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*Research Article*

# Influence of slenderness and aspect ratio on the seismic performance of 3-storey modular diagrid steel structures relative to conventional steel structures: A code-based response spectrum study

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**Abstract**

A study is carried out to evaluate the influence of slenderness ratio and horizontal aspect ratio on the structural performance of 3-storey module diagrid steel buildings in comparison with conventional moment-resisting steel frames. The study considers buildings ranging from 10 to 20 storeys, with an increment of 2 storeys, and each storey is assigned a height of 3.5 m. The bay length in both directions is maintained at 5 m. A series of analytical models with varying vertical and plan aspect ratios are developed and analyzed using response spectrum analysis under seismic loading. Horizontal and Vertical aspect ratios for 10, 12, 14, 16, 18 & 20 storeys were considered, and key dynamic and seismic response parameters, including fundamental time period, natural frequency, lateral displacement and bending moment are evaluated in both principal directions. The results indicate that the diagrid system generally exhibits higher lateral stiffness and a reduced time period in the X direction, with the performance advantage becoming more pronounced at higher slenderness ratios. In the Y direction of lesser width in aspect ratio, the diagrid structure shows marginally greater flexibility at lower slenderness ratios, while the response converges with the conventional frame as slenderness increases.

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## 1. Introduction

Over half of the world's population now resides in cities, and this figure is growing by the day. Multi-storey buildings have evolved because of rapid urbanization and population growth. In comparison to the lateral load-resisting system, the structural system that resists gravity loads is less significant. Due to simplicity, most of the human-built structures have an orthogonal structure. In terms of material utilization, orthogonal structures are not the most efficient. Non-orthogonal constructions such as arches, domes, and trussed frames can be many times more efficient [1]. Diagrid structural systems are most utilized in high-rise buildings, where the horizontal seismic force and associated deflection are typical, where diagrids are most frequently utilized. Most academics have attempted to investigate tall structures with only a certain number of stories and compared them to traditional rigid frame structures [2]. Diagrid structures have evolved into one of the most innovative and versatile buildings due to their ability to withstand gravity loads and offer lateral stability [3].

Slender buildings are gaining popularity for accommodating large space volumes within the smallest possible footprint. There is very limited literature on the slenderness ratio of high-rise diagrid steel buildings. In this regard, the consideration of the slenderness ratio in diagrid steel building is a gap in the literature. A building's slenderness ratio is an important structural

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parameter that significantly influences its behavior, stability, and overall performance under gravity and lateral loads. It is defined as the ratio of the building height to its least lateral dimension. As the slenderness ratio increases, the structure becomes taller and relatively narrower, resulting in a reduction in lateral stiffness and an increase in structural flexibility. Consequently, slender buildings are more susceptible to lateral displacements, inter-storey drifts, and dynamic effects induced by wind and earthquake loads. Higher slenderness ratios are also associated with longer natural time periods, which alter the dynamic response characteristics of the structure. Furthermore, increased lateral deformation may lead to serviceability issues, occupant discomfort, and higher demands on the lateral load-resisting system. Therefore, the slenderness ratio plays a crucial role in the design of tall buildings, as it directly affects structural stability, stiffness, load distribution, and overall seismic and wind performance. Similar observations were reported by Ilgın [4], who identified slenderness ratio as one of the principal design parameters governing the structural behavior of supertall buildings.

The diagrid structural system derives its stability primarily from the principle of triangulation. In conventional analytical assumptions, similar to triangulated trusses, the nodes are generally considered to behave as hinged or pinned connections rather than moment-resisting joints. Under this idealized assumption, the forces acting in the diagrid members are predominantly axial, occurring in the form of tension or compression, while shear forces are transferred through the nodal connections. However, this assumption is mainly applicable to simplified analytical models. In practical applications, sufficient stiffness is required at the connection between the node and the diagrid member to ensure constructability and structural stability. Furthermore, the selection of the diagrid module and the overall modular configuration vary significantly with the height of the building. The degree of geometric consistency adopted in the structural layout influenced both the design of the diagrid system and the size of the structural modules [5]. A recent review by Naik et al. [6] further emphasized that the performance of diagrid structures is strongly influenced by node stiffness, connection detailing, and force transfer mechanisms at diagrid joints.

Recent research on diagrid structural systems has emphasized their efficiency in resisting lateral loads while offering architectural flexibility [7] considering the impact of interior diagrid core the performance of tall steel diagrid structure with various angle were carried out [8, 9]. Sethumadhavan and David further demonstrated that diagrid systems exhibit enhanced seismic performance and ductility owing to their efficient axial-force-resisting mechanism and improved global stiffness. Recent studies have further improved the seismic resilience of diagrid systems by incorporating replaceable steel coupling beams in diagrid core-tube structures, thereby enhancing energy dissipation and post-earthquake reparability [10]. The results of this study showed that diagrid structures with BRBs and YCs can be achieve a significant improvement of the seismic performance and the post yield behavior [9] The paper highlights how slenderness ratios and parametric design approaches significantly influence the performance of diagrid frameworks, particularly in high-rise buildings. In the context of this study, parametric design approaches refer to the systematic variation of key geometric parameters, such as vertical aspect ratio and horizontal aspect ratio and diagrid angle, to evaluate their influence on the structural response of conventional and diagrid steel buildings. By modifying these parameters and comparing the resulting structural behavior, the effects of building geometry on stiffness, displacement, drift, and dynamic characteristics can be assessed. Similarly, Palacio-Betancur and Gutierrez Soto [14] investigated the influence of geometric parameters on the structural properties of tall diagrid buildings and reported that optimization of the structural configuration significantly improves stiffness and overall structural performance. The best-suited geometry can be adopted, which shows the best performance to resist lateral loads [11, 12, 13]. Ashtari et al. [13] proposed an optimization framework for determining the optimum geometrical configuration of diagrid structures, demonstrating that appropriate geometric patterns can significantly improve structural efficiency and seismic performance. Wang and Liu [15] proposed an intelligent optimization approach for high-rise diagrid structures, reporting significant improvements in structural efficiency and material utilization. Lotfy and El Madawy [16] employed a multi-objective optimization approach to improve the seismic response of diagrid tall buildings, highlighting the importance of selecting appropriate geometric parameters for enhanced structural performance. Previous studies have

demonstrated that variable-angle diagrid systems, in which the inclination angle of the diagonal members is intentionally varied, can significantly influence the structural behavior of high-rise buildings. The diagrid angle governs the balance between axial force resistance and lateral stiffness within the structural system. By modifying the inclination of the diagonal members, the efficiency of load transfer, seismic performance, and overall structural response can be optimized. Consequently, the diagrid angle is considered one of the key design parameters affecting the performance of diagrid structures [17]. In the present study, a constant diagrid angle corresponding to the selected 3-storey module configuration was adopted for all analytical models to ensure a consistent basis for evaluating the influence of vertical and horizontal aspect ratios. Slender buildings with variable-angle diagrids, reinforcing the notion that geometric adaptability enhances resilience under lateral forces. Collectively, these works establish diagrid systems as a promising solution for sustainable high-rise design, balancing structural robustness with material efficiency [18]. Complementary studies have examined hybrid configurations and comparative performance across different structural systems, such as diagrid systems, X-braced frame systems, and damper-frame systems. The study compared the seismic performance of diagrid structures with X-bracing arrangements and damper-frame configurations and reported significant differences in displacement, drift, and overall structural response [19]. The analysis of diagrids with and without shear walls revealed how supplemental elements can further stabilize tall structures [5]. Similar observations regarding the effectiveness of diagrid systems in resisting lateral loads in high-rise buildings were also reported by Pagade and Mohite [20]. More recently, Kazemi et al. [21] investigated the influence of floor-plan geometric parameters on the structural performance of diagrid tall buildings and demonstrated that plan geometry significantly affects structural stiffness, lateral displacement, and overall seismic response. Similarly, Alizadegan et al. [22] investigated the influence of form curvature on diagrid tall buildings under wind loading and reported that geometric configuration considerably affects structural efficiency and lateral response. However, studies that simultaneously evaluate the combined influence of vertical aspect ratio and horizontal aspect ratio on the seismic performance of steel diagrid buildings remain limited. A generative design grammar (the term generative design grammar refers to a rule-based computational approach that automatically generates multiple diagrid configurations using predefined geometric and structural rules) for diagrid-like structures, bridging computational design with structural engineering (bridging computational design with structural engineering means integrating algorithmic form generation with structural analysis and optimization), enabling the development of diagrid structures that are both architecturally innovative and structurally efficient [23]. Cascone et al. [24] further proposed stress line inspired structural patterns for tall buildings, demonstrating that structural forms based on principal stress trajectories can improve material efficiency while maintaining adequate lateral stiffness. The influence of building slenderness, expressed by the height-to-plan aspect ratio, on the structural behavior and optimal design parameters of diagrid tall buildings. Parametric building models with varying slenderness ratios and diagrid angles are analyzed using strength-based, stiffness-based, and optimization-based design approaches. Finite element analysis demonstrates that slenderness significantly affects whether stiffness or strength governs the design, as well as the optimal diagrid inclination [11, 25].

