Critical Review on Dynamic Analysis of Steel Framed Building with Soft Story

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***Abstract*— This paper focuses on soft floors. Buildings with a steel frame that have more than one story: Many of these structures lack structural walls on the ground floor, allowing for more flexible use of the area for parking, retail, or other commercial purposes. Soft-storey buildings are those that have floors that are much more flexible or weaker than the floors around them. They stand out by having a plot with lots of empty space. While the open floor plan of the soft story may be appealing from an aesthetic or commercial standpoint, fewer opportunities exist to install shear walls, specialized walls made to distribute lateral forces so that a building can withstand the swaying effect of an earthquake. Flexible storey is another name for soft storey. Buildings with soft flooring have been constructed in great numbers recently. However, it performed poorly during the recent earthquake. The design of structural components on soft stories is crucial and should be different from the upper floors because soft stories are subjected to greater lateral loads during earthquakes, and under lateral loads, their lateral deformations are greater than those of other floors. In this paper, "analysis of soft-storey for Multi-story Steel Structure Building in Zone" from previous research work has been critically reviewed, and a gap in the analysis has been found for further study.**

***Index Terms*— Soft Storey, IS1893 2016, Bracing, weak story, response spectrum analysis**

I. INTRODUCTION

A "soft story" in the context of a steel frame building refers to a structural design flaw where one or more stories (floors) of a building are significantly more flexible or weaker in terms of lateral load resistance compared to the stories above or below. This is a concern primarily in seismic regions where earthquakes can exert strong horizontal forces on buildings. Soft stories can lead to disproportionate and potentially catastrophic damage during an earthquake. Soft story conditions are often observed in buildings with open or irregular floor plans, where a large opening, such as a parking area or commercial space, is present at one or more stories. These open areas create weaker points in the building's lateral load-resisting system, which can result in excessive sway, tilting, or even collapse during an earthquake. Steel frame buildings are not immune to soft story vulnerabilities, although steel is generally considered a strong and ductile material. The key issue in a soft story situation is the imbalance of stiffness and strength between different stories of the building. Steel frame structures, while robust, still require proper design and engineering to ensure that they can withstand lateral forces generated by seismic events.

To mitigate the risk of soft stories in steel frame buildings, engineers and architects employ several strategies:

- Reinforced Design: Ensure that the design of the building's lateral load-resisting system, including braces, columns, and beams, is consistent and well-distributed throughout all stories.
- Shear Walls and Bracing: Incorporate shear walls or bracing systems in the soft story areas to enhance lateral stiffness and strength.
- Column Strengthening: Strengthen or reinforce columns at the soft story level to handle increased forces.
- Moment Frames: Design the structure with moment-resisting frames, which can provide enhanced resistance to lateral forces and prevent excessive sway.
- Additional Structural Elements: Add transfer beams, rigid frames, or other structural elements to distribute seismic loads more evenly across all stories.
- Use of Damping Devices: Install damping devices, such as tuned mass dampers or viscous dampers, to

absorb and dissipate seismic energy, reducing building sway.
- Retrofitting: In existing buildings with soft story issues, retrofitting can involve adding new structural elements or strengthening existing ones to improve overall seismic performance.

It's important to note that building codes and regulations in seismic-prone areas often address soft story conditions to ensure the safety of occupants and the structural integrity of buildings during earthquakes. Engineers and architects work within these guidelines to design and construct buildings that can withstand the forces exerted by seismic events.

1.1 Soft Storey Failure

Due to the limited horizontal space and high cost, multi-story structures in metropolitan areas must have an open, taller first floor for parking automobiles and/or retail shopping, a sizable space for a conference room, or a banking hall. The first level has less strength and stiffness than the upper stories, which are reinforced by brick infill walls, as a result of this practical requirement. In multi-story buildings, this aspect of building construction causes weak or soft-storey issues. Extreme deflections caused by the first story's increased flexibility in turn cause a concentration of forces at the connections to the second storey and cause significant plastic deformation. Additionally, the soft columns disperse the majority of the energy generated by the earthquake. The soft tales are turned into a mechanism in this phase by the formation of plastic hinges at the ends of the columns. The collapse is inevitable in such circumstances. Soft stories should therefore receive special attention in both analysis and design. According to the survey, the damages are primarily caused by the collapse and buckling of columns, especially in areas where parking spaces are not adequately protected. On the contrary, where the parking places are sufficiently covered, the damage is significantly reduced. It is understood that a number of other unfavourable factors, including torsion, excessive mass on upper levels, P-effects, and a lack of ductility in the bottom storey, combine to cause this form of failure. Some of the examples of soft stores are shown in the illustration. Technically and practically speaking, the soft-storey concept is superior than traditional structure. First, as in a base-isolated structure, there is a decrease in spectral acceleration and base shear caused by an increase in the structure's natural period of vibration. But this force reduction comes at a cost—increased structural displacement and inter-storey drift, which has a substantial P-effect and jeopardizes the integrity of the structure. Second, there are instances when a taller first floor is required for parking spaces, retail stores, large meeting rooms, or banking halls. Due to this practical necessity, the first story’s columns are less rigid than those in the stiff upper-floor rooms, which are typically built with masonry infill walls. Figure 1.1 depicts a soft tale failure in the normal sense.

