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Evaluating The Structural Performance of Soft Storey's Through the Use of Haunches

Janhvi B. Adhau[1], Samruddhi U. Adhau[2], Jayashree P. Okate[3], Priyanka G. Kambekar[4], Ashlesha R. Taywade[5], Dr. A. K. Chitkeshwar[6]

[1,2,3,4,5]UG Students, Department of Civil Engineering & P. R. Pote Patil College of Engineering and Management Amravati

[6]Associate Professor Department of Civil Engineering & P. R. Pote Patil College of Engineering and Management Amravati

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Abstract :-The research paper examines the seismic behavior of buildings with soft storeys, which are high-rise structures where the ground floor is open, often for parking. These soft storey create significant changes in the building's lateral stiffness and strength, impacting the building's performance during earthquakes. The study focuses on understanding how soft storeys affect seismic parameters such as storey drift, displacement, base shear, and storey overturning moments. The research evaluates buildings with soft storeys at different levels, using the Equivalent Static Method and seismic analysis through ETABS. It finds that shifting the soft storey to higher floors reduces displacement, and different structural systems can help reduce lateral displacement and story drift. The paper aims to assess the effects of soft storeys in various earthquake zones and with different column shapes.

Keywords: Soft Storey, ETABS, Storey Drift, Equivalent Static Method, Response Reduction Factor.

Introduction :-In recent years, the construction of multi-story reinforced concrete (RC) frame buildings has become common in India, with open ground storey buildings being a prevalent design choice. These buildings often feature open ground floors for parking, commercial use, or other purposes, which makes the first floor structurally weak compared to the upper floors due to the absence of masonry walls. This creates a "soft storey," which is defined as a storey that is at least 70% less stiff than the storey above it, or 80% less stiff compared to the average stiffness of the three stories above it. This lack of stiffness makes the soft storey vulnerable to damage or collapse during earthquakes, as the lateral forces caused by seismic activity are primarily resisted by columns. If these columns are insufficiently strong, the building can experience severe damage or failure.

The fundamental concept of earthquake-resistant design stresses the importance of strong columns and weak beams to ensure that beams yield before columns collapse, thus protecting the occupants. The performance of multi-story buildings during earthquakes depends on the capacity of the structural members to undergo deformation in response to seismic forces. Soft storey buildings, due to their reduced stiffness, rely on the columns to resist lateral forces during an earthquake. If the columns are not adequately designed, the ground floor will fail to resist lateral forces, potentially leading to the collapse of the entire building.

This section also highlights that the ground floor in many high-rise buildings is left open for various purposes, such as vehicle parking, shops, or waiting lobbies, which creates soft storeys in buildings. The study investigates the seismic performance of high-rise structures with intermediate infill frames and analyzes the behavior and performance of soft-storey buildings, both with and without infilled frames.

Necessity :-The use of steel hunches (or braces) is essential in preventing soft storey issues in parking areas and residential flat schemes, particularly in seismic zones. A soft storey occurs when a floor, like a parking level, is significantly weaker than the floors above it due to large openings for parking spaces, which lack sufficient structural reinforcements. These weak floors fail to resist lateral forces such as those from earthquakes or high winds, making the building susceptible to collapse. Steel hunches are employed as a cost-effective solution to address this issue by reinforcing the weaker floors and adding lateral stability. These braces act as vertical supports, transferring loads from the upper floors to the foundation, ensuring the uniform distribution of forces, and reducing the risk of localized structural failure.

The incorporation of steel hunches enhances the building's stiffness and resilience without requiring a complete redesign, making them an ideal solution. In seismic-prone regions, building codes often require additional reinforcement to ensure safety, and steel hunches provide an efficient way to meet these standards. By incorporating these hunches, buildings can withstand dynamic loads and improve their overall durability.

Seismic analysis is crucial in evaluating the responses of reinforced concrete (RC) structures, particularly in soft storeys, to parameters such as base shear, storey displacement, and storey drift. Understanding the seismic behavior of these structures is vital for ensuring their safety, particularly in regions prone to earthquakes.