## 2. Research Gap

Previous studies on diagrid structures have primarily focused on optimizing diagrid angles, evaluating different module configurations, or comparing diagrid systems with conventional structural systems for skyscrapers and supertall buildings under wind and seismic loading, where diagrids are structurally efficient. The seismic performance in low rise building is unexplored largely this creates gap in understanding whether diagrid advantages hold, diminish or reverse. Although the influence of slenderness ratio and plan configuration has been investigated individually, comprehensive studies examining the combined influence of varying vertical slenderness ratio and horizontal aspect ratio on the seismic performance of 3-storey module steel diagrid structures remain largely unexplored. In addition, the available literature provides insufficient guidance on how these geometric parameters affect the dynamic characteristics and seismic response over a broad range of building heights and plan dimensions.

## 3. Novelty and Contribution

To address this gap, the present study performs a comprehensive parametric response spectrum analysis of conventional and diagrid steel building models with varying vertical slenderness ratios and horizontal aspect ratios. The study establishes the influence of these geometric parameters on the fundamental time period, natural frequency, lateral displacement, and bending moment in both principal directions, thereby providing practical design guidance for the seismic design of slender steel diagrid buildings. The methodology flowchart adopted for the comparative analysis of diagrid and conventional steel structures using STAAD Pro is shown in Figure 1.

## 4. Research Methodology

The seismic performance of buildings depends significantly on their overall configuration, including shape, size and geometric characteristics. In earthquake-resistant design, adequate structural strength, stiffness, and inelastic deformation capacity are considered essential to enable buildings to withstand the forces generated during seismic events. These attributes play a crucial role in ensuring that the structure can resist earthquake-induced loads while maintaining stability and structural integrity.

In a conventional framed structure consisting of beams and columns orthogonal to each other the gravity loads are transmitted down through the vertical columns in axial manner, while lateral loads are primarily resisted by the bending of frame through beam-column moment action. In contrast, a diagrid employs a triangulated network of nodes. The diagonal members from the floors above and below connect to a horizontal ring beam. This configuration allows the combined gravity and lateral loads to be resolved into axial tension and compression within the diagonals. In a diagrid structure the lateral stiffness is provided by the axial stiffness of the diagonals rather than frame bending in conventional making the axial deformation much smaller than flexural deformation. As a result, diagrids achieve higher stiffness per unit weight, enabling highly slender, column-free perimeter structures. The important aspects affecting seismic configuration of buildings are overall geometry, structural systems and load paths. The study considered the influence of both the vertical aspect ratio (H/B), commonly referred to as the slenderness ratio, and the horizontal or plan aspect ratio (L/B) on the structural behavior of the buildings. In this context, H represented the total height of the building frame, B denoted the base width, and L corresponded to the length of the building frame. To ensure consistency in the analysis, the structural configurations were maintained as regular in both plan and elevation. The geometric parameters of the buildings were varied by modifying the building height and base dimensions in accordance with the selected aspect ratios. This approach enabled a comparative evaluation of the structural performance under different geometric proportions.

All structures were modelled and analyzed using STAAD Pro CONNECT Edition. As the study is limited to high-rise buildings rather than supertall buildings, Response Spectrum Analysis (RSA) was adopted to investigate the influence of building aspect ratio and slenderness ratio on the seismic performance of steel diagrid structures. The methodology comprises model formulation, numerical analysis and comparative evaluation across different vertical and horizontal aspect ratios. The model performance is evaluated using frequency, time period, maximum lateral displacement, inter-storey drift and bending moments.

## 5. Geometric Parameter of Steel Structures

The study considers buildings ranging from 10 to 20 storeys, with an increment of 2 storeys, and each storey is assigned a height of 3.5 m. The bay length in both directions is maintained at 5m. The floor load considered is 5.75 kN/m2 (including self-weight of slab, partition load and floor finish). The external façade load is computed considering a unit weight of 100 kg/m2. The live load of 4.0 kN/m2 is adopted as per IS 875 (P-II):1987. The seismic parameters follow IS 1893 (P-I) 2016, considering seismic Zone-III with seismic zone factor 0.16 (Clause: 6.4.2).

