ISSN: 2454-9940

INTERNATIONAL JOURNAL OF APPLIED SCIENCE ENGINEERING AND MANAGEMENT

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www.ijasem.org

INTERNATIONAL JOURNAL OF APPLIED SCIENCE ENGINEERING AND MANAGEMENT

ISSN2454-9940
www.ijsem.org
Vol 14, Issuse.3 Sep 2023

COMPARISION OF SEISMIC AND WIND ANALYSIS OF STEEL STRUCTURES WITH AND WITHOUT INVERTED BRACINGS

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ABSTRACT:- An investigation was carried out to assess the load-bearing capacity of a steel building using various bracing systems. The study involved the examination of different types of bracing systems to determine their efficiency in extracting wind load characteristics from the structure. This research focused on a 40-story residential building, which was designed and evaluated for wind loading conditions.

The structural properties of the steel building were analyzed using different bracing systems, including Inverted Bracing, with the assistance of the software ETABS. The investigation considered a wind speed of 50 m/s and examined wind load parameters such as period, drift, and floor displacement for various combinations of bracing systems, including the absence of bracing.

The wind load analysis was conducted in accordance with the Indian Code of Standards IS875:2015 (Part III) using the Diaphragm Analysis Method. Among the design types investigated, it was found that the Inverted Bracing design exhibited the best structural performance under these conditions. In regions prone to high seismic activity, structures are often vulnerable to severe damage.

Gravity load-bearing structures must be designed to resist lateral loads, which can lead to increased stress levels. The bracing system plays a crucial role within the structural framework. Therefore, a thorough analysis of the structure is necessary to determine the most suitable type or optimal arrangement of bracings.

INTRODUCTION

Steel structures are currently the most commonly used due to their which subjected to ductility behavior to the lateral loads such as the wind or earthquakes. Within steel structures, three primary frame types exist: The Moment frames, the truss moment frames, and a braced frames. Frames Braces come in two different varieties: a concentrically braced frames (CBF) and a eccentrically braced frames (EBF). CB enhance a frame's lateral stiffness, reducing lateral drifting. However, this increased stiffness can lead to larger inertia forces during earthquakes. Decreasing the shear forces and the bending moments in columns while increasing axial compression. EBFs are a newer lateral resisting force system designed to withstand seismic events efficiently. EBFs reduce system lateral stiffness and enhance energy dissipation capacity. This energy dissipation occurs at the yielding point of various frame components, including segments of outer beam, a braces, and a columns, primarily remaining elastic. The primary role of the link in EBFs is to provide a weak section, enabling plastic deformation capacity and dissipating energy released during earthquakes. EBF systems with yielding shear links demonstrate stability and greater ductility compared to EBF systems with yielding flexural links, maintaining a constant internal shear force along the link's length. This study focuses on eccentrically braced frames with shear links, evaluating their performance compared to concentric loading and conventional steel buildings. Linear static, linear dynamic, and non-linear static analyses were conducted on the structures to evaluate storey displacement, drift, time period, ductility, and energy dissipation. The study also assesses frame performance under different heights and with varying shear link lengths, conducting seismic analyses for comparison.

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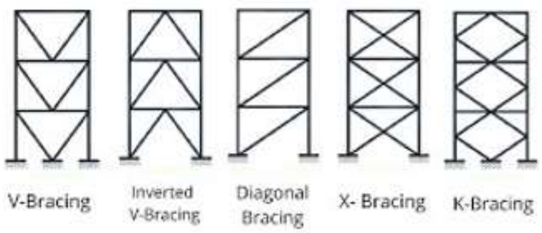
BRACING SYSTEM

Bracing systems play an crucial role in ensuring a stability & safety of the modern buildings. These structural elements are essential for resisting lateral forces such as wind, seismic activity, and other loads that could otherwise cause a building to sway or even collapse. Well-designed bracing constructions significantly enhance building safety and performance. A building's capacity to endure various forces and minimize structural damage while safeguarding its occupants is crucial. Buildings designed to withstand lateral forces, including wind and seismic pressures, often employ a bracing construction solution, known for its exceptional structural strength. Braced frames are commonly constructed using high-strength structural steel members, which excel in both tension and compression.

Vertical loads are primarily supported by frames' beams and columns, while the bracing structure serves to support lateral loads. This combination of elements ensures the building's overall stability and resilience to external forces.



