Analysis of Diaphragm Effect on Space Framed Structures

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***Abstract*—Diaphragm action is a critical mechanism controlling the seismic and wind response of steel buildings, long-span roof systems and space-framed structures. In conventional steel buildings, floor and roof diaphragms are generally treated as rigid, flexible or semi-rigid horizontal systems that collect lateral forces and transfer them to vertical lateral-load-resisting elements. However, in steel space framed structures, the interaction between three-dimensional member action and diaphragm stiffness is more complex because load transfer is distributed through interconnected members rather than through planar frames alone. This review critically synthesizes literature related to diaphragm behaviour, steel space frame action, conventional steel framing, seismic response parameters and numerical modelling assumptions. The paper highlights that rigid diaphragm assumptions may simplify design but can misrepresent actual behaviour in large-span, irregular or flexible roof/floor systems. Flexible and semi-rigid diaphragm modelling improves realism but requires careful definition of in-plane stiffness, joint connectivity and load-transfer paths. The review identifies gaps in comparative studies between steel space frames and conventional steel structures, limited validation of semi-rigid diaphragm models, and insufficient design-oriented guidance for large-span steel systems. Future work should integrate finite element validation, diaphragm stiffness calibration, nonlinear dynamic analysis and practical design recommendations for robust seismic performance of steel space-frame systems.**

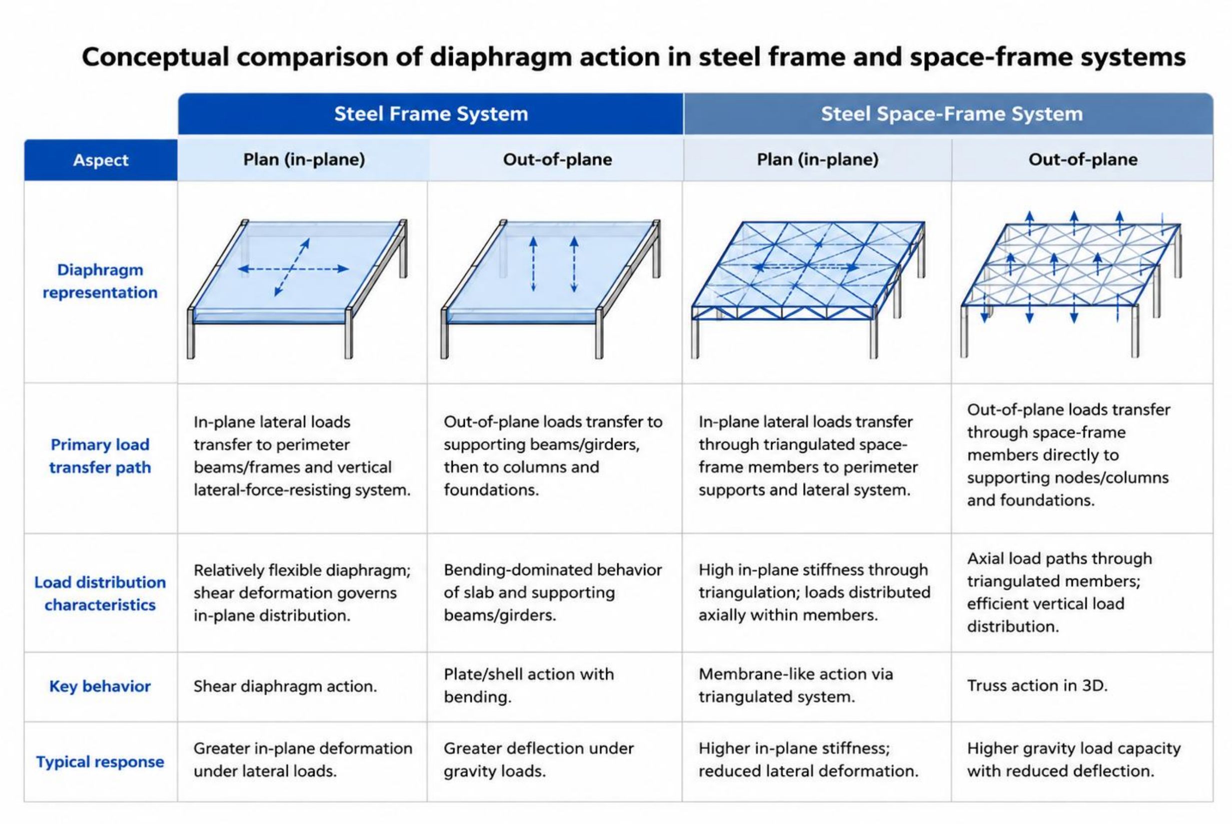
***Index Terms*— steel space frame; diaphragm action; rigid diaphragm; flexible diaphragm; semi-rigid diaphragm; seismic analysis; conventional steel structure; lateral load resisting system; finite element modelling; STAAD. Ro.**

