Web of Scholars: Multidimensional Research Journal (MRJ)
Volume: 02 Issue: 08 | 2023 ISSN: (2751-7543)
http://innosci.org

Exploring the Consequences of Key Global Building Code Provisions on Open Ground Storey Structures: Literature Survey

Pappu Kumar, Ajay Kumar
Assistant Professor, Department of Civil Engineering, Sandip University, Madhubani, Bihar, India

Nitish Kumar
Research Scholar, Department of Civil Engineering, Sandip University, Madhubani, Bihar, India

Abstract: *Open ground storey buildings are a common architectural design found in many regions worldwide. These structures feature an unobstructed ground floor, often used as parking or commercial spaces, with residential or office floors above. However, the design of open ground storey buildings presents unique challenges in terms of structural stability and safety during seismic events. This paper provides a comprehensive literature survey that examines the implications of major international codal design provisions on such structures. The study begins by exploring the global building codes and regulations governing open ground storey buildings. It investigates the specific provisions related to structural design, material requirements, and construction practices aimed at enhancing the seismic performance of these buildings. Various international codes, such as the International Building Code (IBC), Eurocode, and Indian Standards, are analyzed to identify similarities and differences in their approaches. The consequences of these design provisions are then examined in terms of structural behavior and performance during seismic events. The literature survey delves into case studies, experimental tests, and numerical simulations conducted to evaluate the effectiveness of these provisions. Key factors such as lateral load distribution, column design, and bracing systems are discussed in detail. The findings of this study highlight the importance of implementing appropriate design provisions to ensure the safety and resilience of open ground storey buildings. By understanding the implications of major international codal design provisions, engineers and architects can make informed decisions to enhance the seismic performance of these structures. This research contributes to the body of knowledge in structural engineering and provides valuable insights for future developments in building codes and regulations.*

Keywords: *Open ground storey buildings, Seismic performance, Global building codes, Structural design provisions, Lateral load distribution, Resilience.*

1. INTRODUCTION

In densely populated urban areas, particularly in developing countries like India, the need for space has become increasingly important. In order to accommodate the growing population and address the demand for parking, the ground storey of buildings is utilized. These types of buildings, known as Open Ground Storey (OGS) buildings, have no infilled walls in the ground storey but have infilled walls in all upper storeys. The infill walls are typically constructed using brick masonry. The upper storeys of OGS buildings are relatively rigid, resulting in smaller inter-storey drifts but higher curvatures, shear forces, and bending moments in the ground storey columns. Consequently, the columns in the ground storey experience significant demands in terms of strength. Unfortunately, many OGS buildings have suffered collapse during past earthquakes in various countries. The failure of these buildings can be attributed to the occurrence of a "storey mechanism" in the ground storey. This mechanism arises from the sudden reduction in lateral stiffness and mass in the ground storey, leading to elevated stresses in the columns during seismic activity. In numerous instances, ground-storey columns have sustained severe damage or complete failure, resulting in extensive building damage. The presence of infill walls throughout the upper storeys, except for the ground storey, significantly increases the overall stiffness of these levels. As a result, the upper storeys tend to move as a cohesive unit, with most of the horizontal displacement occurring in the flexible ground storey itself. The incorporation of parking spaces within the ground storey of buildings, known as OGS buildings, has become crucial in densely populated areas. However, the vulnerability of these structures to seismic events, primarily due to the distinctive storey mechanism in the ground storey, necessitates careful consideration of design and construction practices to ensure their safety and resilience.

