative Study Of Omrf & Smrf Structural System For Tall & High Rise Buildings Subjected To Seismic Load,‖ IJRET: International Journal of Research in Engineering and Technology eISSN: 2319-1163 | pISSN: 2321-7308

7. Valsson Varghese, Yogesh R. Borkar, ―Comperative Study Of S.M.R.F. Building Over O.M.R.F. Building With Seismic And Wind Effect,‖ International Journal of Engineering Research and Applications (IJERA), ISSN: 2248- 9622, www.ijera.com Vol. 3, Issue 3, May-Jun 2013, pp.1501-1503

8. K. Bhattacharya and S. C. Dutta, "Assessing lateral period of building frames incorporating soil-flexibility," *Journal of Sound and Vibration*, vol. 269, no. 3–5, pp. 795–821, 2004.

9. G. Saad, F. Saddik, and S. Najjar, "Impact of soil-structure interaction on the seismic design of reinforced concrete buildings with underground stories," in *Proceedings of the 15th World Conference on Earthquake Engineering*, Lisbon, Portugal, 2012.

10. S. H. R. Tabatabaiefar and A. Massumi, "A simplified method to determine seismic responses of reinforced concrete moment resisting building frames under influence of soil-structure interaction," *SoilDynamics*

and Earthquake Engineering, vol. 30, no. 11, pp. 1259–1267, 2010.

11. P. Raychowdhury, "Seismic response of low-rise steel moment resisting frame (SMRF) buildings incorporating nonlinear soil structure interaction (SSI)," *Engineering Structures*, vol. 33, no. 3, pp. 958–967, 2011.

12. R. K. Goel and A. K. Chopra, "Period formulas for moment-resisting frame buildings," *Journal of Structural Engineering*, vol. 123, no. 11, pp. 1454–1461, 1997.

13. H. Crowley and R. Pinho, "Period-height relationship for existing European reinforced concrete buildings," *Journal of Earthquake Engineering*, vol. 8, no. 1, pp. 93–119, 2004.

14. H. Crowley and R. Pinho, "Simplified equations for estimating the period of vibration of existing buildings," in *Proceedings of the 1st European Conference on Earthquake Engineering and Seismology*, p. 1122,Geneva, Switzerland, 2006.

15. C. G. Karayannis, B. A. Izzuddin, and A. S. Elnashai, "Application of adaptive analysis to reinforced concrete frames," *Journal of Structural Engineering*, vol. 120, no. 10, pp. 2935–2957, 1994.

16. M. J. Favvata, M. C. Naoum, and C. G. Karayannis, "Limit states of RC structures with first-floor irregularities," *Structural Engineering and Mechanics*, vol. 47, no. 6, pp. 791–818, 2013.

17. W. Pong, Z. H. Lee, and A. Lee, "A comparative study of seismic provisions between international building code 2003 and uniform building code 1997," *Earthquake Engineering and Engineering Vibration*, vol. 5, no. 1, pp. 49–60, 2006.

18. A. Do˘gang¨un and R. Livao˘glu, "A comparative study of the design spectra defined by Eurocode 8, UBC, IBC and Turkish Earthquake code on R/C sample buildings," *Journal of Seismology*, vol. 10, no. 3, pp. 335–351, 2006.

19. S. K. Ghosh and M. Khuntia, "Impact of seismic design provisions of 2000 IBC: comparison with 1997UBC," in *Proceeding of the 68th Annual Convention-Structural Engineers Association of California (SEAOC '99)*, pp. 229–254, Santa Barbra, Calif, USA 1999.

20. Y. Singh, V. N. Khose, and D. H. Lang, "A comparative study of code provisions for ductile RC frame buildings," in *Proceedings of the 15th World Conference on Earthquake Engineering*, pp. 24– 28, Lisbon, Portugal, 2012.

21. V. N. Khose, Y. Singh, and D. H. Lang, "A comparative study of design base shear for RC buildings in selected seismic design codes," *Earthquake Spectra*, vol. 28, no. 3, pp. 1047–1070, 2012.

22. N. Imashi and A. Massumi, "A comparative study of the seismic provisions of Iranian seismic code (standard no. 2800) and international building code 2003," *Asian Journal of Civil Engineering: Building and Housing*, vol. 12, no. 5, pp. 579–596, 2011.

23. S. H. C. Santos, L. Zanaica, C. Bucur, S. S. Lima, and A. Arai, "Comparative study of codes for seismic design of structures," *Mathematical Modelling in Civil Engineering*, vol. 9, no. 1, pp. 1–12, 2013.

24. Jack P. Moehle John D. Hooper Chris D. Lubke, ―Seismic Design of Reinforced Concrete Special Moment Frames: A Guide for Practicing Engineers,‖ NEHRP Seismic Design Technical Brief No. 1, NIST GCR 8-917-1, National Institute of Standards and Technology, U. S. Department of Commerce.

25. Sang Whan Han, N Y. Jee, ―Seismic behaviors of columns in ordinary & intermediate moment resisting concrete frames‖, www.sciencedirect.com, Engineering structures- 27 (2005), 951-962

26. T. Visnjic, M. Panagiotou & J. P. Moehle,‖ Seismic Response of Two 20-Story Reinforced Concrete Special Moment Frames Designed with Current Code Provisions‖,15 WCEE – LISBOA 2012.