I. INTRODUCTION

Steel structures are widely adopted in industrial buildings, commercial facilities, auditoriums, stadium roofs and long-span structures because of their high strength-to-weight ratio, constructability and capacity for modular fabrication. Space framed steel structures differ from conventional steel frames because their members form three-dimensional grids capable of distributing load through multiple interconnected paths. This load-sharing advantage improves redundancy and stiffness efficiency, but it also complicates seismic and wind response prediction when floor or roof diaphragm action is introduced.

A diaphragm is a horizontal or nearly horizontal structural system that transfers lateral loads generated by earthquake or wind actions to vertical resisting systems such as braced frames, moment frames, shear walls or columns. In conventional steel buildings, the diaphragm assumption strongly influences lateral force distribution, torsional response, displacement and member force demand. In steel space frame systems, diaphragm action may either improve global stability by tying the structure together or alter internal force distribution due to the spatial stiffness already provided by the frame.

The title selected for this review, "Comparative Analysis of Diaphragm Effect on Steel Space Framed Structures with Conventional Steel Structure", therefore requires a critical evaluation of diaphragm assumptions, modelling techniques, seismic response parameters and research gaps. The focus of the paper is not a single case-study result but a broader review of how diaphragm effects have been investigated and how future analytical frameworks should compare space-framed and conventional steel structures.



Conceptual comparison of diaphragm action in steel frame and space-frame systems

	Steel Frame System		Steel Space-Frame System	
Aspect	Plan (in-plane)	Out-of-plane	Plan (in-plane)	Out-of-plane
Diaphragm representation				
Primary load transfer path	In-plane lateral loads transfer to perimeter beams/frames and vertical lateral-force-resisting system.	Out-of-plane loads transfer to supporting beams/girders, then to columns and foundations.	In-plane lateral loads transfer through triangulated space-frame members to perimeter supports and lateral system.	Out-of-plane loads transfer through space-frame members directly to supporting nodes/columns and foundations.
Load distribution characteristics	Relatively flexible diaphragm; shear deformation governs in-plane distribution.	Bending-dominated behavior of slab and supporting beams/girders.	High in-plane stiffness through triangulation; loads distributed axially within members.	Axial load paths through triangulated members; efficient vertical load distribution.
Key behavior	Shear diaphragm action.	Plate/shell action with bending.	Membrane-like action via triangulated system.	Truss action in 3D.
Typical response	Greater in-plane deformation under lateral loads.	Greater deflection under gravity loads.	Higher in-plane stiffness; reduced lateral deformation.	Higher gravity load capacity with reduced deflection.

Fig. 1. Conceptual load-transfer mechanism of diaphragm action in steel frame and space-frame systems. Source: Authors' schematic based on diaphragm mechanics discussed in FEMA P-1026 and recent diaphragm-flexibility literature [1], [2].