Figure 1: Typical example of OGS building

2. OPEN GROUND STOREY (OGS)

The presence of infill walls in the upper storeys of an Open Ground Storey (OGS) building significantly enhances the overall stiffness of the structure, similar to a typical infilled framed building. This increased stiffness leads to higher base shear demands on the building. In a typical infilled frame building, the increased base shear is distributed between the frames and infill walls across all storeys. However, in OGS buildings, where the ground storey lacks infill walls and truss action, the entire increased base shear is resisted solely by the ground storey columns, without any load sharing from adjacent infill walls. As a result, the ground storey columns experience amplified shear forces, resulting in elevated bending moments and larger curvatures. This leads to relatively larger drifts at the first floor level. Additionally, the significant lateral deflections further contribute to increased bending moments due to the P-Δ effect. Plastic hinges tend to form at the top and bottom ends of the ground storey columns. Meanwhile, the upper storeys of the building generally remain undamaged and exhibit almost rigid body movement. This phenomenon is commonly referred to as a "soft-storey collapse," "storey-mechanism," or "column mechanism" in the ground storey. In summary, the absence of infill walls in the ground storey of an OGS building results in increased demands on the ground storey columns, leading to larger curvatures and drifts. The damage primarily occurs in the ground storey columns, while the upper storeys remain relatively intact, causing a characteristic soft-storey collapse.

3. MULTIPLICATION FACTOR (MF) PROVISIONS IN VARIOUS CODES

In practical scenarios, Open Ground Storey (OGS) buildings can be categorized as extreme soft-storey structures. Therefore, it is crucial to design these buildings with special provisions that aim to enhance the lateral stiffness or strength of the soft or open storey. In this context, the consideration of infill wall strength and stiffness is disregarded. One common recommendation found in building codes is to amplify the bending moments and shear forces acting on the columns in the soft or open storey by using a multiplication factor (MF). This factor is applied to the bare frame analysis results to account for the increased demands on the columns. By magnifying these forces, the design ensures that the columns in the soft or open storey are adequately designed to withstand the additional loads and avoid potential failure or excessive deformation. The purpose of this approach is to address the vulnerability of the soft or open storey in OGS buildings, where the absence of infill walls reduces the overall lateral stiffness and load-sharing capacity. By considering the amplified forces, engineers can effectively strengthen the columns in the soft or open storey and mitigate the risk of structural damage or collapse during seismic events. To summarize, in the design of OGS buildings, it is essential to adopt special provisions that aim to increase the lateral stiffness or strength of the soft or open storey. By applying a multiplication factor to magnify the bending moments and shear forces acting on the columns in the soft or open storey, engineers can ensure the structural integrity and resilience of these buildings.

4. INDIAN STANDARDS IS-1893:2002

Following the Bhuj earthquake incident, the IS 1893 code underwent revisions in 2002 to incorporate new design recommendations aimed at improving the seismic performance of Open Ground Storey (OGS) buildings. Clause 7.10.3(a) of the revised code specifies that the columns and beams of the soft storey should be designed to withstand 2.5 times the calculated storey shears and moments under seismic loads, considering the analysis of a bare frame. This multiplication factor (MF) of 2.5 is applied uniformly to all OGS framed buildings, indicating that existing OGS buildings designed according to earlier codes are considered highly vulnerable to seismic loading. However, the prescribed MF of 2.5 does not account for various factors such as the number of storeys, number of bays, type and quantity of infill walls, and other parameters. This limitation has raised concerns and resistance in design and construction practices due to the cost implications and challenges associated with accommodating heavy reinforcement in the columns of the ground storey. According to IS 1893 (2002), a storey is classified as a soft-storey, which is a type of vertical irregularity, if its lateral stiffness is less than 70% of the stiffness of the adjacent storey or less than 80% of the average lateral stiffness of the three storeys above it. Furthermore, a storey is categorized as an extreme soft-storey if its lateral stiffness is less than 60% of the storey above or less than 70% of the average stiffness of the three storeys above. Stilts or open ground storey buildings are classified as extreme soft-storey structures, which are a subset of vertically irregular buildings. In summary, the revisions to the IS 1893 code in 2002 introduced design recommendations for OGS buildings, including the application of a multiplication factor (MF) of 2.5 for the design of soft storeys. However, concerns regarding the practical applicability and associated costs have arisen, as the proposed MF does not consider various factors. Additionally, the code provides criteria to classify soft-storeys and extreme soft-storeys based on the lateral stiffness of the storeys. OGS buildings fall into the category of extreme soft-storeys, highlighting their unique vulnerability in seismic events.