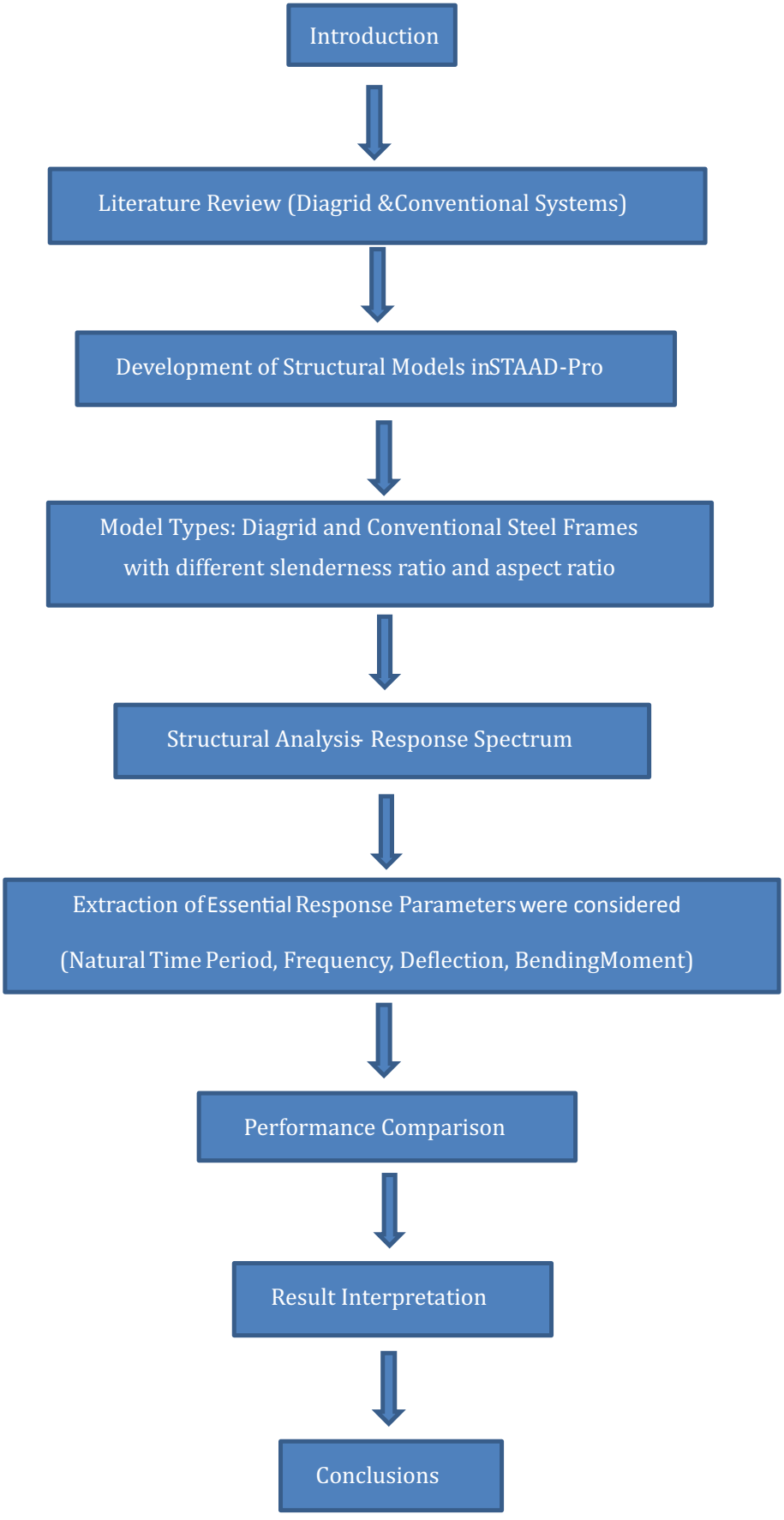



Fig. 1. Schematic representation of the study

The structure considered is an SMRF with response reduction factor of 3 (clause 7.2.6), Importance factor of 1 (clause 7.2.3) and medium soil. Tube sections of 750×750×36 mm is utilized for columns, corner members, diagrids, and interior vertical members, while ISWB 400 beams are provided along the perimeter and ISWB 350 beams for internal spans. Adopting identical member sections across all heights isolates the influence of parameter such as deflection, storey drift etc., by eliminating variations from re-optimization, ensuring that the differences in base shear, deflection, and bending moment are solely due to the study parameters. Yet this simplification does not reflect actual design practice, where member sections are typically varied along the building height according to gravity, seismic, strength, and serviceability requirements. The diagrid configuration employed in the analysis is based on a 3-storey module. Figure 2 shows a schematic representation of the 3-storey diagrid module.

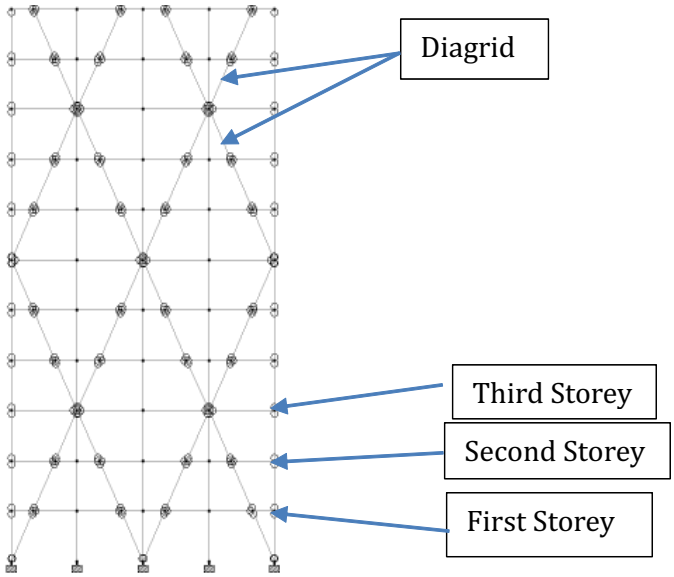



Fig. 2. Schematic representation of the 3-storey diagrid

The vertical distance covered by one repeating triangular pattern is called a storey module. A 3-storey diagrid module in which each diagrid diagonal member extends over three floors was adopted for all analytical models, resulting in a diagrid inclination angle of approximately 64.54°. From the previous study and analysis of diagrid steel structure among 2-storey module, 3-storey module and 4-storey modules, the 3-storey module showed better seismic performance than others. This angle was maintained constant throughout the study to ensure a consistent basis for comparing the influence of vertical and horizontal aspect ratios on structural behavior. Consequently, a parametric investigation of different diagrid angles was not included within the scope of the present research.

Modal analysis was performed considering the first ten vibration modes to capture the dynamic characteristics of the structures. A damping ratio of 5% was adopted for all models, consistent with the recommendations of IS 1893 (Part 1): 2016 for steel structures. The modal responses were combined using the Square Root of Sum of Squares (SRSS) method. All column bases were assumed to be fixed, which represents fully restrained support conditions. The response spectrum analysis was performed considering the combined contribution of all extracted modes.

To ensure a consistent basis for comparison among the analytical models, identical member sections were adopted for all conventional and diagrid steel structures considered in the study. This approach was intentionally selected to isolate the influence of vertical aspect ratio, horizontal aspect ratio, and structural configuration on the seismic response of the structures. The primary objective of the investigation was to perform a comparative parametric assessment of different geometric configurations rather than a detailed design optimization of individual buildings.

Therefore, the variation of member sizes with building height and performance-based member design was not included within the scope of the present study.

### 5.1. Aspect Ratio

Horizontal Aspect ratios and Vertical Aspect ratios for 10-, 12-, 14-, 16-, 18- & 20-storeys were considered and their influence on the behaviour of the conventional and diagrid steel buildings for 3 storey module buildings is compared. The vertical aspect ratio (VAR) represents the ratio of building height to base dimension and is varied by changing the number of storeys from 10 to 20, resulting in values from 1.75 to 3.5. (For example, a 10-storey VAR has a height of 10 m×3.5 m = 35 m and building width of 20 m. Therefore, the VAR is = 35/20 =1.75) The horizontal aspect ratio (HAR) represents the plan geometry defined by bay configurations ranging from 4×4 to 4×8, corresponding to values from 1.0 to 2.0. (For example, a building dimension 4 bay x 4 bay each of 5 m is 20×20 m, therefore HAR = 20/20 =1 and for 4 bay×5 bay each of 5 m is 25×20 m, therefore HAR = 25/20 =1.25). These variations were selected to study the influence of building slenderness and plan elongation on structural response. The vertical and horizontal aspect ratios are as given in Table 1 and Table 2 respectively.

Table 1. Vertical aspect ratio

| Vertical Aspect Ratios | VAR- 1.75 | VAR- 2.1 | VAR- 2.45 | VAR- 2.8 | VAR- 3.15 | VAR- 3.5 |
|---|---|---|---|---|---|---|
| | 10 Storey | 12 Storey | 14 Storey | 16 Storey | 18 Storey | 20 Storey |

Table 2. Horizontal aspect ratio

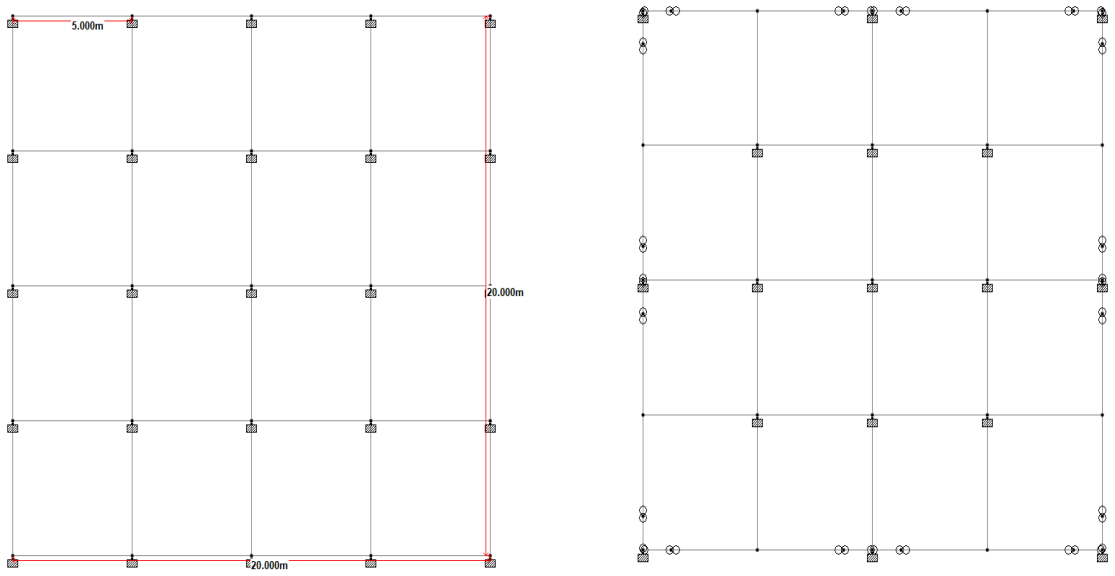
| Horizontal Aspect Ratios | HAR- 1.0 | HAR- 1.25 | HAR- 1.5 | HAR- 1.75 | HAR- 2.0 |
|---|---|---|---|---|---|
| | (4 × 4 Bays) | (4 x 5 Bays) | (4 x 6 Bays) | (4 x 7 Bays) | (4 x 8 Bays) |

In total, 30 building models were analyzed in X and Y for conventional steel buildings and total 30 building models were analyzed in X and Y for 3-storey module diagrid steel buildings. The analysis was carried out using STAAD.Pro CONNECT Edition. Figure 3(a) and 3(b) show the plan views of conventional and diagrid steel structures. Figure 4(a) and 4(b) show elevation views and Figure 5(a) and 5(b) show 3D views of conventional and diagrid structures.