II. NEED AND SIGNIFICANCE OF THE REVIEW

The need for this review arises from the gap between common design assumptions and the actual behaviour of steel structures with spatially distributed stiffness. Many building analyses adopt idealized rigid diaphragms because they reduce computational complexity and simplify lateral force distribution. However, diaphragm flexibility can significantly modify fundamental period, displacement pattern, inter-storey drift and torsional effects, especially in low-rise buildings, long-span roofs and irregular structures. Huang et al. reported that flexible diaphragm effects become more significant for buildings with large plan aspect ratios and low heights, demonstrating the limitations of routine rigid diaphragm modelling [2].

For conventional steel frames, diaphragm action has been studied in relation to lateral load transfer, stiffness distribution and seismic force demand. In space-framed steel structures, however, diaphragm behaviour remains less standardized because the roof/floor system interacts with a three-dimensional grid rather than a two-dimensional frame line. This makes comparative review essential for identifying whether diaphragm action produces consistent improvements in displacement control, drift reduction, force redistribution and torsion resistance across different steel structural forms.

III. REVIEW METHODOLOGY

The review was prepared using a title-only thematic approach. The title was taken as the research boundary, and literature was classified according to the key technical concepts embedded in the title: diaphragm effect, steel space framed structures, conventional steel structures, lateral load behaviour, seismic response and numerical modelling. The review prioritizes peer-reviewed journal literature, design guidance and recent studies related to diaphragm flexibility and steel frame response.

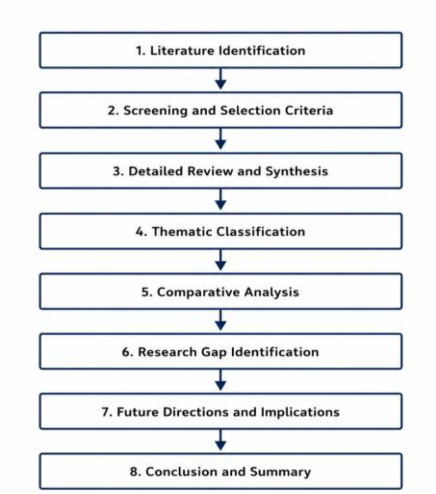


Fig. 2. Review methodology adopted for the title-only revision of the manuscript.

IV. LITERATURE SELECTION CRITERIA

Criterion	Included studies	Reason for inclusion
Structural system	Steel frames, space frames, long-span roof systems, steel/composite frame systems	Directly relevant to comparison between space-framed and conventional steel structures
Diaphragm behaviour	Rigid, flexible and semi-rigid diaphragms; diaphragm discontinuity; floor and roof diaphragm effects	Captures the central technical variable of the review
Loading condition	Seismic, wind and lateral load studies	Diaphragm action is most critical under horizontal loading
Analysis method	Finite element modelling, ETABS/STAAD/RAM/OpenSees-based studies, response spectrum and nonlinear analysis	Supports modelling-oriented review suitable for journal submission
Performance parameter	Displacement, drift, base shear, modal period, force distribution, torsion and energy dissipation	Provides measurable basis for comparative evaluation

V. THEMATIC CLASSIFICATION OF LITERATURE

Existing literature may be classified into six major themes: diaphragm flexibility, steel space-frame behaviour, conventional steel-frame response, lateral load transfer, seismic response parameters and numerical modelling. Thematic classification helps distinguish between studies that examine diaphragm action as a modelling assumption and those that examine it as a physical load-resisting mechanism.