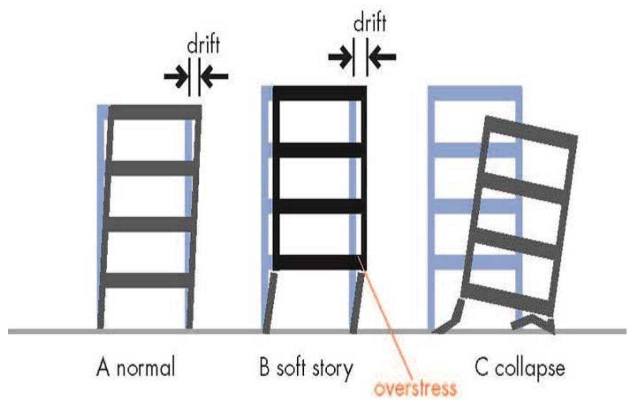

Figure 1. Soft story failure

II. RELATED WORK

Vyshnavi Pesaralanka et al. (2023) investigated the effect of a soft story and its location on the seismic behaviour of a supporting building and NSCs. The lowest (ground), middle, and top story levels of the hypothetical building models were supposed to contain the soft story. To analyse structural behaviour, story displacements and inter-story drift ratios were examined. To comprehend the behaviour of NSCs, the floor response spectra and the amplification effects of NSCs on the floor acceleration responses were investigated. According to the analysis's findings, the bottom soft story has a significant vertical stiffness irregularity, and its location has a significant impact on the floor response spectra. At the soft-story level, it was discovered that the floor acceleration reaction was amplified more. This study found that the component's acceleration is amplified most noticeably in middle soft-story buildings. The code-based formulation's linear assumption may cause peak floor response demands to be underestimated or exaggerated, it was discovered after peak floor response demands and the code-based formulation were compared. [1]

George C. Manos et al. (2022) Due to the existence of masonry infills in the upper floors, multi-story, old reinforced concrete (RC) structures with a "soft story" on the ground floor experience significant damage to the soft story during earthquakes. They briefly examined certain aspects of the relationship between brick infill and RC frames. To avoid such soft-story inadequacies, it consists of RC infills that are put inside the ground floor frames' bays and paired with RC jacketing of the surrounding frame. The effects of such a refit were investigated through the measured behaviour of single-story, one-bay frames built to 1/3 scale and exposed to horizontal stresses of the cyclic seismic variety. It was established that this retrofit increases stiffness, strength, and plastic energy consumption significantly for the better. It was also shown how crucial it is to have strong steel connectors connecting this RC infill to the surrounding frame. Additional design goals were set with the intention of preventing early failure of the RC infill panel and/or fracture of the steel links and safeguarding the surrounding RC frame from unintended local damage in order to accomplish these desired beneficial effects on such sensitive buildings. A numerical methodology that was proven to be capable of reasonably predicting these crucial response mechanisms and was validated using the resulting experimental results can now be used for design purposes. [2]

Florin Pavel and Gabriel Carale (2019) completed a seismic evaluation for a Bucharest, Romania-typical low-code, high-rise, soft-storey reinforced concrete (RC) building. After the earthquake in 1977, the majority of these structures were not retrofitted, were not well-maintained, and were impacted by two more earthquakes in the Vrancea region in 1986 and 1990. The seismic assessment of these buildings is therefore a pressing issue given that many people in Bucharest still live there. As a result, a fragility study is carried out first using the outcomes of standard pushover analyses as well as incremental dynamic analyses. Additionally, a thorough sectional investigation of the ground-floor vertical structural parts' seismic resilience is also carried out, highlighting the brittle seismic behaviour of several RC vertical structural elements. The analyses also revealed that the construction has more transverse strength, but its longitudinal displacement capability is only approximately half as great. Last but not least, data gathered after the 1977 Vrancea earthquake supports the observation that the mean annual collapse probabilities calculated using the ground motions for a Monte-Carlo simulated earthquake catalogue for the Vrancea intermediate-depth seismic source have the same order of magnitude on both principal directions of the structure. [3]