Positioning bracing elements poses a challenge as it can disrupt the overall appearance of a building's façade and the arrangement of windows and doors. Nevertheless, bracing has evolved into an integral component of contemporary and postmodern architectural designs.

One of the most significant threats to our planet is earthquakes, which varying in a magnitude on a Richter scale. Demolishing existing structures and rebuilding them to meet current building codes can be impractical, expensive, and time-consuming. Therefore, the focus is on preventing major disasters by first identifying deficient buildings and conducting thorough evaluations of their structural strength and performance. Earthquake loads that act on a building's foundation are referred to as base shear, while the forces acting on each storey's slab are known as lateral loads. Knee bracings are employed in steel structures to withstand these lateral loads, particularly in retrofitting projects. These knee elements concentrate damage in secondary structural members, making repairs or replacements more straightforward and cost-effective. In the present study, various elements implemented in a structures, and seismic forces resistance is thoroughly analyzed. Knee braced frames are explored as a nonlinear strengthening method, particularly focusing on diagonal elements. Members were given a maximum lateral stiffness to ensure stability. Shear yielding or flexural elements were designed to provide ductility during severe seismic events. Higher seismic impacts were reducing the lengths of the various bracing configurations, resulting in cost-effective retrofitting of knee elements.

IMPORTANCE OF SIESMIC ANALYSIS

Seismic design plays an important role in the structural analysis & design of buildings, especially those located in earthquake-prone areas. Its goal is to ensure that the building can continue to function and serve its purpose even during seismic events. Over time, seismic engineering has evolved, and the complex calculations involved in structural analysis have been automated using tools like ETABS, STAAD Pro, ROBOT, and TEKLA. These software tools offer several advantages, including the creation of safe, stable, and durable structures with optimized designs that are cost-efficient. Certain structures, such as hospitals and educational buildings, require more rigorous analysis, often ranging from 25-50% higher than that of residential or commercial structures.

To enhance a building's seismic resistance, various structural systems have been adopted, including seismic isolation systems, energy dissipation systems, and active control systems. These systems work to dissipate lateral forces during seismic loads without causing any damage to a structural elements. Additionally, development of new structural systems and the use of non-traditional civil engineering materials and techniques have further improved seismic resilience. Dynamic analysis-based approaches provide a more accurate representation of a building's behavior under simulated seismic conditions during the design process.

IMPORTANCE OF WIND ANALYSIS

The following are Wind load analysis

- Stability to the counter a toppling, uplift or sliding of a buildings
- Strong structural components were to a resist the excess loads throughout the life cycle of the building.
- To reduce the potential for the damage and the cracking of exterior walls, interior partitions, and the ceilings, especially when a challenging factors like wind-induced a deflection,, frequencies, and the drift, one must consider the mass and stiffness of the structural materials, which also play a significant role in wind load considerations.

OBJECTIVES

- To evaluate the study on the seismic behavior in the steel braced frames.
- To compare inverted bracing with a normal structure without bracing.
- Evaluates the loads and loading combinations based on the seismic loads.
- To investigate the displacement of the multi-story steel frame building for the seismic loads.

LITERATURE REVIEW

Significant study had been conducted on the seismic behavior of a eccentrically braced frames, with a focusing on the seismic response of the steel-framed structures. This section reviews some of relevant studies. The seismic performance of the steel moment-resisting frames with eccentric braces has been examined. It was examined as the buildings of 6, 9, and 15 stories with eccentric configurations exhibited minimal displacement. Studies have also investigated the global seismic response of 3- and 8-story the eccentrically braced frames designed for locations in western & eastern North America. However, different the models did not a consistently predicting the magnitude of maximum deformation or its location along the heights of the structure, leading significant in the results, especially at the 84th percentile.

An investigation was carried out to assess the impact of the link in eccentrically braced frames, particularly regarding their response to lateral loading. These eccentric frames exhibit the lateral stiffness akin to a concentrically braced frames and display ductility with moment frames. This characteristic renders eccentrically braced frames as efficient lateral framing systems capable of significant energy dissipation, effectively managing substantial seismic and wind forces.