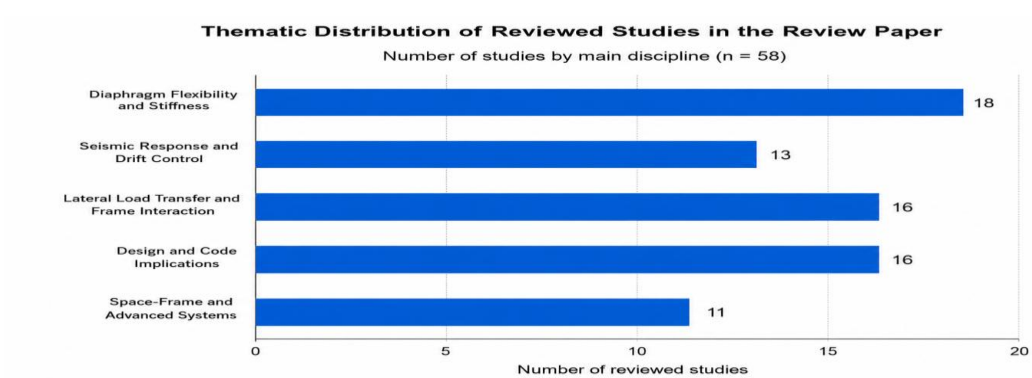


Fig. 3. Thematic classification of literature used in the review synthesis.

VI. DETAILED LITERATURE REVIEW

6.1 Diaphragm Action in Steel Structures
Diaphragm action allows floor and roof systems to act as horizontal load-collecting planes. These elements transfer wind and seismic loads to vertical load-resisting systems and help control structural deformation. FEMA P-1026 emphasizes that rigid-wall flexible-diaphragm buildings require special attention because diaphragm flexibility may dominate lateral response and force distribution [1]. Although the FEMA guide focuses primarily on a broader class of rigid-wall flexible-diaphragm buildings, the underlying principles are transferable to steel structures with flexible roof or deck systems.
The diaphragm may be idealized as rigid, flexible or semi-rigid. Rigid diaphragms assume negligible in-plane deformation and distribute lateral forces according to relative stiffness of vertical resisting elements. Flexible diaphragms distribute forces mainly according to tributary mass or area and may show higher in-plane deformation. Semi-rigid diaphragms capture intermediate behaviour and are generally more realistic for steel deck, composite slab and long-span roof systems.

6.2 Steel Space Framed Structures
Steel space frames are three-dimensional structural systems formed by interconnected members arranged to resist loads through axial force, bending and torsion. Their primary advantage is multi-directional load transfer, which reduces localized force concentration and improves redundancy. However, this same three-dimensional behaviour makes diaphragm interaction more complex than in planar conventional steel frames. When diaphragm action is introduced into a space frame, the diaphragm can restrain relative in-plane movement, redistribute lateral forces and modify modal characteristics.
Studies on steel space roof systems have shown that roof diaphragm action affects seismic behaviour of hall-type structures, particularly when roof stiffness, support conditions, member layout and modulation geometry vary [3]. This is important because large-span steel roof systems may be flexible in-plane and cannot always be treated as perfectly rigid diaphragms.

6.3 Conventional Steel Structures and Diaphragm Assumptions
Conventional steel structures generally consist of beams and columns arranged in orthogonal bays, with lateral resistance provided by moment frames, braced frames or dual systems. In such systems, diaphragm action is often assumed to ensure compatibility of lateral displacement at a given floor level. The rigid diaphragm assumption is computationally convenient, but it may overestimate uniformity of force transfer when the floor system is flexible or discontinuous.
In tall or irregular buildings, floor diaphragm flexibility may influence torsion and dynamic response. Research on diaphragm flexibility in asymmetric-plan structures shows that the effect of diaphragm flexibility depends on stiffness distribution, yielding level and the degree of diaphragm flexibility [4]. This demonstrates that diaphragm assumptions must be selected based on actual structural characteristics rather than convenience alone.

6.4 Diaphragm Flexibility and Seismic Response
Diaphragm flexibility affects fundamental period, top displacement, inter-storey drift and base shear. Huang et al. developed a simplified method for evaluating diaphragm flexibility in frame-shear wall structures and reported that flexible diaphragm models can produce considerably larger displacement and drift responses in low-rise structures with large aspect ratios [2]. Although this study was not limited to steel space frames, its findings are valuable because they demonstrate how diaphragm in-plane deformation can alter seismic response parameters.
The implication for steel space-framed structures is significant. If a space frame roof or floor is modelled as fully rigid when it is actually flexible, the analysis may underestimate drift concentration, local member force demand and torsional sensitivity. Conversely, ignoring useful diaphragm stiffness may overestimate lateral displacement and lead to conservative or uneconomical design.