## 6. Modelling of Structure Using STAAD.Pro CONNECT Edition

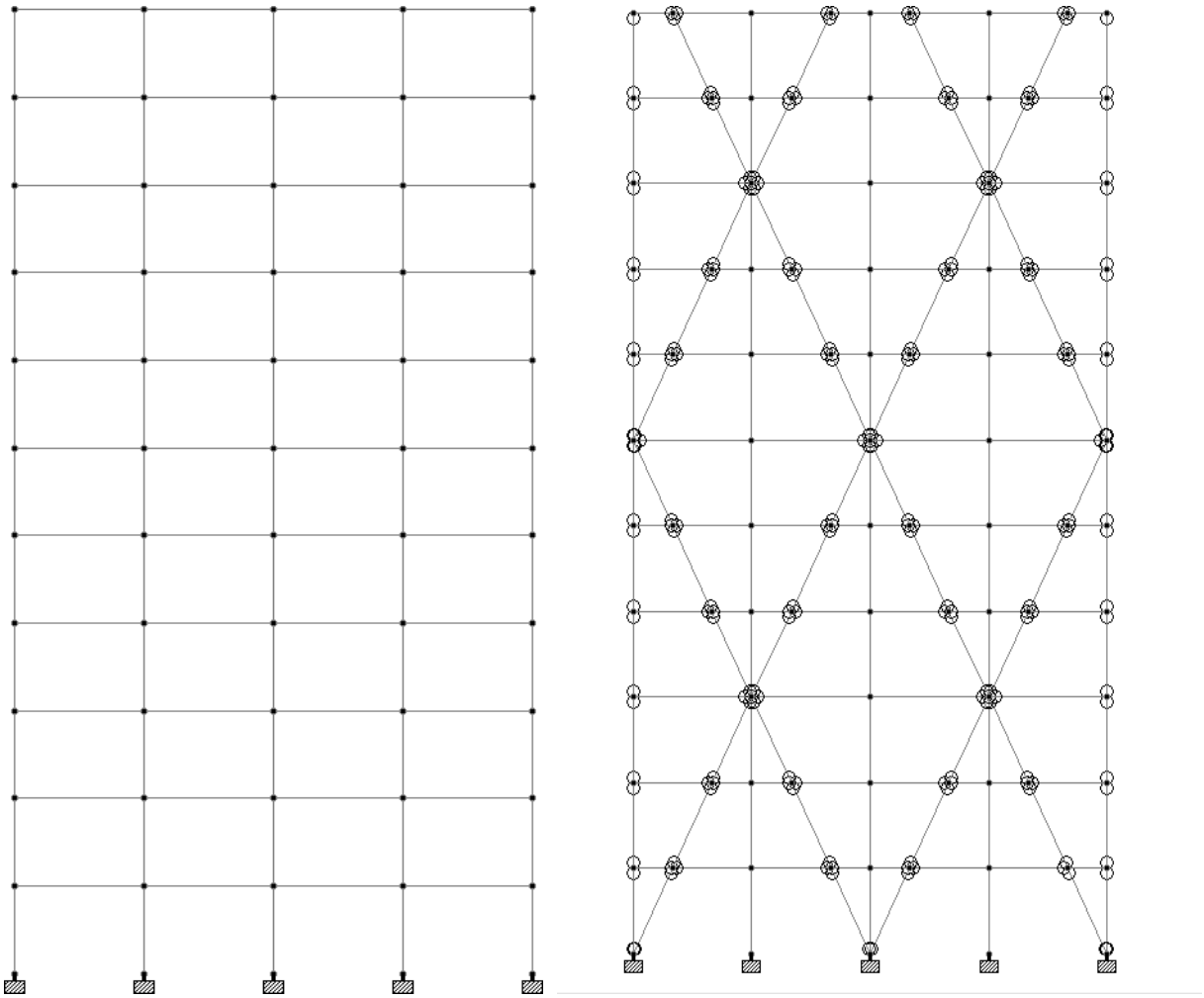
The comparison was carried out using the results obtained from the Response Spectrum Analysis (RSA), performed in STAAD.Pro CONNECT Edition. RSA is a linear elastic analysis procedure widely adopted in code-based seismic design due to its computational efficiency and its established acceptance in practice. RSA presumes linear-elastic behavior and approximates inelasticity only via the R- factor, yielding elastic demands rather than actual inelastic redistributions, while its smoothed spectrum and statistical modal combination (SRSS/CQC) overlook time- domain effects. Analytical models were developed and analyzed using STAAD.Pro CONNECT Edition (Bentley Systems, USA), Student Version. Mode 1 corresponds to the natural period used in seismic design and governs the overall lateral response of the structure whereas higher modes describe local deformation and complex shapes. The seismic parameters like Time period, frequency, displacement, bending moment, have been studied for mode shape-1 with varying horizontal and vertical aspect ratios.

MC_X denotes the conventional steel building model in the X direction, whereas MD_X denotes the diagrid steel building model in the X direction. Similarly, MC_Y and MD_Y represent the conventional and diagrid steel building models in the Y direction, respectively. Throughout the study, the term aspect ratio refers to the horizontal aspect ratio (HAR), whereas the term slenderness ratio refers to the vertical aspect ratio (VAR).



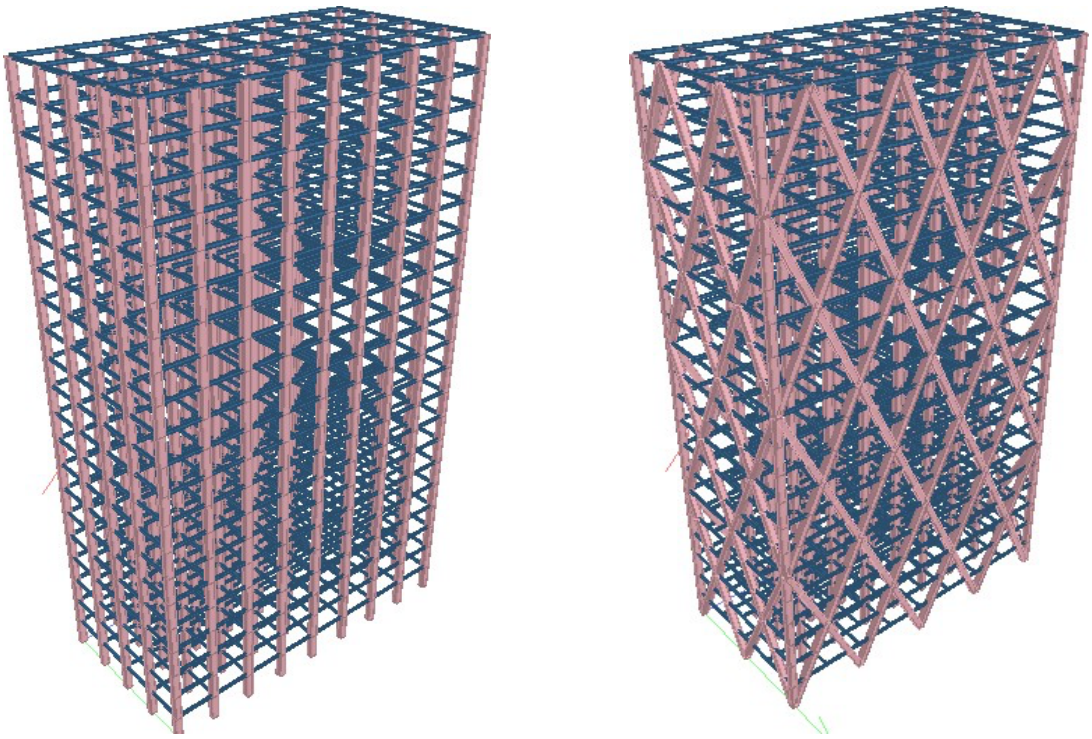

(a) (b)

Fig. 3. Plan of (a) Conventional and (b) Diagrid Steel Building



(a) (b)

Fig. 4. Elevation view of 10 storey (a) Conventional and (b) Diagrid Steel Building



(a) (b)

Fig. 5. STAAD.Pro model of 20 storey (a) Conventional and (b) Diagrid Steel Building

## 7. Results and Discussion

### 7.1 Natural Time Period

The comparison of fundamental time periods between conventional steel structure and the diagrid steel structure, as shown in Figure 6(a-e), demonstrates a clear and consistent trend across all slenderness ratios and horizontal aspect ratios.