In a study conducted by Arathi Thamarakshan and Prof. Arunima S in 2017, steel braced frames emerged as a structural system employed to withstand earthquake loads efficiently. They are known for their cost-effectiveness, ease of erection, space efficiency, flexibility, and the ability to provide the required a strength and a stiffness. A Bracing is often utilized for retrofitting purposes, and various types of steel bracings are available. This particular investigation utilized the ETABS software to analyze steel frames with different configurations. The results of the analysis were compared with those of analysis pushover, leading to recommendations for optimal frame configurations.

Jinko Kim, Junhee Park, Prof. Sang-Dae Kim. et. al (2009). An investigation was carried out the seismic performance of a framed structures equipped with the chevron-type buckling restrained braces. The research involved evaluating key behavior factors, includes overstrength, ductility, and presenting the findings.

Two distinct structural configurations were considered: structure frame systems and dual systems, each spanning 4, 8, 12, and 16 stories, a designed in accordance with IBC 2003, AISC LRFD, and AISC Seismic Provisions. Analysis included nonlinear static pushover assessments employing two distinct loading patterns, as well as incremental dynamic analysis conducted through 20 iteration
earthquake records were examined & compute the behaviour factors. Time history analyses were another 20 earthquakes to obtain the dynamic responses. The dual systems, designed with the smaller seismic load, showed superior static and dynamic performances.

D Yuvraj, P Sunil, SK Rafi(2011). This study investigates the load-bearing capacity of a steel building employing various structural systems, particularly different types of bracing systems. The research aimed to optimize the wind load resistance of the building structure. To achieve this, a 40-story residential building was designed and assessed under varying wind load conditions. The structural attributes of the steel building were analyzed using different bracing configurations, including X Bracing, Chevron Bracing, and V Bracing. TEKLA software facilitated the structural analysis. In this study, wind speeds 50 m/s were considered, and wind load parameters such as the period, drift, and floor displacement were evaluated for the steel building with different combinations of bracing systems, including no bracing. Wind load analysis was conducted in accordance with IS875:2015 (Part III) using the Diaphragm Analysis Method. The findings indicated that the Chevron bracing design exhibited the most favorable structural performance among the various design types, particularly in terms of wind load resistance.

Luigi DI Sarno, Amr S. Elnathan (2004). It evaluates the performance of seismic and the steel moment resisting frames (MRFs) that have been retrofitted using bracing systems. The 3 brace configurations employed are SCBFs, BRBFs and MBFs. To assess their effectiveness, a nine-storey steel perimeter MRF were designed by insufficient lateral stiffness to meet the codal drift limitations in a high seismic hazard zone. The results show that MBFs prove to be the most economical bracing systems. In comparison to MRFs, they exhibit 70% lower maximum storey drifts and 50% approximately the lower drifts than a SCBFs. Interestingly, configurrations incorporating restrained bucking the mega braces offer slightly superior seismic performance compared to MBFs, despite their greater weight. Moreover, the use of steel for structural elements and connections in mega-brace configurations is reduced by 20% compared to SCBFs. This reduction in construction costs makes MBFs an attractive option for retrofitting seismic applications.

METHODOLOGY

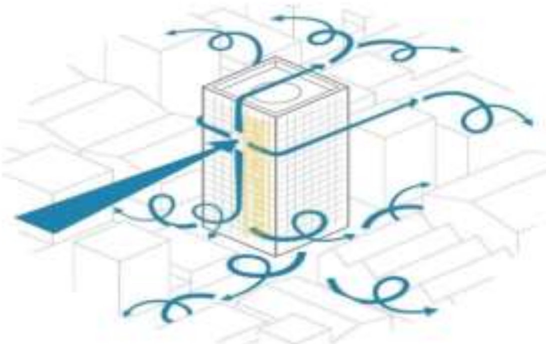
The careful selection of an analysis method is paramount as it provides vital insights into a structure's behavior under various loads. A well-crafted design should closely align with the actual physical response of the structure to avoid unnecessary over-design, forces and ultimately, structural failure.

In the 20th century, many steel building designs predominantly relied on linear analysis methods. While elastic analysis offers insight into a structure's elastic capacity and the location of initial yielding, it falls short in predicting force redistribution during yielding. To better understand how structures behave during major earthquakes when elastic limits are exceeded, engineers have turned to inelastic procedures for design and evaluation.

In recent years, seismic region building design has shifted towards Performance-Based Seismic Design. This approach aims to accurately predict a building's performance under varying earthquake ground motion intensities throughout its design life. It's worth noting that many prior analyses often overlooked the influence of semi-rigid connections, which significantly impact the response and seismic performance of steel frames.