5. LITERATURE SURVEY

The literature review provides a comprehensive examination of the seismic behavior of infill walls and open ground storey buildings. It offers an overview of previous studies conducted on the development of seismic fragility curves.

Hashmi and Madan (2008) The study conducted non-linear time history and pushover analysis on Open Ground Storey (OGS) buildings. The findings of the study suggest that the multiplication factor (MF) prescribed by IS 1893 (2002) for these buildings is sufficient in preventing collapse.

Özer and Erberik (2008) Vulnerability curves were developed for reinforced concrete (RC) frame structures in Turkey. The study considered RC frames of 3, 5, 7, and 9 storeys with different levels of seismic design quality: poor, medium, and good. Variables such as concrete and steel strength, as well as the modulus of elasticity, were taken into account. The analysis focused on four damage states: slight or no damage (DS1), significant damage (DS2), severe damage (DS3), and collapse (DS4). To obtain seismic demand statistics, non-linear time-history analyses were performed, evaluating the maximum inter-storey drift ratio for various sets of ground motion records.

Rota et. al (2010) A novel method was proposed for the development of fragility curves specifically designed for masonry buildings. The approach involved determining probability density functions (PDFs) by utilizing two main components: (1) selected damage state-based pushover analysis and (2) PDFs of displacement demand derived from nonlinear time history analysis. By combining these two analytical techniques, the study aimed to establish a comprehensive framework for constructing fragility curves tailored to masonry structures.

Sattar and Abbie (2010) The study's findings demonstrated that the pushover analysis revealed notable improvements in the initial stiffness, strength, and energy dissipation of infilled frames compared to bare frames, despite the infill walls exhibiting brittle failure modes. Similarly, the results from dynamic analysis indicated that fully-infilled frames exhibited the lowest risk of collapse, while bare frames were identified as the most vulnerable to earthquake-induced collapse. The enhanced collapse performance of fully-infilled frames was attributed to the increased strength and energy dissipation capabilities conferred by the presence of the infill walls.

Patel (2012) The study encompassed various analyses, including linear methods such as Equivalent Static Analysis and Response Spectrum Analysis, as well as nonlinear techniques like Pushover Analysis and Time History Analysis. The focus was on a low-rise open ground storey framed building, with infill wall stiffness represented by an equivalent diagonal strut model. The results obtained from the analysis indicated that multiplying the beam and column forces of the ground storey by a factor of 2.5, as prescribed by current design codes, was excessively high for low-rise open ground storey buildings. The study concluded that the issue of open ground storey buildings cannot be accurately identified solely through elastic analysis, as the stiffness of such buildings and comparable bare-frame structures are nearly identical. Therefore, a more comprehensive approach, incorporating nonlinear analysis methods, is necessary to effectively address the challenges associated with open ground storey buildings.

Tavares et. al (2012) A study was undertaken to establish fragility curves for various bridge classes in eastern Canada. The research focused on developing bridge-system fragility curves that account for the vulnerability of critical components, enabling the assessment of the probability of bridge damage. The relationship between bridge damage and the intensity of ground motion was modeled using a power law approach proposed by Cornell et al. (2002).

Rajeev, P and Tesfamariam, S (2012) The study focused on the poor seismic performance exhibited by non-code conforming reinforced concrete (RC) buildings, particularly those designed primarily for gravity loads before the 1970s. The research aimed to demonstrate the seismic vulnerability of structures by considering the presence of soft storeys (SS) and the quality of construction (CQ). To achieve this, three-, five-, and nine-storey RC frames designed prior to the 1970s were analyzed. A probabilistic seismic demand model (PSDM) was developed for these gravity load designed structures using nonlinear finite element analysis. The model incorporated the interactions between soft storeys and the quality of construction to capture the structural response accurately. The study proposed this approach as a predictive tool that can enhance regional damage assessment tools such as HAZUS. It enables the development of enhanced fragility curves specifically accounting for the effects of known soft storeys and the quality of construction.