In conventional moment-resisting frames, seismic forces are resisted primarily through beam-column flexural action, resulting in comparatively lower lateral stiffness. In contrast, the triangulated configuration of the diagrid system enables the inclined members to resist a significant portion of the lateral load through axial tension and compression. The fundamental time period, governed by lateral stiffness, is shorter in diagrid systems than in conventional moment frames because the axial tension/compression in their inclined members yields considerably less deformation than the flexural beam-column action of frames, thereby increasing stiffness.

In the X direction, the diagrid system shows percentage reduction is relatively small at lower slenderness ratios but increases steadily with height when compared with the conventional moment resisting frame. At a slenderness ratio of 1.75, the reduction in time period generally lies in the range of 2.24% to 9.02% depending on the aspect ratio. As the slenderness ratio increases to 3.5, the reduction becomes significant, typically ranging from 26.61% to 27.58%. This monotonic increase in percentage reduction indicates that the diagrid system becomes progressively more effective in enhancing the lateral stiffness in the X direction.

In the Y direction, the comparison between the conventional structure and the diagrid structure exhibits a different but systematic trend. For lower slenderness ratios (1.75 to 2.1), the diagrid structure generally shows a marginal increase in time period, with percentage increases typically ranging 0% to 11.29% especially for higher horizontal aspect ratios. This indicates slightly higher flexibility of the diagrid system in the Y direction at lower heights. However, as the slenderness ratio increases (≥ 3.15), the increase in time period is generally limited to 4.28%, and in some cases the values become nearly comparable.

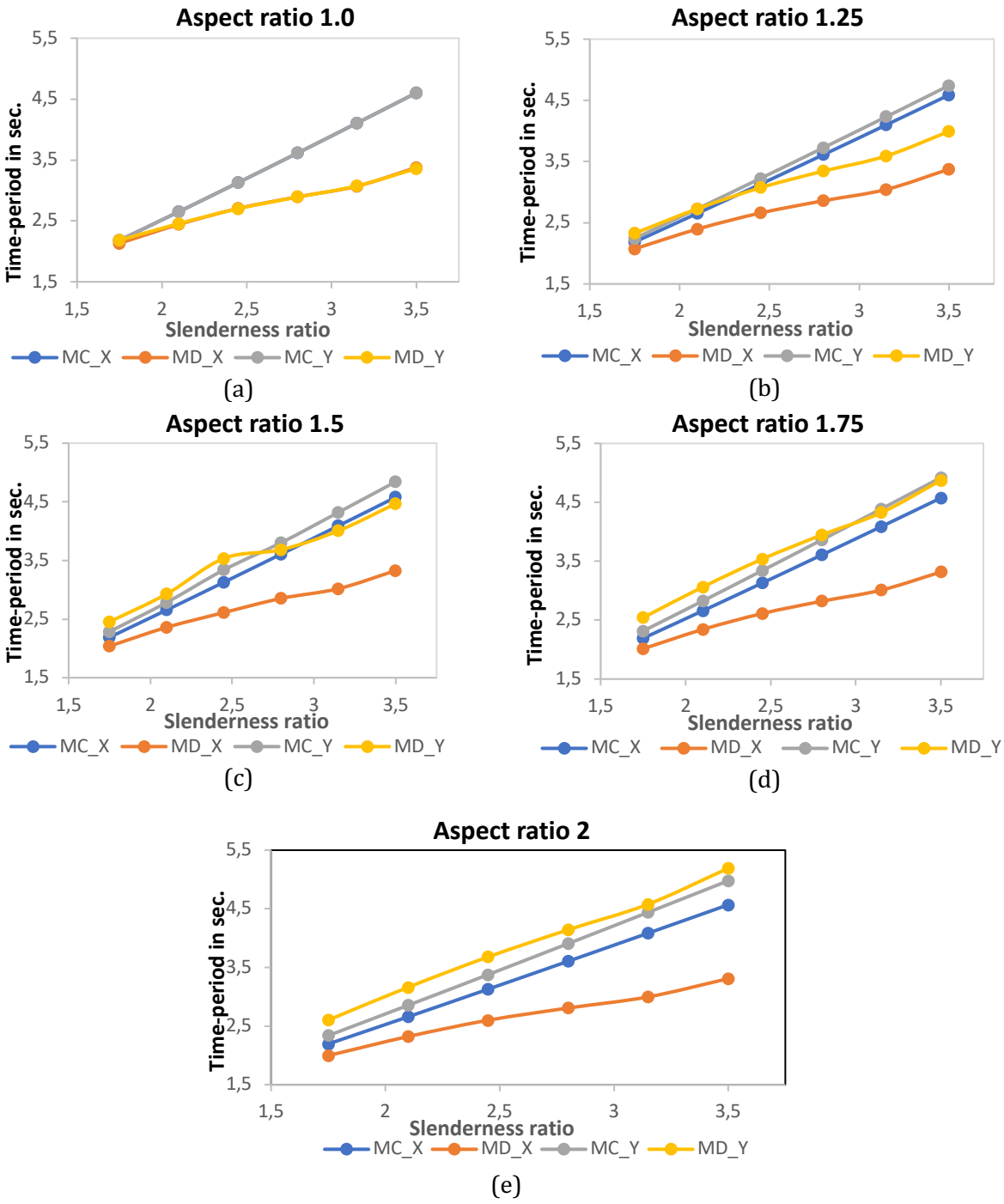



Fig. 6. Fundamental time period variation with slenderness ratio and aspect ratio (a) 20 m x 20 m in plan (b) 20 m x 25 m in plan (c) 20 m x 30 m in plan (d) 20 m x 35 m in plan (e) 20 m x 40 m in plan

### 7.2 Frequency

In general, the natural frequency of a structure, as shown in Figure 7(a–e), is inversely proportional to its fundamental time period. The higher natural frequencies observed in the diagrid structures indicate an increase in global lateral stiffness. This improvement is primarily attributed to the triangulated configuration of the inclined perimeter members, which provides an efficient load-transfer mechanism by resisting seismic forces predominantly through axial tension and compression. Consequently, lateral deformation is reduced, and the overall structural rigidity is enhanced. The fundamental natural frequency of a structure is governed by the following relationship:

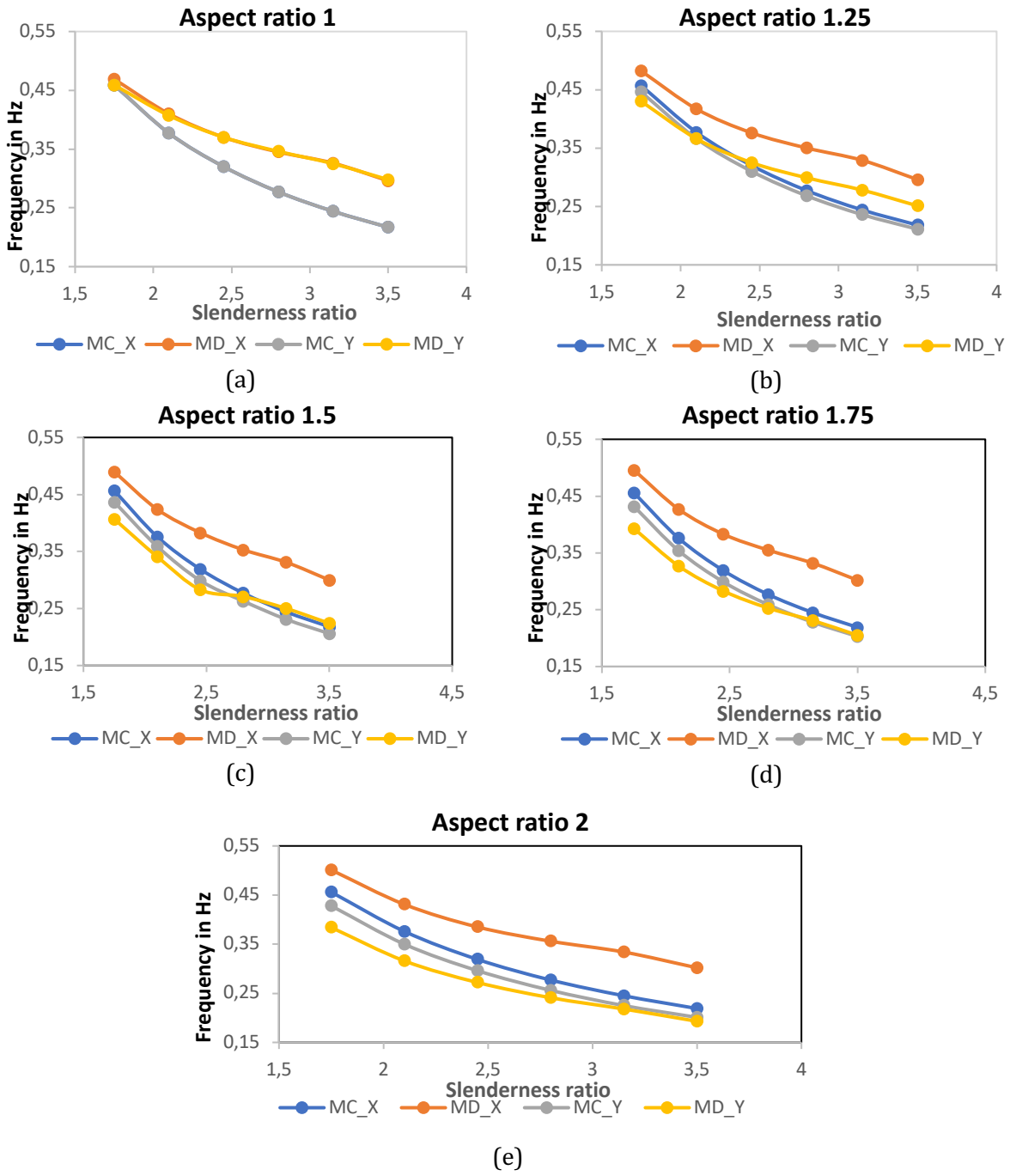



Fig. 7. Natural frequency variation with slenderness ratio and Horizontal aspect ratio for mode shape 1 (a) 20 m x 20 m in plan (b) 20 m x 25 m in plan (c) 20 m x 30 m in plan (d) 20 m x 35 m in plan (e) 20 m x 40 m in plan

$$f_n = \frac{1}{2\pi}\sqrt{\frac{k}{m}} \tag{1}$$

Where; $f_n$ = natural frequency (Hz), k = equivalent lateral stiffness (N/m), and m = generalized mass (kg).

Since all analytical models considered in this study possess nearly identical material properties and comparable mass distributions, the increase in equivalent lateral stiffness provided by the diagrid system results in an increase in the natural frequency. Correspondingly, the fundamental time period decreases according to

$$T = \frac{1}{f_n} = 2\pi\sqrt{\frac{m}{k}} \tag{2}$$

Thus, the higher natural frequencies observed in the diagrid structures indicate greater lateral stiffness and improved resistance to seismic-induced deformation.

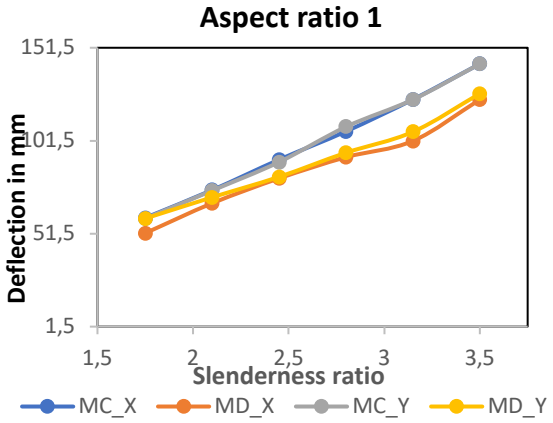
Therefore, the observed reduction in the fundamental time period corresponds to an increase in natural frequency, indicating a stiffer structural response compared with the conventional moment resisting frame in the X direction. Conversely, in the Y direction, the marginal increase in time period at lower slenderness ratios implies a slight reduction in natural frequency, indicating comparatively higher flexibility in that direction. However, at higher slenderness ratios where the fundamental time period of conventional and diagrid systems becomes nearly comparable, the corresponding natural frequencies also converge.

### 7.3 Structure Deflection

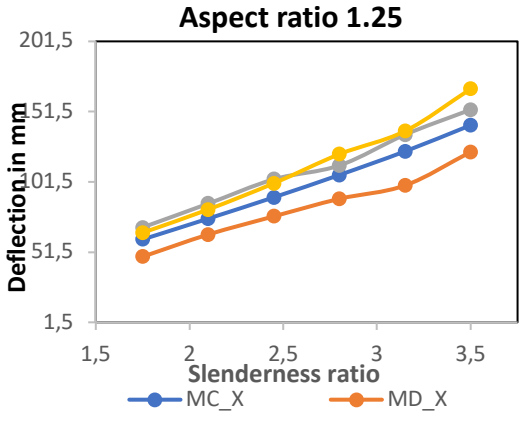
The deflection response of diagrid steel structures, as shown in Figure 8(a-e), in comparison with conventional moment resisting steel frames exhibits a clear dependence on both slenderness ratio and horizontal aspect ratio, with distinct directional behavior. The reduction in lateral displacement is primarily attributed to the axial-force resisting mechanism of the diagrid members. Under seismic loading, the inclined members develop alternating tension and compression, allowing a substantial portion of the lateral force to be transferred through axial action rather than beam-column bending. This efficient load-transfer mechanism significantly increases the global stiffness of the structure and reduces lateral sway, particularly in taller buildings where lateral deformation becomes more critical.

In the X direction, the diagrid system shows a significant reduction in lateral deflection relative to conventional systems. At a lower slenderness ratio (1.75 to 2.1), the percentage reduction is found to be substantial, ranging from 15% to 29.10%. As the slenderness ratio increases up to 3.5, the reduction in deflection is found to be less than 13 % to 19 % compared with the conventional steel structure. As the slenderness ratio increases, the height-to-base ratio of the building becomes larger, making the structure more susceptible to lateral deformation. Consequently, the contribution of the diagrid system becomes increasingly significant because the triangulated members provide additional lateral stiffness that effectively controls sway in slender buildings.

In the Y direction, for aspect ratio close to unity, and lower slenderness ratio, the diagrid system shows deflection values 2 % to 14 % which is slightly lower than those of conventional steel structure. However, as the horizontal aspect ratio increases beyond 1.25, the diagrid structure begins to exhibit higher deflections, particularly at higher slenderness ratios, by 9.6 % to 59.38 % compared with the conventional steel building. The comparatively higher displacement observed in the Y direction at larger aspect ratios can be attributed to the reduction in effective structural depth in that direction. As the plan becomes more elongated, stiffness becomes direction-dependent, reducing the efficiency of the diagrid system in resisting lateral loads along the narrower direction.