Adopting to evaluate the design methodology empowers engineers to quantify the probability that of a building design meets specified seismic performance objectives. As highlighted in the previous chapter, effective performance-based analysis can lead to optimized sections of frames. Essential concepts, the demand and a capacity, play a important role in the context of performance. Demand represents the seismic ground motion, which generates complexing horizontal displacement patterns in structures that may vary over time.

On the other hand, the capacity signifies structure ability to resist seismic demands. The overall capacity of a structure depends on the strength and deformation capabilities its individual components. Assessing capacities out of elastic limits of nonlinear analysis, the Pushover becomes necessary procedure.

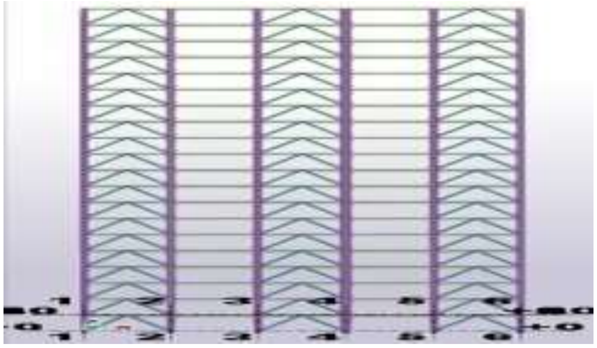


Wind load on surface of building

The procedure details are covered in various chapters, focusing on sequential elastic analysis, which assesses nonlinear response for a building through individual contributions. It relies on how well the capacity can withstand seismic demands, ensuring it aligns with design objectives. If the capacity curves and a demand displacements are shown, than the performance check is to be conducted to ensure that the structural and non-structural components should be within acceptable limits for both forces and displacements given by the demand.

Moment resisting frames, structural response can be enhanced by incorporating steel bracing. These bracings, whether concentric or eccentric, offer multiple arrangements such as cross bracing-X, diagonal bracing -D and V-type bracing. Frames without bracing tend to experience inelastic responses, often failing at beam and column connections during severe earthquakes. MR frames have low elastic stiffness and can encounter the P-Δ effect, especially in high-rise buildings. Concentric bracings are added to increase lateral stiffness and ductility, forming a vertical truss system to resist lateral loads effectively. Bracings optimize lateral stiffness while minimizing weight addition, thereby increasing natural frequency and reducing lateral drift which can be achieve ductility inelastic action, with failure occurring through yielding truss under tension or compression buckling. To address these failures, BRBs or SCEDs can be employed.

Investigation yields a performance-based analysis that helps determine optimal frame sections. Two critical terms in this context are demand, representing earthquake ground motion producing complex horizontal displacement patterns, and capacity, signifying the structure's ability to resist seismic demands. Demand estimates expected response during ground motion, while capacity reflects its seismic resistance capability.



STRUCTURAL ANALYSIS AND DESIGN

STRUCTURAL BUILDING DETAIL

The building has dimensions of 15m X12m X3m. It has a uniform shape along the X and Y axes and columns were fixed at ground level. This study focuses on a G+40 story steel building with 5 bays in the X-direction and 4 bays in the Y-direction, aiming to investigate the impact of various bracing systems. The following table provides building details for the analysis.

The design wind pressure, wind pressure at any height above mean ground level (Pz) is determined using the formula:

$Pz = 0.6 \text{ X } Vz^2$

Where Pz represents the wind pressure in N/m² at height z, and Vz is the design wind speed in m/s at height z. The design wind pressure (Pd) can be calculated as:

$Pd = K_d * K_a * K_c * P_z$

Here, Kd is the Wind directional factor, Ka is the Area, terrain, size factor, and Kc is the topography factor. This calculation assumes a mass density of air as 1.20 kg/m³, which may vary with atmospheric temperature and pressure.

WIND LOADS DATA as per IS 875:2015 (part 3)

Certainly, here's a rewrite of the provided information:

- The basic wind speed for the region is 50 m/s.
- The risk coefficient (K1) is set to 1, as per clause 6.3.1.
- The terrain category (K2) is designated as Category-2, following clause 6.3.2.
- The topography factor for wind (K3) is equal to 1, as indicated in clause 6.3.3.
- The building falls under Class B.
- The windward direction coefficient (Cp) is 0.8.
- The leeward coefficient (Cv) is 0.5.
- The geographical area in consideration is Nellore.