Haldar et al.(2016) The Indian Standard, along with many other national codes, did not provide explicit guidelines for modeling infills and understanding the expected performance of infilled frames. This paper reviewed and examined the modeling and design provisions related to unreinforced masonry (URM) infills in major national seismic design codes. Additionally, a macro model for URM infilled frames was presented. Using the developed model, an analytical study was conducted to investigate the impact of open ground storeys on the seismic performance of RC frame buildings. The buildings were designed and detailed according to the amendment of the Indian Standard (BIS) in 2002, which required the beams and columns of the open ground storey to be designed for 2.5 times the design base shear compared to uniformly infilled frame buildings.

Sakhiya et al.(2019) The seismic performance of high-rise buildings with parking spaces on the ground story in densely populated cities has been a significant concern addressed in this paper. To accommodate parking needs, the trend has been to utilize the ground story of the building itself. These buildings, known as Open Ground Story (OGS) buildings, are prevalent in India, particularly for parking provisions. However, it has been observed that in OGS buildings, the ground story columns are prone to severe damage or complete failure. This occurs due to the sudden reduction in lateral stiffness and mass in the ground story, resulting in heightened vulnerability during seismic loading. To prevent soft story failures, the paper proposes the application of a multiplication factor obtained through static nonlinear analysis, taking into account the stiffness and strength of infill walls. By considering the infill properties, the aim is to enhance the seismic performance and mitigate the risks associated with OGS buildings. In summary, this paper addressed the concern of seismic performance in high-rise buildings with ground-level parking spaces in crowded cities. It emphasized the common occurrence of OGS buildings in India for parking provisions and the vulnerability of the ground story columns. To prevent soft story failures, a multiplication factor was proposed based on static nonlinear analysis, accounting for the stiffness and strength of infill walls.

Niharika et al.(2020) The study revealed a significant improvement in the performance of the building following the retrofitting measures. However, upon observing the hinge formation pattern, it was noted that the damage had propagated to the second storey. To further enhance the performance, retrofitting was carried out on the second storey, and a subsequent pushover analysis (POA) was performed. Additionally, retrofitting was conducted on the respective stories where damage propagation to upper stories was observed. Through analyzing the hinge patterns and capacity curves, it was observed that in retrofitted buildings, the capacity increased up to a certain storey. However, beyond that point, no further increase in capacity was observed. Based on these findings, the study concluded that retrofitting an open ground storey building does not solely involve retrofitting the ground storey. Instead, it requires retrofitting of all columns/stories where damage distribution occurs after the retrofitting of the open ground storey.

Rama et al.(2021) The focus of the present study was to investigate the impact of soil flexibility on the seismic response of open ground storey buildings. Analytical investigations were conducted using SAP2000 software, considering typical models of open ground storey buildings and incorporating soil flexibility. Static nonlinear analysis, specifically pushover analysis, was utilized to analyze the lateral response of the structures. To account for different boundary conditions, three soil conditions were simulated: hard, medium, and soft, as classified in IS 1893 (Part 1) 2016. The study observed that soil flexibility resulted in increased lateral displacement and secondary forces due to the P-Delta effect. Furthermore, a parametric study was conducted to examine the influence of soil flexibility on open ground storey buildings with various slenderness ratios.

Kanake et al.(2022) In the study, the following observations were made: Firstly, it was observed that shear forces and moments acting on columns were comparatively lower in the infilled frame compared to the bare frame. Secondly, the introduction of RC structural walls in the open ground storey resulted in the structure acquiring desirable strength, stiffness, ductility, and frequency characteristics. Lastly, the bare frame structure exhibited higher base shear compared to the infilled frame structure.

Bilgin et al.(2022) This paper aimed to compare the seismic design provisions of Albania, Croatia, Iran, and Turkey for mid-rise reinforced-concrete (RC) frames. The historical development of these provisions was provided, and a comparison was made to highlight the main differences in minimum requirements for column and beam detailing and analysis in mid-rise RC frames. For the study, 4-story, 5-story, and 6-story buildings were designed according to each design code, and their performance was evaluated using a displacement-based adaptive pushover procedure and eigenvalue analysis. The findings of the study revealed that the recent Turkish code had the highest level of requirements, while the Albanian code had the lowest level of requirements in terms of member size and reinforcement detailing. The comparison shed light on the variations in design provisions among the considered countries, providing valuable insights into the different levels of seismic design requirements for mid-rise RC frames.