Objectives :-

- Strengthen the ground floor (parking area) to avoid weak or soft storey conditions.
- Ensure uniform load transfer between floors to maintain structural stability.
- Increase the building's resistance to lateral forces during earthquakes.
- Reinforce the building to avoid collapse or major damage in critical areas.
- Provide an affordable and efficient method for retrofitting or new construction.
- Meet building regulations and codes related to structural resilience.
- Use steel hunches to extend the lifespan and performance of the building.

LiteratureReview :-

1. Dr.SavitaMaru (2014) were made to investigate the seismic response of soft story buildings with various arrangements under static and dynamic earthquake stress. According to calculations, base shear in RC-framed buildings with brick masonry infill on the upper floors and soft ground floors that are subjected to earthquake loading can be more than twice what is predicted by the equivalent earthquake force method with or without infill or even by the response spectrum method when there is no infill in the analysis model.
2. B. LalithaChandrahas, P. PoluRaju. "BEHAVIOUR OF SOFT STOREY RC FRAMED BUILDING UNDER SEISMIC LOADING". International Journal of Civil Engineering and Technology (IJCIET), Volume-4, Issue-8 [2017].The demand for the construction of commercial floors and parking facilities in the building's lower stories has increased because of India's urbanisation. For the structure under consideration, the behaviour of RC-framed buildings with soft storeys has been observed in terms of hinge formation patterns, total lateral drift, storey shear, overturning moment, and duration. It has been found that the infill wall significantly affects the frame's rigidity and lateral resistance.
3. Shamshad Ali. "ANALYSIS OF BUILDING WITH SOFT STOREY DURING EARTHQUAKE". International Research Journal of Engineering and Technology (IRJET)Volume-3, Issue-4 [2017]. Due to the lack of infill walls, there is a break in the structure's rigidity at the soft story. Though it can be present on any other storey level of the building, the soft or weak storey is most frequently seen on the ground floor. This effort involved a seismic investigation of the impacts of soft story building frames on G+6 buildings. By converting the soft story to different floors, five versions were produced. When

considering soft storeys with the same floor heights, the impact of infill walls has been disregarded. To analyse the building, STAAD PRO v8i is used. The information is set down in. The data is organized by storey drift, displacements, and base shear.

4. Ankita R Uplenchwar. “SEISMIC ANALYSIS OF A STRUCTURE WITH SOFT STOREY AND FLOATING COLUMN”. The International Journal of Progressive Research in Science and Engineering (IJPRSE) Volume-3, Issue-7 [2022]. In this paper, study on behaviour of structure having soft story and floating column is to be analysed. An investigation is performed On analytical model of a multistorey building recognizing the presence of a floating column and soft storey using the software ETABS. To study the effect of earthquake on this kind of buildings, Equivalent static analysis and Response spectrum analysis have Been considered. The parameters like storey drift, storey shear, buliding torsion, storey moment have been studied in detail.
5. PraveshGairola “SEISMIC ANALYSIS OF OPEN SOFT STOREY BUILDING FOR DIFFERENT MODELS” International Journal of Engineering Research & Technology (IJERT)Volume. 8 Issue -05[2019]. In this paper an investigation has been made to study the seismic behaviour of soft storey building with different models (Bare Frame, Infill frame, Bracing Frame, Shear wall frame) in soft storey building when subjected to earthquake loading. It is observed That, providing different models improves resistant behaviour of the structure when compared to soft storey provided. With the Availability of fast computers, so that software usage in civil engineering has greatly reduced the complexities of different aspects in The analysis and design of projects.
6. Mahesh Pawar. AkshayMahajan. “SEISMIC VULNERABILITY OF COLUMN IN MULT STORY BUILDING WITHOUT INCLUDING SOFT STORY AND INCLUDING SOFT STORY AT DIFFERENT LEVELS”. International Journal of Engineering Research & Technology (IJERT) Volume- 3, Issue-8 [2019]. The current analytical study investigates the impact of a few buildings with soft storey behaviour parameters. With the aid of the Computer programme E-TABS 2016, the entire building is modelled. Utilizing comparable static analysis, parametric studies on Displacement, inter-storey drift, and storey shear have been conducted to examine how these characteristics affect the behaviour of Structures with soft storeys. Three models were used to analyse the chosen building.
7. Md. Hussain. “SEISMIC ANALYSIS OF MULTISTOREY BUILDING WITH AND WITHOUT SOFT STOREY”.International Journal of Research in Advent Technology. Volume-6, Issue-8 [2018]. The performance of the structure was examined by considering ground storey, ground and 1st storey, 3rd and 4th storey, ground and 6th storey, 6th storey, 12th storey, and ground, 1st, and 2nd storey as soft storeys in this project. A model of G+12 storeys was created and analysed for tall structures including soft storey for different levels using ETABS. Point the soft storey at the characteristic to better understand it. In this study, the equivalent static approach and the response spectrum method were both applied.
8. Shamshad Ali. “ANALYSIS OF BUILDING WITH SOFT STOREY DURING EARTHQUAKE”. International Research Journal of Engineering and Technology (IRJET)Volume-3, Issue-4 [2017]. Due to the lack of infill walls, there is a break in the structure's rigidity at the soft story. Though it can be present on any other storey level of the building, the soft or weak storey is most frequently seen on the ground floor. This effort involved a seismic investigation of the impacts of soft story building frames on G+6 buildings. By converting the soft story to different floors, five versions were produced. When considering soft storeys with the same floor heights, the impact of infill walls has been disregarded. To analyse the building, STAAD PRO v8i is used. The information is set down in. The data is organized by storey drift, displacements, and base shear.