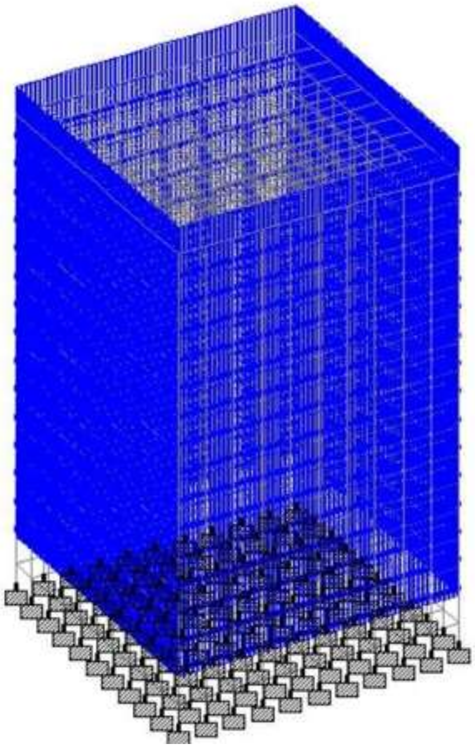
Description of the Building in detail

- Location - Nellore
- Type of a Building - Residential Building (G+40)
- Dimension - 15m x 12m
- Structure type - Steel Structure
- Length -X-Direction - 15m
- Length- Y-Direction - 12m
- No. of Bays -X-Direction - 5 bays @3.0m
- No. of Bays -Y-Direction - 4 bays @3.0m
- Total Height of Building - 123m
- Floor to Floor Height - 3m
- Slab Thickness - 110 mm
- Beam Size - ISMB600
- Column Size - ISWB600-1
- Secondary Beam for Slab - ISMB300
- 17. V-Bracing - ISMB200

MATERIAL PROPERTIES FOR STEEL STRUCTURE

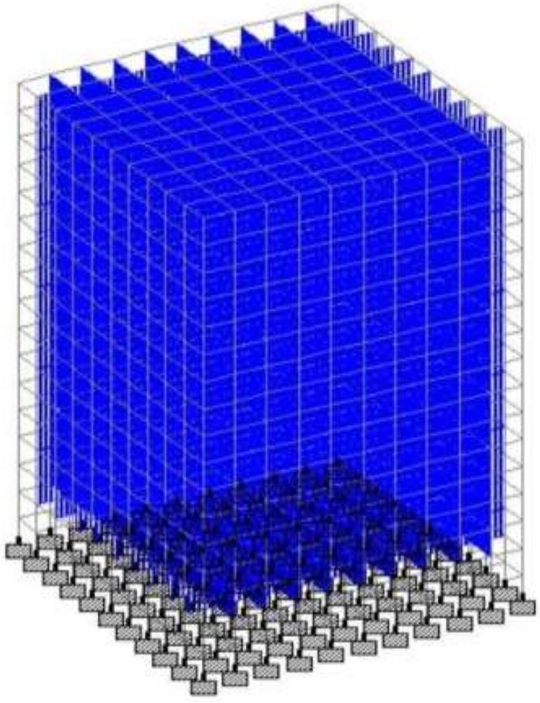
- Steel Grade (I-section) - Fe345
- Rebar - HYSD500
- Young’s Modulus(E) - 2. 1*105N/mm2
- Shear Modulus - 80,000N/mm2
- Poisson’s Ratio - 0.3
- Concrete Grade - M30
- 9”wall loading:

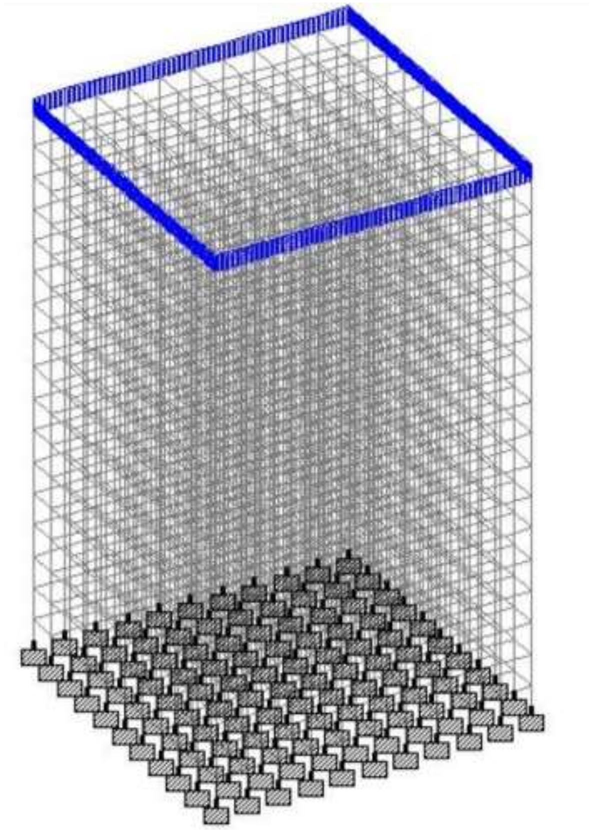
Loading=0.228*3*18*= 13 kn/m



4”wall loading: Loading=0.114*3*18*= 6.7kn/m

parapet loading: Loading=0.114*1*18*= 2.05 kn/m





5.1 BASE SHEAR CALCULATION

Plan & elevation of a 6-storey of a building as shown in figure.

Given data,

Zone = III

Live load = 3kN/m^2 Columns = ISHB250-2 Beams = ISLB200 Bracing = ISMB175

Thickness of Deck = 110mm Thickness of wall = 120mm

Importance factor = 1.0

5.2 Computation of Seismic Weights:

(Assuming unit weight of concrete 25kN/m3 and 20kN/m3 for masonry)

1) SLAB: Dead load to self-weight of Deck = Volume of Deck * unit weight of concrete.
= (9*9*0.11) * 25
= 222.75kN.

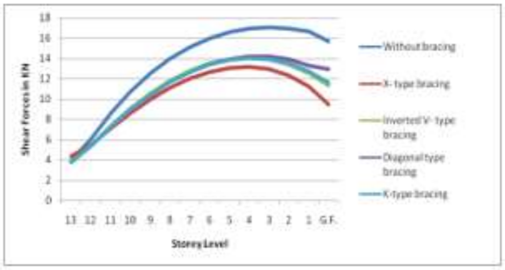
2) COLUMNS: from steel tables TABLE-1 ISHB250-2 = 54.7kg/m = 547N/m
Dead load due to self-weight (16 no's) = No. of columns * self-weight * length of column.
= 16 * 0.547 * 3 = 26.26kN.

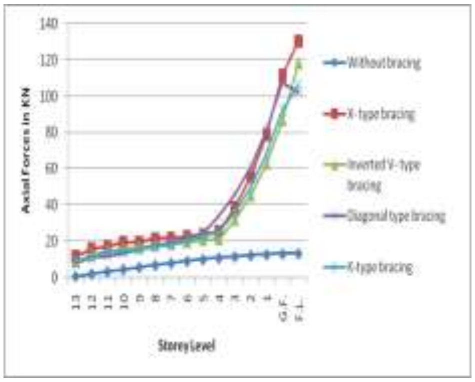
3) BEAMS
ISLB200 = 19.8kg/m = 198N/m
Dead load to self-weight (18 no's) = 0.198 * 18 * 3 = 10.7kN

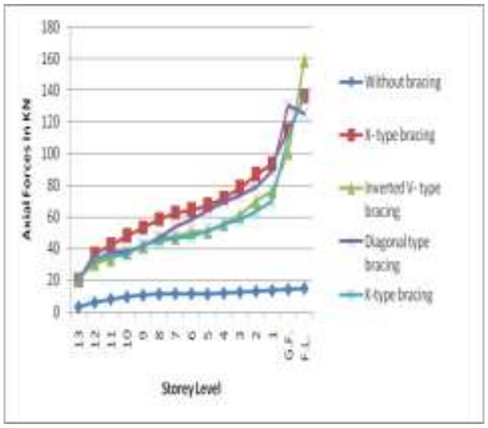
4) WALL
Self-weight of wall per unit length = 0.12 * 3 * 20 Dead load due to weight = (9+9+9+9) * 7.2
= 259.2kN.