J.M. Jara et al. (2019) aimed to evaluate the seismic vulnerability of typical soft-story structures, analyse the seismic damages seen during the visual inspection of the affected area, and propose retrofit alternatives including braces and energy dissipation systems to increase the seismic capacity of existing buildings. According to the findings, elastoplastic and viscous dampers are good substitutes for reducing the seismic vulnerability of existing low-rise, soft-story buildings. The pairing of braces in one bay and elastoplastic dissipaters in the other proved to be a workable retrofit choice when the structures' number of floors rose. This study investigated several seismic retrofit techniques for existing soft-story structures. Based on data on structures in Mexico City that were harmed by the earthquake that occurred on September 19, 2017, the buildings were chosen. The predicted seismic behaviour of four-, six-, and eight-story buildings was evaluated using accelerograms from seismic sensors nearby the locations of building collapses. As potential retrofit methods, the usage of braces, metallic energy dissipaters of elastoplastic behaviour, and viscous dampers was taken into consideration. Three original buildings were also examined for comparison's sake. These structures had no retrofit systems installed. The findings of the nonlinear studies performed after the investigation of the earthquake damages lead to the following conclusions: Soft-story structures made up more over half of the destroyed buildings. The majority of the 2 to 8 story buildings that sustained damage in Mexico City were situated in areas with soft ground. Models that weren't adapted were created in accordance with the regulations that applied in Mexico in the 1970s and 1980s. The damages that were seen following the earthquake's occurrence were justified by the results of the drift ratio and rotation demands in the first story columns. Braces can be added as a way to lessen the consequences of quakes in the future. Base-shear standards, however, would necessitate altering already-built foundations, which is never a simple structural operation to carry out. [4]

Pravesh Gairola and Sangeeta Dhyani (2019) examined the seismic response of soft-storey buildings under earthquake stress using various models (Bare frame, Infill frame, Bracing Frame, and shear wall frame). It has been found that using different models rather than only soft storeys improves the structure's resistance behaviour. They came to the conclusion that all constructions have a lateral load that is zero at the bottom and maximum at the top storey based on the results of applying the analogous static approach. The first level was found to have the highest storey shear force, while in every case, the top storey had the lowest storey shear force. The bare frame building has a significant displacement when compared to the rest. It shown that bare frame buildings in seismically active areas could likewise exhibit larger displacement than the remainder of the building. [5]

Niloufar Mashhadiali and Ali Kheyroddin (2018) attempted to suggest the hexa-braced frame, a creative alternative to the traditional steel-braced frames for improving seismic response. According to the suggested design, the V and inverted-V bracings are connected by vertical structural elements over three stories to create a hexagonal bracing arrangement, which has two stories braced at the top and bottom. In order to lessen the likelihood of the soft-story mechanism, which is a worry in traditional steel-braced frames, deformation demands were distributed along the height of the frame. The braced columns were made to resist bending moments using a straightforward analysis process in order to accomplish this goal. The seismic response of the suggested bracing system was assessed using a set of 4-, 10-, and 20-story structure models through nonlinear static (monotonic and cyclic) and dynamic calculations. The outcomes were contrasted with the benchmark responses of comparable X-braced frame models. The hexa-braced frame system has the appropriate structural behaviour for seismic resistance, according to analytical results, and it can fulfil the goal of equal distribution of lateral distortion to lessen soft-story failure. [6]

Pradnya V. Et al. (2017) studied the effect of introducing a soft story in a multistory building. The goals include applying the response spectrum approach in ETABS software to do the seismic analysis of the following three models of G+15 RC buildings. The computation of a number of seismic reactions, including modal time period, tale stiffness, narrative drifts, and lateral displacements. Additionally assessed are the open ground story's column forces. Based on these responses, a comparison is made between the behaviour of a soft-storied building and a completely infilled frame construction. It was shown that designing an infill wall utilising an equivalent strut technique allows for very strong control over displacement and drift. Soft-storied buildings are observed to have a longer modal time period than completely infilled frame buildings. [7]

M.P. Mishra et al. (2017) emphasized the significance of seismic safety measures that will be suitable and beneficial for experts and builders in order to remedy poor construction practices and provide a design that is safe, affordable, and appropriate for the needs in accordance with the seismic zones and site conditions. Most often, soft floors show larger strains at the first floor's columns, and the columns fail because plastic hinges do not form at the anticipated positions, crushing the columns. In addition, soft flooring decrease the load-resisting system's lateral rigidity, which contributes to the progressive collapse of buildings during powerful earthquakes. With regard to drifts, displacements, shear force, bending moments, and other factors, the results of the ETABS-2016 analysis of buildings to determine the consequences of drifts and drifting limitations under Zone III have been summarized. [8]