(a)




(b)

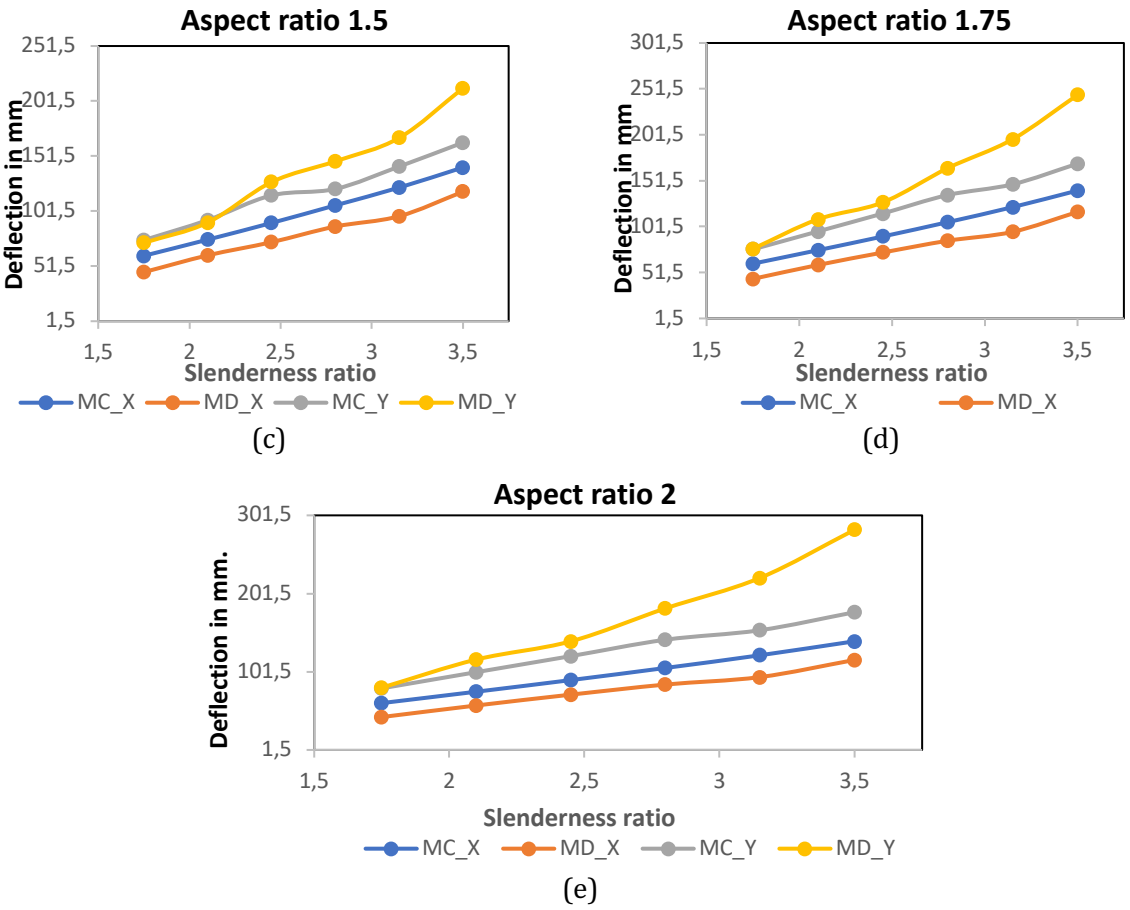
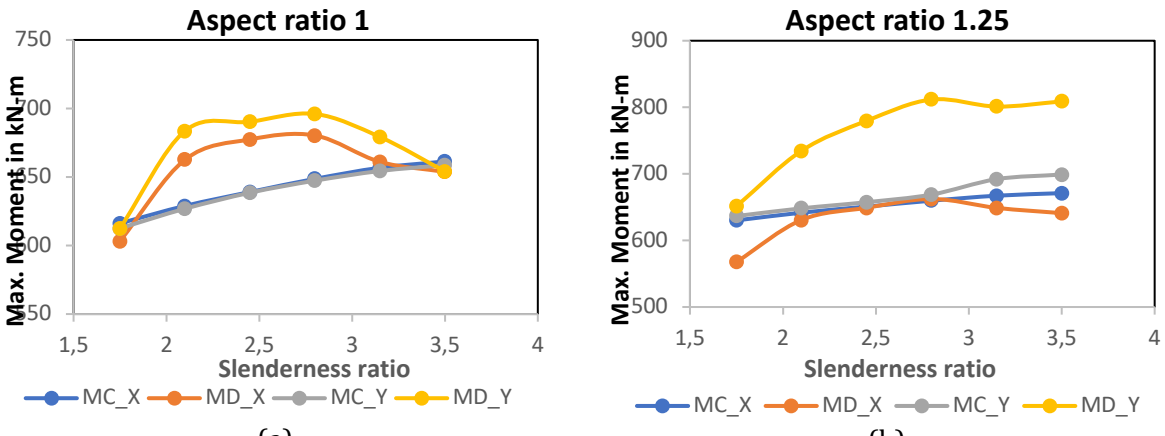



Fig. 8. Maximum lateral deflection variation with slenderness ratio and horizontal aspect ratio for mode shape 1. (a) 20 m x 20 m in plan (b) 20 m x 25 m in plan (c) 20 m x 30 m in plan (d) 20 m x 35 m in plan (e) 20 m x 40 m in plan

### 7.4 Maximum Bending Moment

As shown in Figure 9(a-e), in the X direction, the diagrid system generally exhibits lower bending moments than conventional steel structural systems, particularly as the horizontal aspect ratio increases. For horizontal aspect ratio of 1.0, the difference in bending moment is relatively small and in some intermediate slenderness ratios (2.1 to 2.8), the diagrid system even shows marginally higher moments. However, as the horizontal aspect ratio increases from 1.25 to 2.0, the diagrid system consistently shows a reduction in bending moment ranging from 2.10 % to 20.68 % at higher slenderness ratio. The reduction in bending moment is associated with the change in the internal force-resisting mechanism introduced by the diagrid system. Unlike conventional frames, where beams and columns resist seismic forces mainly through flexure, the inclined diagrid members transfer a considerable portion of the lateral load through axial tension and compression. Consequently, bending demands on the primary framing members are reduced, resulting in improved structural efficiency and better utilization of steel.

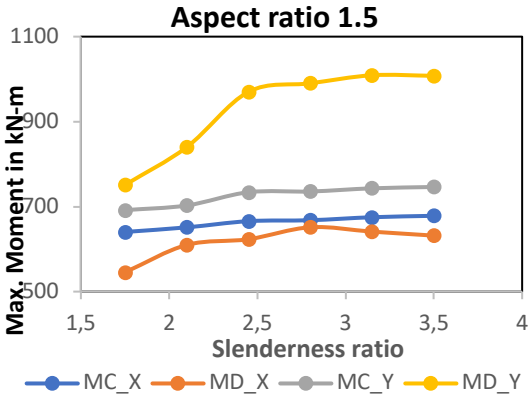
In the Y direction, the bending moment for diagrid structure increased from 2.31 % to 61.15 % compared with the conventional steel structure and this increase becomes more pronounced with both increasing slenderness ratio and horizontal aspect ratio. The increase in bending moment observed in the Y direction for larger aspect ratios indicates that the structural stiffness becomes less uniform as the building plan becomes increasingly elongated. Under these conditions, a greater proportion of the seismic load is resisted through flexural action, resulting in higher bending moments despite the presence of the diagrid system.