The condition assessment of soft storey building using haunches and without haunches :-

Earthquake-resistant structures are designed to better withstand seismic activity than regular buildings. While complete protection isn't possible, these structures aim to prevent collapse during rare, strong earthquakes and reduce functional damage during more frequent, less severe ones, thus minimizing loss of life and ensuring safety.

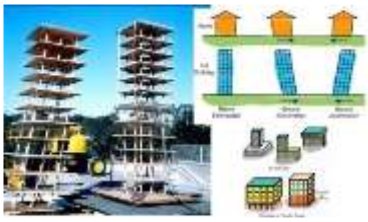

Fig.1. Seismic forces on structure

Soft Storey :-

Open ground storey buildings perform poorly in earthquakes due to the lack of lateral stiffness at the ground level. The upper storeys, being stiffer, move as a single block, causing large horizontal displacements at the weaker ground level, similar to an inverted pendulum. This results in high stress on ground-level columns, which can lead to severe damage if they lack strength or ductility. Such soft-storey buildings are especially vulnerable during earthquakes.

With urbanization, multi-storey buildings are increasingly common, often designed with open ground floors for parking or retail use. These open spaces reduce structural stiffness, creating a "soft storey," which is much more flexible and weaker than the floors above. This structural irregularity, known as soft storey irregularity, makes buildings highly vulnerable during earthquakes. Soft storeys, typically found at lower levels but also possibly at intermediate floors, face larger lateral deformations under seismic loads. If a floor is 70% less stiff than the one above, it is classified as a soft storey. The lack of shear walls in these spaces further reduces earthquake resistance, increasing the risk of collapse.

General Behavior of Soft Storey :-

Soft storey buildings, especially those with open ground floors, have shown poor performance in past earthquakes. Due to the stiffness of upper floors (with walls), movement is concentrated at the soft storey, making the building behave like an inverted pendulum. This leads to high stress on columns, which may fail if not sufficiently strong or ductile.

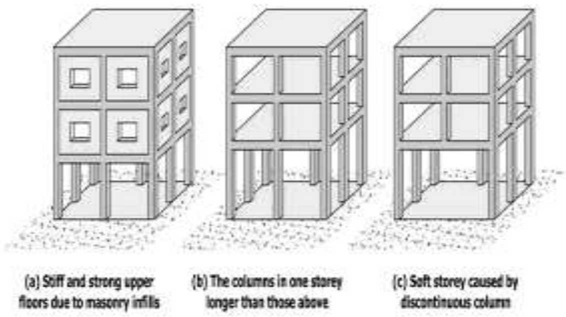

Fig.2. Soft Storey Scenarios

What is StoreyDrift :- Storey drift (inter-storey drift) refers to the relative lateral movement between two consecutive floors of a building. It's a critical design factor in earthquake engineering, as excessive drift can damage both structural and non-structural elements.**What is Haunches:-** A haunch is a structural feature used in various building projects. It is essentially a reinforced section at the bottom of a beam or a column, where the cross-section increases in size. This creates a wedge-like shape, with the wider part at the bottom and the narrower part at the top.