6. SUMMARY

This paper presents a literature survey that explores the implications of major international building code provisions on open ground storey structures. Open ground storey buildings, characterized by an unobstructed ground floor commonly used for parking or commercial spaces, pose unique challenges in terms of structural stability and safety during seismic events. The study begins by examining global building codes and regulations governing open ground storey structures, focusing on provisions related to structural design, material requirements, and construction practices aimed at enhancing seismic performance. Through an extensive literature review, including case studies, experimental tests, and numerical simulations, the consequences of these design provisions are analyzed in terms of structural behavior and performance during seismic events. Key factors such as lateral load distribution, column design, and bracing systems are discussed in detail. The findings highlight the importance of implementing appropriate design provisions to ensure the safety and resilience of open ground storey buildings. The study emphasizes the need for engineers and architects to understand the implications of major international building code provisions to make informed decisions in enhancing the seismic performance of these structures. The research contributes to the field of structural engineering by providing valuable insights for future developments in building codes and regulations. In summary, this literature survey serves as a comprehensive resource for understanding the implications of key global building code provisions on open ground storey structures. It underscores the importance of proper design provisions and offers valuable insights for improving the seismic performance and safety of these buildings.

REFERENCES

1. IS 1999 – 1959 (Reaffirmed 1999): Methods of sampling and analysis of concrete, Bureau of Indian Standard, New Delhi.
2. IS 383 – 1970: Specification for coarse and fine aggregates from natural sources for concrete, Bureau of Indian Standard, New Delhi.
3. IS: 10262 – 1982 (Reaffirmed 2004): Recommended Guidelines for Concrete mix design, Bureau of Indian Standard, New Delhi.
4. IS: 10262 – 2009: Recommended Guidelines for Concrete mix Proportion, Bureau of Indian Standard, New Delhi.
5. IS: 12269 – 2013: Specification for 53 Grade Ordinary Portland Cement, Bureau of Indian Standard, New Delhi.
6. IS: 2386 (Part I, III), 1963: Methods of Test for aggregates for Concrete, Bureau of Indian Standard, New Delhi.
7. IS: 4031 (Part 4, 5 and 6) – 1988: Methods of Physical Teats for Hydraulic Cement, Bureau of Indian Standard, New Delhi.
8. Hashmi, A. K. and A. Madan (2008) Damage forecast for masonry infilled reinforced concrete framed buildings subjected to earthquakes in India. Current Science. 94. 61-73.
9. Kumar, Ajay & Yadav, Onkar & Kumar, Sagar. (2023). AN OVERVIEW ARTICLE ON INCORPORATING HUMAN HAIR AS FIBRE REINFORCEMENT IN CONCRETE. 11. 967-975.
10. Özer AY, B. and M. A. Erberik [2008] "Vulnerability of Turkish low-rise and mid-rise reinforced concrete frame structures" Journal of Earthquake Engineering, 12(S2):2-11,2008. doi: 10.1080/13632460802012687 .
11. Kumar, A., Yadav, O. and Kumar, A.N., A REVIEW PAPER ON PRODUCTION OF ENVIRONMENT FRIENDLY CONCRETE BY USING SEWAGE WATER.
12. MatLab (2007), "MatLab - Programming software for all kind of problems" [online]. < http:// www.mathworks.com/ > (July 20, 2012).
13. Rota, M., A. Penna, C. Strobbia , G. Magenes (2008) "Direct derivation of fragility curves from Italian post-earthquake survey data" the 14th World Conference on Earthquake Engineering, October 12-17 2008, Beijing, China .
14. Yadav, O. and Kumar, C., 2023. An Investigation of Ultra High Performance Concrete for the Durability Properties: Literature Survey. *Nexus: Journal of Advances Studies of Engineering Science*, *2*(8), pp.11-18.
15. Seismostruct (2009), "SeismoStruct - A computer program for static and dynamic nonlinear analysis of framed structures", [online]. < http://www.seismosoft.com/ >.
16. Yadav, O., Kumar, A. and Kumar, M., 2023. Literature Survey on Evaluation of High Volume Fly Ash (HVFA) Concrete Mechanical Properties after Being Exposed to High Temperatures. *Nexus: Journal of Advances Studies of Engineering Science*, *2*(8), pp.19-26.
17. Sattar, S and Abbie B. L. (2010) Seismic Performance of Reinforced Concrete Frame Structures with and without Masonry Infill Walls, 9th U.S. National and 10th Canadian Conference on Earthquake Engineering, Toronto, Canada, July.
18. Kumar, P. and Alam, M.F., Seismic Analysis of RC Building with Steel Bracing.