Rahul Kapase et al. (2017) objective of this study is to identify an efficient retrofitting method for existing open-ground-story reinforced concrete frame buildings. This soft floor creates a major weak point in an earthquake. Since soft stories are classically associated with retail spaces and parking garages, they are often on the lower stories of a building, which means that when they collapse, they can take the whole building down with them, causing serious structural damage that may render the structure totally unusable. The analysis is done with Response Spectrum Analysis, as per IS: 1893-2002. Various features of the lateral stiffness strengthening system, namely lateral bracings and shear walls, increase the column size in the soft ground floor. The entire project is done with an ETABS 3D model, and the comparison of these models has been presented with their combinations and is proposed to reduce the stiffness irregularity and discontinuity in the load path incorporated by the soft ground floor and the floating columns, respectively. The results are plotted for both frames with and without floating columns by comparing them in terms of Story shear, story displacement, story drift, and time period. Out of all the three methods used to evaluate base shear, Multi-story buildings with shear walls have performed better compared to normal multi-story buildings. Storey displacement of the first structure model in 2D is 2 mm at soft storey, which is less than the other models. For the same model, the ground floor displacement is less for the shear wall retrofit model, which is 3.3mm at the top of the retrofit. Storey displacement of the second structure for model 2 is also 2mm at the bottom of the soft storey, and for shear wall retrofit, it is 3.7mm at the top of the retrofit. [9]

Mahapara Firdous et al. (2017) studied that buildings with soft storeys exhibit poor performance during earthquakes and concluded that soft storeys are to be provided in upper stories and that the combined effect of soft storey and column orientation is to be studied by means of software aid to prevent failure of buildings during earthquakes. The behaviour of a building during an earthquake depends on various factors, such as the shape, size, and geometry of the building. The growth of population and the scarcity of land have constrained the architects and engineers to provide areas of parking inside the building, leading to the formation of a weak or soft storey inside the building. Also, the desire to build aesthetically appealing structures has inspired the engineers to build structures different from the conventional ones. The analysis is done on buildings with soft floors using nonlinear static, dynamic, and response spectrum analysis. The orientation of columns affects the lateral stiffness of the building. Hence, orientations and soft floors should be introduced in such a way that lateral and vertical stiffness irregularities are not created in the building. [10]

Pramod M. Gajbe et al. (2016) investigated the behaviour of soft-storey at various floor levels of buildings under seismic load actions for Multi-storeyed steel structure buildings in zone 2 accordingly. Their study's findings demonstrated that soft-storey flooring will significantly affect how buildings behave structurally from the bottom level to the top floor, and that their structural capability will be reduced under lateral stresses. Structure has an impact on displacement and relative story drifts. The structure is shifting from floor to floor as a result of the seismic effect on the soft storey, with the top storey at each of the floors listed below experiencing the most displacement. Soft story is at its greatest on the ground floor and continues to be so up to the fifth floor, which causes the drift in the structure caused by seismic action to increase floor by floor. According to the Indian standard, IS 1893 (Part 1): 2002, "Criteria for earthquake-resistant design of structures," the storey drift caused by a service load in any storey must not be greater than 0.004 times the storey height. [11]

Shalaka Dhokane and K. K. Pathak (2016) modelled G+9 steel frames with different types of bracing patterns and different combinations of soft stories using the software STAAD Pro. For various parameters, including column displacement, maximum deflection, storey drift, maximum bending moment, maximum axial force, and maximum shear force, the impact of these various bracings on the soft storey was investigated. The most effective sort of bracing will be chosen based on the observed outcome. They came to the conclusion that, as compared to the G and 5th floors of soft-storey steel-framed buildings, the biggest reduction in deflection occurred in the G and 9th storeys. The top soft story was chosen above the bottom soft storey as a result. In G and 9th-type buildings, the X1 brace in the X direction exhibits the greatest reduction in storey drift. Compared to an unbraced building model, the application of X bracing reduces storey drift by 60–90% in all bracing configurations.

III. RESEARCH GAP

From all of the aforementioned research publications, it is clear that the majority of researchers focused on R.C.C. buildings, and very few have worked in steel-framed buildings. Also, retrofit methods like using bracing are still a work in progress. Especially in India, steel-framed structures are now very popular due to their ease of construction and shorter construction times. The ground floor is mainly utilised in all these structures as the parking floor, which is susceptible to more damage due to seismic loading due to reduced lateral stiffness. So Special attention is required to overcome this weakness or soft story effect in steel-framed structures with the use of various techniques, like the Bracing system.

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