6.5 Numerical and Finite Element Modelling Approaches
Numerical modelling of diaphragm action may be carried out using rigid diaphragm constraints, shell elements, membrane elements, equivalent bracing, semi-rigid springs or detailed finite element

discretization. For conventional steel buildings, rigid diaphragm constraints are often adequate when the floor slab is stiff and the plan is regular. For steel space frames and large-span roofs, shell or semi-rigid diaphragm modelling may provide better representation because it permits in-plane deformation and stress flow.

The selection of diaphragm model affects global response. Rigid constraints reduce degrees of freedom and enforce uniform in-plane displacement, while shell or membrane elements capture diaphragm shear deformation. Equivalent bracing models are useful for practical steel deck or roof diaphragm modelling but require stiffness calibration. Fully detailed FE models provide the most realistic representation but increase modelling effort and convergence complexity.

VII. COMPARATIVE ANALYSIS OF EXISTING STUDIES

Study / source	System studied	Method	Key finding	Relevance to present review
FEMA P-1026 [1]	Rigid-wall flexible-diaphragm buildings	Design guidance and analytical background	Flexible diaphragms require special seismic design attention	Provides theoretical basis for diaphragm flexibility
Huang et al. [2]	Frame-shear wall buildings	ETABS finite element models	Flexible diaphragm effects are stronger in low-rise structures and large aspect ratios	Shows limitations of rigid diaphragm assumption
Fenkli et al. [3]	Steel space roof hall structures	Numerical seismic analysis	Roof diaphragm effect depends on lateral stiffness, support and roof geometry	Directly relevant to steel space-frame systems
Eivani et al. [4]	Asymmetric-plan buildings	Numerical seismic assessment	Diaphragm flexibility affects response depending on asymmetry and yielding	Useful for torsion-sensitive steel buildings
Hadianfard and Sedaghat [5]	Braced steel buildings with flexible joist diaphragms	Nonlinear static and dynamic analysis	Ignoring diaphragm flexibility can be unsafe or uneconomical	Relevant to steel-frame seismic modelling
Tena-Colunga et al. [6]	Irregular buildings with slab systems	Dynamic property analysis	Rigid diaphragm assumption may not capture actual dynamic response	Supports realistic diaphragm modelling

VIII. COMPARATIVE BEHAVIOUR OF DIAPHRAGM MODELLING ASSUMPTIONS

The choice of diaphragm assumption has a direct influence on model behaviour. A no-diaphragm model permits independent frame movement and may exaggerate lateral flexibility. A flexible diaphragm model captures in-plane deformation but requires realistic stiffness estimation. A semi-rigid diaphragm model is often most suitable for long-span steel floors and roofs because it balances realism and computational practicality. A rigid diaphragm model is simple and often suitable for regular buildings with stiff floors, but it may be unsuitable for large-span space frames or flexible roof systems.

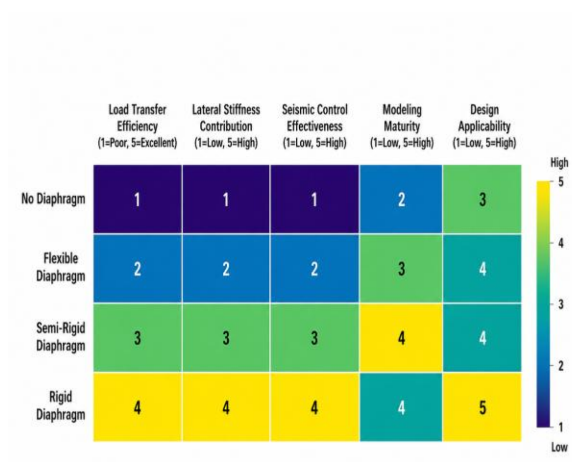


Fig. 4. Qualitative comparison of diaphragm modelling assumptions for steel frame and space-frame analysis. Scores are interpretive and based on synthesis of reviewed literature [1]-[6].