19. Kumar, A. and Yadav, O., 2023. Concrete Durability Characteristics as a Result of Manufactured Sand. Central Asian Journal of Theoretical and Applied Science, 4(3), pp.120-127.

20. Kumar, N., Kumar, P., Kumar, A. and Kumar, R., 2023. An Investigation of Asphalt Mixtures Using a Naturally Occurring Fibre. AMERICAN JOURNAL OF SCIENCE AND LEARNING FOR DEVELOPMENT, 2(6), pp.80-87.

21. Kumar, A., Yadav, O. and Shukla, R., 2023. A COMPREHENSIVE REVIEW PAPER ON PARTIAL CEMENT SUBSTITUTION IN CEMENT MORTAR WITH WOOD ASH. *Research in Multidisciplinary Subjects*, *1*, p.26.

22. IS 456 (2000). “Indian Standard for Plain and Reinforced Concrete” Code of Practice, Bureau of Indian Standards, New Delhi. 2000.

23. IS 1893 Part 1 (2002) Indian Standard Criteria for Earthquake Resistant Design of Structures, Bureau of Indian Standards, New Delhi.

24. Haldar, Putul & Singh, Yogendra & Paul, D.. (2016). Simulation of Infills for Seismic Assessment of Open Ground Storey RC Frame Buildings. Journal of Structural Engineering, CSIR SERC Chennai. 43. 38-47.

25. Sakhiya, J & Gohel, Jay. (2019). A COMPARATIVE STUDY ON EFFECT OF OPEN GROUND STOREY BUILDING ON SEISMIC PERFORMANCE OF HIGH RISE BUILDING BY USING DIFFERENT PROVISION OF INFILL. 26-36.

26. Niharika, T & Ramancharla, Pradeep. (2020). PERFORMANCE ASSESSMENT OF UPPER STORIES IN AN OPEN GROUND STOREY BUILDING WITH RETROFITTED GROUND STOREY.

27. Rama Rao, G.V. & Sunil, J & Ramanathan, Vijaya. (2021). Soil-structure interaction effects on seismic response of open ground storey buildings. Sādhanā. 46. 10.1007/s12046-021-01633-0.

28. Kumar, D., Singh, A., Kumar, P., Jha, R.K., Sahoo, S.K. and Jha, V., 2020. Sobol sensitivity analysis for risk assessment of uranium in groundwater. Environmental Geochemistry and health, 42, pp.1789-1801.

29. Kumar, P., Agarwal, S., Bhushan, M., Aind, S.P. and Shyam, G.M., 2022. Groundwater Contaminant Transport Analysis and Numerical Solution of Diffusion in Saturated Aquifer. INTERNATIONAL JOURNAL OF SPECIAL EDUCATION, 37(3).

30. Kanake, Sushant & Dongre, Archanaa. (2022). Seismic Response of Open Ground Multi-Storey Building Retrofitted with Infill Wall, Shear Wall and Steel Bracing.. 10.21203/rs.3.rs-2183625/v1.

31. Bilgin, Huseyin & Hadzima-Nyarko, Marijana & Işık, Ercan & Ozmen, Hayri & Harirchian, Ehsan. (2022). A comparative study on the seismic provisions of different codes for RC buildings. Structural Engineering & Mechanics. 83. 195-206. 10.12989/sem.2022.83.2.195.