Need of Haunches in Soft Storey:

There are many damage reports about the soft-story construction against earthquakes. The first story in a multi-story apartment building is expected to use for parking lot or commercial space. In these buildings, shear walls with boundary columns are used as partition wall in the upper stories whereas the first-story is single-bay moment resisting frame. Once an earthquake would occur, deformation of the structure is concentrated to the soft first-story. Therefore, the building is in danger of causing story collapse.

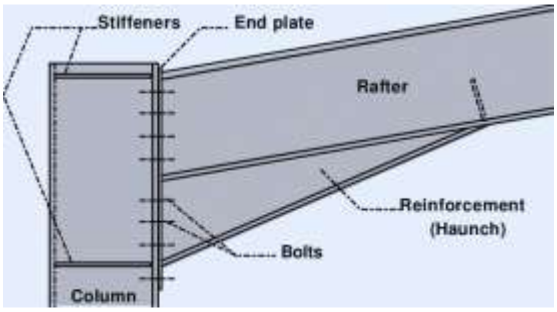

Fig.3. Haunch at Beam-Column

Perspective Plan view of G+13 Storied Building:-

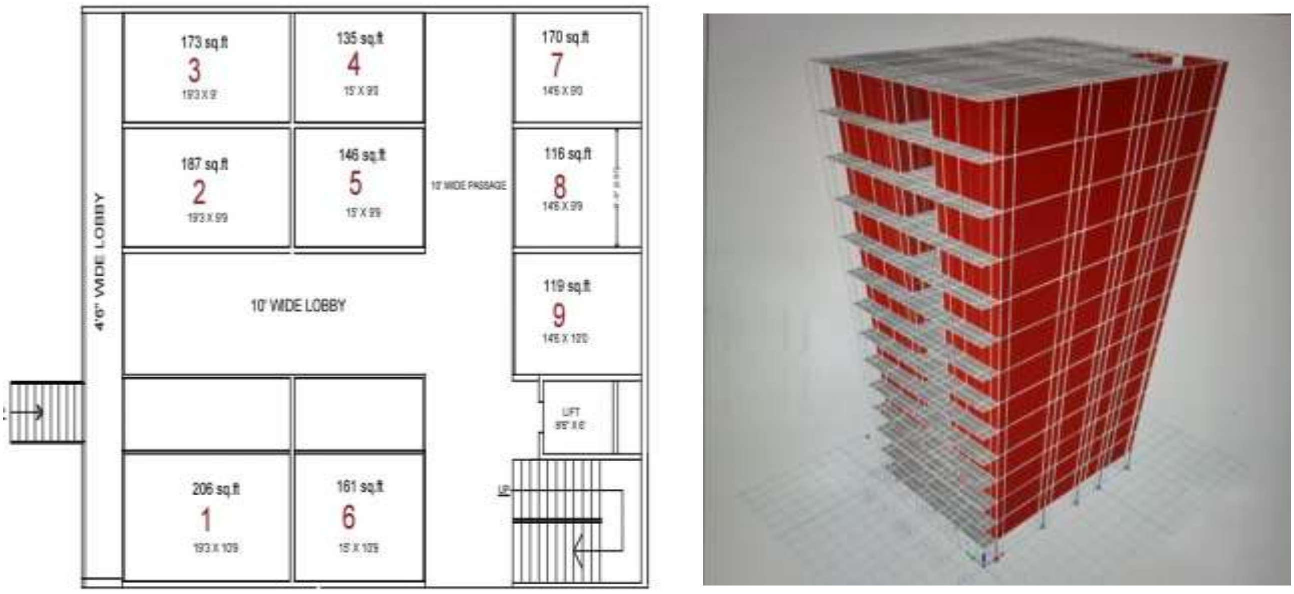

Fig.4. Plan & Elevation of G+13 Building

Equivalent static method :-

In this analysis, an array of forces is used to represent the consequence of earthquake ground motion. It follows the assumption that the building is responsive in its fundamental mode. This is applicable for low rise building and the building which do not rotate significantly about its axis. Further researches have been made to increase its application to high rise buildings and low level of rotation about its axis.