IX. RESEARCH TRENDS

- Movement from idealized rigid diaphragm assumptions toward semi-rigid and shell-based diaphragm modelling.
- Increasing focus on diaphragm flexibility in irregular, low-rise and large-aspect-ratio structures.
- Greater use of finite element modelling to capture in-plane shear deformation of floor and roof systems.
- Rising interest in steel space roofs, modular steel systems and composite floor diaphragms under seismic actions.
- Need for design-oriented simplification of detailed FE findings for routine structural engineering practice.

X. RESEARCH GAP

Although diaphragm action has been widely studied in conventional building systems, the comparative influence of diaphragm action on steel space framed structures and conventional steel structures remains insufficiently synthesized. Existing research often treats diaphragm action as a modelling assumption rather than as a physical mechanism interacting with the three-dimensional stiffness of space frames. The literature also lacks clear guidance for selecting rigid, flexible or semi-rigid diaphragm models for steel space frames under earthquake and wind loading.

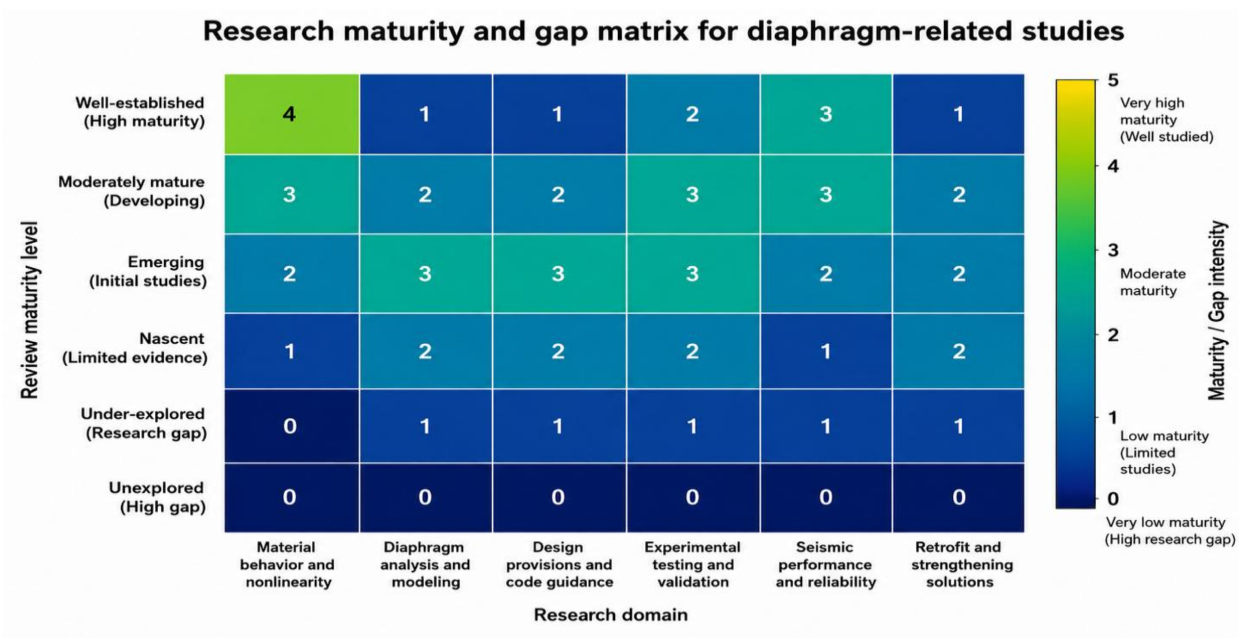


Fig. 5. Research maturity and gap matrix showing weaker evidence for steel space-frame-specific diaphragm studies.

- Limited direct comparative studies between steel space frames and conventional steel frames under identical diaphragm assumptions.
- Insufficient calibration of semi-rigid diaphragm stiffness for steel space roof and long-span systems.
- Limited validation of STAAD. Ro or FE models against experimental or field-monitored diaphragm behaviour.
- Inadequate understanding of diaphragm effects on torsion, member force redistribution and modal characteristics in space frames.
- Lack of codal or design-oriented guidance for diaphragm modelling in steel space-framed structures.