5) Live Load (Imposed Load) (25%)
= unit weight * area of deck
= (0.25*3) * (9*9)
= 60.75kN.

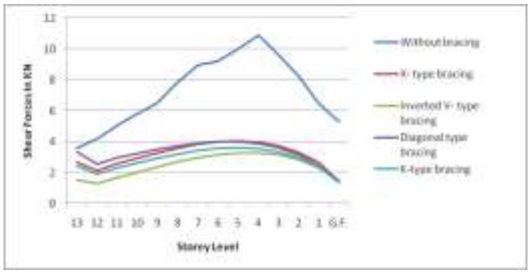
Load on all Floors
W1 = W2 = W3 = W4 = W5 = DECK + COLUMNS + BEAMS + WALLS + LIVE LOAD
= 222.75 + 26.26 + 10.7 + 259.2 + 60.75
= 579.66kN 580kN
Load on Roof Slab (L.L on Slab is Zero) W6 = 222.75 + (26.26/2) + 10.7 + (259.2/2)
= 376.18kN 380kN
Total Seismic Weight
WS = WS1 + WS2 + WS3 + WS4 + WS5 + WS6
= (6 * 580) + 380
= 3860kN
Natural period, Ta = 0.09 * = 0.09 *
= 0.54 s
Moment Resisting Frame with in-Fill Walls Type of soil = Medium soil
For Ta = 0.54 sSa/g = 2.5
Zone factor: for Zone III, Z = 0.16 Importance factor, I = 1.0 Response Reduction factor, R = 3.0Base Shear (VB)
VB = Ah * W
= 0.0667 * 3860
VB = 257.47kN
Storey shear forces are calculated as follows (last column of the table),V6 = Q6 = 77.27kN
V5 = V6 + Q5 = 77.27 + 81.90 = 159.17kN V4 = V5 + Q4 = 159.17 + 52.42 = 211.59kN V3 = V4 + Q3 = 211.59 + 29.49 = 241.08kN V2 = V3 + Q2 = 241.08 + 13.11 = 254.19kNV1 = V2 + Q1 = 254.19 + 3.28 = 257.47kN



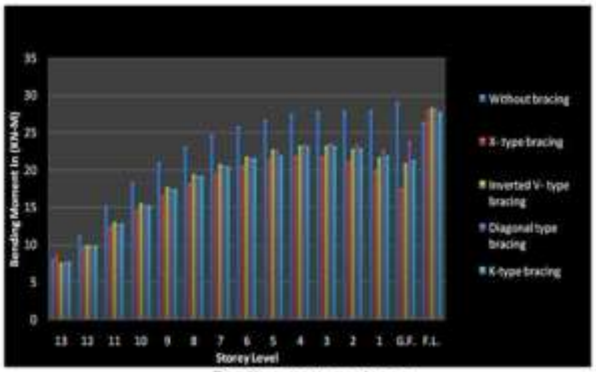




storey drift along x-direction
storey drift along y direction
Shear forces along x direction



Shear force along y direction



Bending moment along x

Bending moment along x direction

CONCLUSIONS

- The utilization of steel bracing stands as an advantageous concept for strengthening or retrofitting both existing and new structures.
- Steel bracings effectively diminish flexural and shear demands on beams and columns while transferring lateral loads through axial mechanisms.
- Implementing steel bracing has minimal impact on the total weight of an existing building.
- Braced buildings exhibit reduced lateral displacement compared to their unbraced counterparts, with maximum reductions of 30.80% and 55.18% along the X and Y directions.
- Braced buildings also experience decreased storey drift compared to unbraced ones, with maximum reductions of 30.80% and 55.18% along the X and Y directions.
- The axial forces in braced buildings increase in comparison to unbraced ones, with maximum increases of 89.75% and 89.02% along the X and Y directions.
- Braced buildings demonstrate lower shear forces compared to unbraced ones, with maximum reductions of 24.00% and 63.54% along the X and Y directions.
- The bending moment due to shear in braced buildings decreases in comparison to unbraced ones, with maximum reductions of 40.02% and 90.15% along the X and Y directions.
- The base shear in braced buildings increases compared to unbraced ones, with maximum increases of 21.18% and 38.60% along the X and Y directions.
- In conclusion, the overall performance of braced buildings surpasses that of unbraced buildings, with inverted bracing proving to be the most effective in reducing seismic parameters across the board.