Steps for equivalent static method are as follows-

1. Firstly, the calculation of lumped masses into various floor levels is done. This involves calculation of masses on roofs and other floors taking into consideration the weight imposed by walls, columns, beams, floors, infills and slabs.

2. Then fundamental natural period is determined using the formula

$T_a = 0.075 \text{ x } h^{0.75}$

Where, T_a is the fundamental natural period of vibration in seconds and h is the height of building in meters. This is as per Cl 7.6.2 of IS 1893 Part 1: 2016.

3. As per Cl 7.6.1. of IS 1893 Part 1: 2016, we calculate Base Shear, $V_B = A_h$

4. Then the design Base Shear is distributed along the height of the building as per expression:

$$Q_i = V_B \frac{W_i h_i^2}{\sum_{i=1}^{n} W_i h_i^2}$$

Q_i = Design lateral forces at level i,

W_i = Seismic weights of the floor i

h_i = Height of the floor i

n = Number of stories

ETABS Software:-

Etabs is a sophisticated, yet easy to use, special purpose analysis and design program developed specifically for building systems. Etabs 2020 features an intuitive and powerful graphical interface coupled with unmatched modeling, analytical, design, and detailing procedures, all integrated using a common database. Although quick and easy for simple structures, Etabs can also handle the largest and most complex building models, including a wide range of nonlinear behaviors necessary for performance based design, making it the tool of choice for structural engineers in the building industry.

With the help of Etabs, you can visualize the design and examine the behavior of the structure under different loading scenarios by creating 3D models of the structures. It helps in the early detection of any issues by civil engineers. Etabs also provides a range of tools for analyzing the seismic performance of structures.

Etabs offers the widest assortment of analysis and design tools available for the structural engineer working on building structures. The following are the portions of the types of systems and analyses that EtabsS can handle easily –

1. Multi-story commercial, government and health care facilities
2. Parking garages with circular and linear ramps
3. Buildings with curved beams, walls and floor edges
4. Buildings with steel, concrete, composite or joist floor framing
5. Projects with multiple towers, etc..

Results:-

The analysis of maximum storey drift highlights a noticeable improvement in the structural performance of buildings with haunches compared to those without. In buildings without haunches, the highest drift was observed at the soft storey level, indicating a significant weakness in that region. However, the introduction of haunches led to a substantial reduction in drift across all storeys, particularly at the lower levels where the structural vulnerability is most pronounced. This reduction in lateral displacement is due to the enhanced stiffness and better load distribution provided by the haunches. The overall seismic behavior of the buildingimproves with haunches, demonstrating their effectiveness in controlling inter-storey drift and minimizing potential damage during an earthquake.

The results are performed by ETABS software on Zone V:

Parameter comparison for Storey Displacement:-

Table 1.Storey displacement at each floors

Maximum Storey Displacement		
Storey	Without Haunches	With Haunches
14	37.763	17.402
13	35.455	16.664
12	32.98	15.81
11	30.371	14.847
10	27.668	13.799
9	24.965	12.681
8	22.273	11.515
7	19.604	10.323
6	17	9.133
5	14.504	7.999
4	12.16	6.907
3	10.011	5.878
2	8.114	4.945
1	6.367	4.054
0	0	0