XI. CHALLENGES AND LIMITATIONS IN EXISTING STUDIES

The first major challenge is modelling uncertainty. Diaphragm stiffness is affected by deck profile, slab thickness, fastener spacing, weld detailing, openings, edge constraints and collector members. These factors are rarely represented fully in simplified analytical models. The second challenge is validation. Many numerical studies compare only global displacement or base shear while neglecting local diaphragm shear flow, collector force and connection demand. The third challenge is transferability. Findings from reinforced concrete buildings, timber diaphragms or wall-diaphragm systems cannot be directly transferred to steel space frames without considering differences in stiffness, geometry and load path.

A further limitation is that many studies consider either rigid or flexible diaphragm behaviour but do not adequately examine semi-rigid response. In practice, many steel floor and roof systems behave between the two idealized extremes. This makes semi-rigid modelling essential for realistic analysis, but it also requires reliable stiffness input and mesh-sensitive interpretation.

XII. FUTURE RESEARCH DIRECTIONS

- Develop validated numerical models comparing conventional steel frames and steel space frames under no-diaphragm, flexible, semi-rigid and rigid diaphragm conditions.
- Use shell or membrane elements to explicitly model diaphragm in-plane stiffness and compare results with simplified rigid constraints.
- Conduct parametric studies on diaphragm stiffness, span-to-depth ratio, roof geometry, bracing layout, plan aspect ratio and support condition.
- Include nonlinear time-history analysis to capture diaphragm force redistribution, yielding and post-elastic behaviour under strong earthquakes.
- Validate analytical models using experimental, field monitoring or benchmark data for steel deck and space-frame diaphragm systems.
- Formulate practical design recommendations for selecting diaphragm assumptions in STAAD.Pro, ETABS and finite element platforms.
- Integrate diaphragm openings, collector elements, edge chords and connection flexibility into future models.

XIII. PRACTICAL, INDUSTRIAL AND ACADEMIC IMPLICATIONS

For practicing engineers, this review emphasizes that diaphragm modelling assumptions should be selected based on structural form, plan geometry, floor/roof stiffness and lateral-load-resisting system configuration. For industrial and long-span buildings, semi-rigid diaphragm modelling may prevent underestimation of local deformations and collector forces. For academic researchers, the topic offers strong scope for nonlinear finite element modelling, experimental validation, code-based comparison and development of design charts for space-frame diaphragm interaction.

In industrial steel buildings, roofs are often lightweight and may behave as flexible or semi-rigid diaphragms. Treating such systems as rigid can lead to inaccurate force distribution. Similarly, ignoring diaphragm contribution may overestimate displacement and result in uneconomical member sizes. A balanced modelling strategy is therefore required for safe and economical design.

XIV. CONCLUSION

This review establishes that diaphragm action is a decisive parameter in the lateral behaviour of steel structures. In conventional steel frames, diaphragm assumptions are relatively well understood and commonly applied in design. In steel space framed structures, however, diaphragm action interacts with three-dimensional load transfer and may influence stiffness, displacement, drift, torsion, base shear and internal member forces in a more complex manner. The literature shows that rigid diaphragm assumptions are convenient but may be inappropriate for long-span or flexible roof systems, while fully flexible assumptions may neglect useful load-sharing capability. Semi-rigid diaphragm modelling offers a more realistic alternative but requires careful calibration.

The major research gap lies in the absence of systematic comparative studies that evaluate diaphragm effects on steel space frames and conventional steel structures under consistent modelling assumptions. Future research should adopt validated finite element models, nonlinear dynamic analysis and practical design-oriented interpretation to support accurate diaphragm modelling in steel space framed structures. Overall, the topic is suitable for a Scopus-indexed review paper because it connects structural modelling assumptions with seismic performance, design reliability and practical steel construction challenges.

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