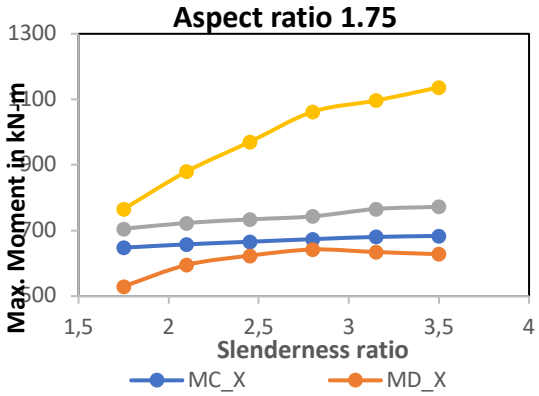

(a)



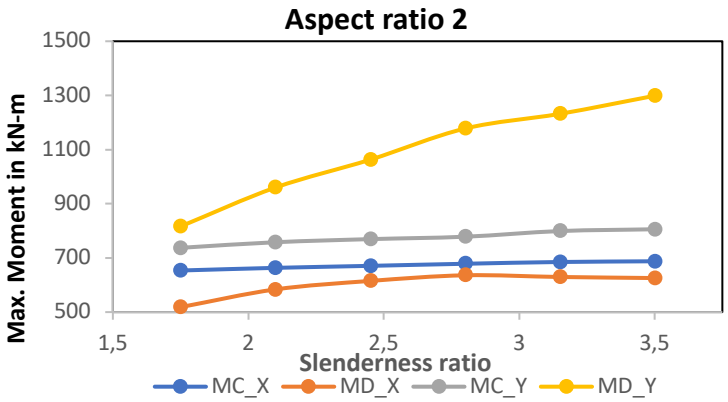

(b)




(c)




(d)




(e)

Fig. 9. Maximum bending moment variation with slenderness ratio and horizontal aspect ratio for mode shape 1. (a) 20 m x 20 m in plan (b) 20 m x 25 m in plan (c) 20 m x 30 m in plan (d) 20 m x 35 m in plan (e) 20 m x 40 m in plan

Table 3. Summary of structural performance comparison between conventional and diagrid steel structures for varying slenderness ratios and horizontal aspect ratios

| Parameter | Direction | Percentage Change (Diagrid vs Conventional) | Key Finding |
|---|---|---|---|
| Fundamental Time Period | X | Reduction of 2.24–27.58% | Diagrid exhibits higher lateral stiffness, especially at higher slenderness ratios. |
| Fundamental Time Period | Y | Increase of 0–11.29% | Diagrid is slightly more flexible at lower heights. |

| Parameter | Direction | Percentage Change (Diagrid vs Conventional) | Key Finding |
|---|---|---|---|
| Natural Frequency | X | Increase in natural frequency corresponding to reduction in time period | Higher natural frequency indicates improved stiffness. |
| Natural Frequency | Y | Slight decrease at low slenderness ratios; comparable at high SR | Dynamic characteristics converge at higher slenderness ratios. |
| Maximum Deflection | X | Reduction of 19–29.10% | Diagrid effectively controls lateral deflection. |
| Maximum Deflection | Y | Reduction of 14% or increase of 59% | Behavior depends on HAR and slenderness ratio. |
| Bending Moment | X | Reduction of up to 31% | Diagrid reduces bending demand, particularly at higher HAR. |
| Bending Moment | Y | Increase of 61% | Bending moment increases with HAR and slenderness ratio. |

## 8. Conclusions

The comparison was carried out between the 3-storey module diagrid structure and the conventional moment resisting structure.

- In the X direction, with increasing horizontal aspect ratio the diagrid system exhibits consistently higher lateral stiffness than the conventional frame, evidenced by a progressive reduction in the fundamental time with increasing slenderness ratio.
- The Reduction in the fundamental time period in X direction is limited to 9 percent at lower slenderness ratios, it becomes substantial for taller and more slender buildings, up to 27 percent at higher slenderness ratio compared with lower slenderness ratios.
- In the Y direction, of a constant building depth, the diagrid system shows marginal increases in time period by 11 percent at lower slenderness ratios, particularly for higher horizontal aspect ratios, indicating minor flexibility at lower heights.
- As the slenderness ratio increases, in Y direction the time period difference reduces significantly. At higher slenderness ratios, the diagrid structure exhibits stable and balanced dynamic performance.
- Natural frequency is inversely proportional to the fundamental time period. In X direction increase in natural frequency indicates stiffer response of diagrid structure compared to conventional frame,
- In Y direction, at lower slenderness ratios slightly reduced natural frequency indicates higher flexibility, while at higher slenderness ratios the convergence of time periods signifies comparable natural frequencies and similar dynamic behavior of both systems.
- In X direction, the diagrid system exhibits substantial reductions in lateral deflection of 29 Percent at lower slenderness ratio and the percentage reduction decreases up to 19 percent with increase in slenderness ratio and aspect ratio.
- In Y direction diagrid system exhibits marginally lower deflections of 14 percent at lower slenderness and aspect ratio whereas it exhibits slightly higher deflection of 59 percent at higher slenderness ratio and aspect ratio
- In the X direction, the diagrid system generally develops lower bending moments which is up to 21 percent compared to conventional steel frame, with the reduction becoming more pronounced as the horizontal aspect ratio increases.
- In the Y direction, the diagrid structure exhibits slightly higher bending moments than the conventional system and this amplification intensifies with both increasing slenderness ratio and horizontal aspect ratio which may be up to 61 percent.

- The fundamental time period increases consistently and non-linearly with increasing slenderness ratio, the increase is gradual at low slenderness and steepens at higher values. For a fixed slenderness ratio, the time period also increases as the plan aspect ratio increases, from 20 m × 20m to 20 m × 40 m since elongating the plan adds mass without adding stiffness in the governing direction. Beyond a slenderness ratio of about 3.0, the period elongates rapidly, so this range should be treated as a design threshold rather than a straightforward extrapolation.
- Frequency shows the inverse trend to time period, decreasing sharply at low slenderness ratios and flattening out at higher values. Frequency also reduces as plan aspect ratio increases, confirming that more slender, more elongated structures become dynamically softer, with fundamental mode shifting to lower frequencies. As the frequency drops, the structure moves closer to the low frequency band where resonance and human perceptibility of motion become governing rather than strength.
- Lateral deflection increases markedly with slenderness ratio, and the rate of increase in deflection accelerates at higher slenderness ratio. Deflection also increases with aspect ratio as elongating the plan adds mass without adding stiffness in the governing direction, so the structure sways more for the same slenderness ratio. Lateral deflection governs serviceability well before strength becomes critical, particularly for the 20 × 40 m plan, where deflection nearly doubles that of the 20 × 20 m plan at the same slenderness ratio.
- The bending moment generally rises with increasing slenderness ratio due to the larger overturning lever arm and higher modal mass participation in taller structures, and it also rises with increasing aspect ratio because of the greater tributary mass and lateral load carried by a base of unchanged critical width. The slight reduction seen for squarish plans at high slenderness suggests a shift in modal mass participation (higher modes contributing more to base demand), while the steadily rising moment for elongated plans indicate the base and foundation must be sized for demand that keeps growing with both height and plan elongation.
- The slenderness ratio 3.0 and aspect ratio 1.5 will be the threshold value, below these values strength typically governs, above them serviceability increasingly govern the design.

From a practical design perspective, the findings of this study indicate that 3-storey module diagrid systems can be considered an effective alternative to conventional steel moment-resisting frames for medium- to high-rise buildings located in seismic regions. The improved lateral stiffness and reduced lateral displacement observed in the diagrid structures suggest that appropriate selection of building slenderness ratio and horizontal aspect ratio during the preliminary design stage can significantly enhance seismic performance. The results presented in this study may assist structural engineers in selecting suitable structural configurations during the conceptual design phase, thereby improving structural efficiency while maintaining satisfactory seismic performance. Overall, the results indicate that selecting appropriately proportioned diagrid systems can significantly enhance seismic performance, improve lateral stiffness, and provide more efficient structural behavior than conventional steel moment-resisting frames.

## 9. Future Scope

- Future studies may incorporate nonlinear seismic assessment methods, such as nonlinear time history analysis and pushover analysis, to evaluate the inelastic behaviour and performance of diagrid structures under strong earthquake excitations.
- The present study uses uniform member sections for direct comparison among structural systems and aspect ratios. Future research may adopt performance-based and code-compliant member design procedures to evaluate seismic behaviour under realistic design conditions.
- Further investigations may focus on the influence of diagrid inclination angles, module configurations, and higher-mode effects to identify optimal geometric arrangements and improve the seismic performance of diagrid steel structures.

- Experimental validation and analysis under different seismic zones, soil conditions, and earthquake records may also be carried out to enhance the applicability and reliability of the findings.

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