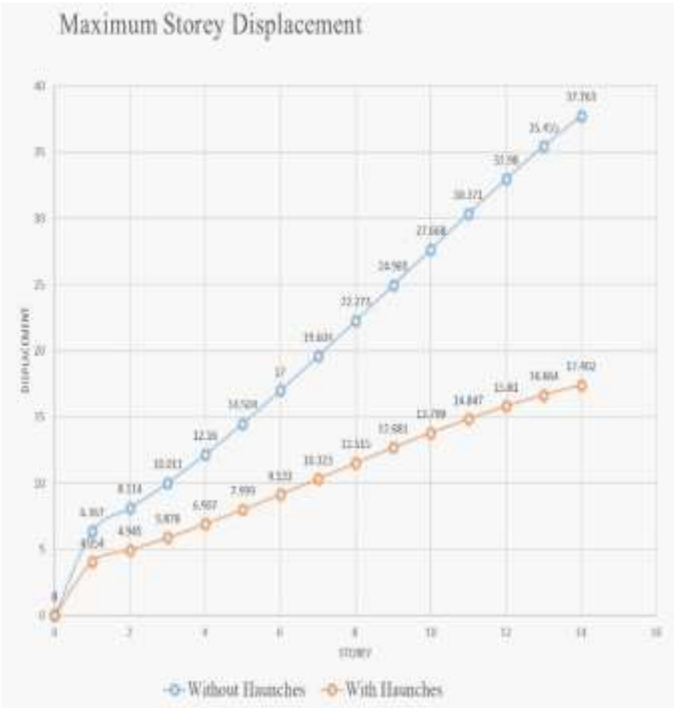

Fig.4. Comparison of storey displacement with & without hunches

Parameter comparison for Storey Drift:-

Table 2.Storey drift at each floors

Maximum Storey Drift		
Storey	Without Haunches	With Haunches
14	2.308	0.737
13	2.475	0.854
12	2.609	0.963
11	2.703	1.048
10	2.703	1.118
9	2.692	1.166
8	2.669	1.192
7	2.604	1.19
6	2.496	1.134
5	2.344	1.092
4	2.149	1.029
3	1.897	0.933
2	1.747	0.819
1	6.376	4.054
0	0	0

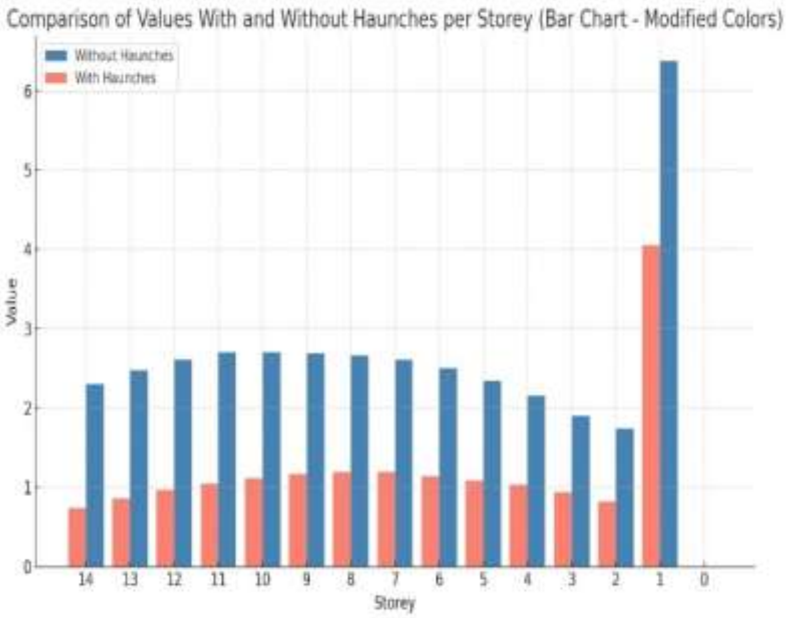

Fig.5. Comparison of storey drift with & without hunches

Conclusions:-

The incorporation of haunches into the structural system leads to significant improvements in the overall seismic performance and stability of the structure. The results indicate a noticeable reduction in key parameters such as maximum storey displacement, storey drift, moment at the first storey, and overall storey deflection when haunches are utilized. This improvement can be attributed to the enhanced stiffness and better load distribution provided by haunches, which help in resisting lateral forces more effectively. Consequently, the structure becomes more resilient to seismic activity, minimizing potential damage and ensuring greater safety and performance during an earthquake.

- The maximum storey displacement is reduced by 53.91% compared to the structure without haunches.
- The maximum storey drift is decreased by 36.27%.
- The moment in the first storey is reduced by 19.51%.
- The maximum storey deflection shows a reduction of 34.43%.

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