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Behaviour of Long-Span Steel Truss Systems with Different Geometrical Configurations under Lateral Loads Using STAAD.Pro: A Review

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***Abstract-** A long span steel roof truss is the preferred structural system for column free enclosures used in industrial, commercial and institutional applications because the forces of the structure can be determined as predominantly axial member forces due to the triangulation. The structural efficiency of this type of roof, however, relies in part on the internal geometry of the truss, and also on the cross sectional shape of the members, and their interaction under lateral (wind) loading has been little discussed in the literature systematically.This review brings together and combines previous research (2004-2019) on gravity and wind-load behaviour of steel roof trusses, and recent developments in wind-load code provisions, computational optimisation (2020-2025) and structural health monitoring, and compares this to a nine-configuration STAAD.Pro case study for Fink, Howe and King Post trusses for angle, channel and ISMB sections.Lateral loading tests have shown that the Howe truss is the one having a more uniform distribution of forces under lateral loading than the Fink and King Post trusses and rolled steel beam (ISMB) sections are the stronger and more serviceable sections than channel and angle sections. The quantity comparison of the different cost also indicates that Howe truss configuration using ISMB sections is the least cost. Recently, computational studies demonstrate that the code-compliant section selection is not the only way to save material; with metaheuristic and machine learning based optimisation methods 15-25% of material can be saved.Other potential avenues of research include other long-span truss configurations and combinations of wind and seismic loads, comparing optimisation algorithms with traditional designs, performing a life cycle cost and embodied carbon analysis, and field instrumentation of existing long-span trusses.*

***Keywords:** Long-Span Structures, Steel Roof Truss, Fink Truss, Howe Truss, King Post Truss, Lateral Wind Load, STAAD.Pro, Structural Optimisation, Finite Element Analysis.*

I. INTRODUCTION

1.1 Overview of the Topic

When a large unbroken floor space is needed, single-storey steel framed structures are favoured because of the rapid erection of steel structures and its lightness compared to reinforced concrete structures [1]. A frequent problem in these types of structures is the slenderness of the members, which is usually accentuated by the need for economical framing and consequently increased member slenderness and hence tendency to instability under combined bending and axial compression. However, as has been demonstrated in a triangulated truss, where most of the forces on the individual members are tensile or compressive, rather than bending, this is not so easy [1, 2].

A clear span is over 12 m for roof structures and they are called “long-span”. The interior spaces in long-span roof structures are columns-free and allow for the creation of flexible spaces; this leads to lower costs of substructures and shorter construction time, which is why long-span roof structures are often used, for example, in factories, warehouses, exhibition halls and stadia [3] [4]. Typically the roof is the only significant structural element other than the perimeter walls, and must satisfy strength, serviceability, weathertightness and constructability requirements.

The internal geometry of a truss (pattern of top chord, bottom chord and web members) and the cross sectional shape given to the members controls the distribution of the applied gravity and lateral load to the individual members. The Howe truss, the King Post truss, and the Fink (Flink) truss shown in Figures 1 – 3 are the three most common truss designs used for

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long span industrial roofing applications, and are discussed in this paper.

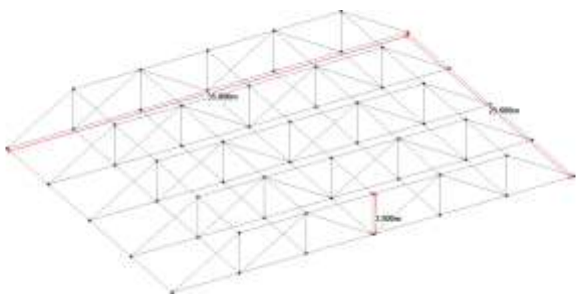

Fig. 1. Howe truss configuration — diagonal web members slope toward mid-span and carry compression, distributing bottom-chord load relatively evenly [1].

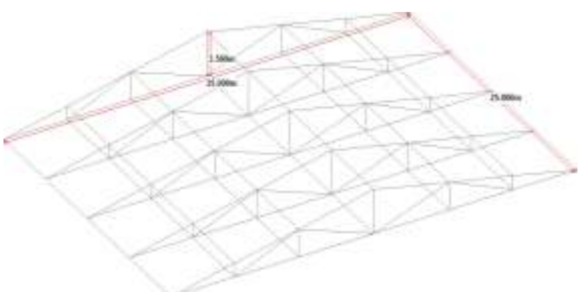

Fig. 2. King Post truss configuration — a single central post connects the apex to the tie beam, suited to shorter individual truss bays [5].

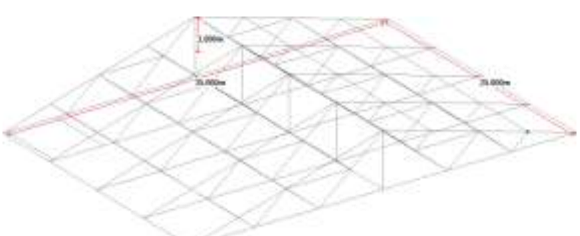

Fig. 3. Fink (Flink) truss configuration — repeated V-pattern web members transmit concentrated load efficiently to the supports [1].

1.2 Importance and Motivation

One of the main lateral loads a long span roof structure is subjected to is wind, which has historically been the cause of roof sheeting being blown off and complete collapse of lightly braced steel sheds [6]. The procedures based on code (e.g. IS 875 (Part 3)) yield a set of standardised design wind pressures, allowing a reasonable degree of reliability in the design without a detailed wind tunnel analysis for each project, but the design wind pressure may vary significantly depending on the code edition applied, the geometry of the truss chosen, the section of the members specified [6, [7]. It is therefore very practical to have a systematic understanding of how these three factors relate to each other, which is what structural designers need.

1.3 Objectives of the Review

The objective of this review is to (i) summarize the current knowledge regarding geometry and section behavior of steel trusses under gravity load and lateral loading, both from a theoretical and experimental point of view; (ii) differentiate between long-term approaches, that have been proven to be code compliant, and recent advances, derived from computational and monitoring research, of this field of comparison; (iii) identify the most important technical challenges and research gaps that still remain in this area; and (iv) present directions for further research, based on a representative nine-configuration STAAD.A pro case study on Fink, Howe and King Post trusses using angle, channel and ISMB sections.

II. LITERATURE REVIEW

2.1 Existing Studies

The investigation of truss geometry has been undertaken at least since Nakazawa et al. [8] who used field tests and finite-element dynamic tests to characterise the vibration response of a timber truss bridge in the form of a king-post truss; and, Branco and Cruz [5] who, through non-destructive testing and full-scale cyclic load tests, characterised historic timber trusses in the form of a king-post truss. For steel truss research, quite a lot of work has been accomplished in comparing truss geometry and member sections with STAAD.Usually from 7 m to 44 m, using either Pro or SAP2000 or Ansys.

Based on this, Harod and Pahwa [1] compared Pratt, Fink and Howe steel roof trusses in Ansys and reported the maximum deformation for the Fink roof truss, the minimum for the Howe roof truss, the Fink truss having the largest total weight, and the Howe truss having the smallest total weight — a situation that was confirmed independently by the nine-configuration case study described in Section III. Chitte et al. [9] did a comparison between the Limit State Method (IS 800:2007) and the Working Stress

Method (IS 800:1984) of a 30 m Pratt truss and found that the former method saved 23% of steel compared to the latter. Qasim et al. [4] have validated STAAD.There was good agreement between the output of a 28 m × 44 m stadium roof truss and AISC LRFD hand calculation, which suggests the use of STAAD.Pro as a trusted analysis and verification tool. There have been a number of studies which have specifically looked at the effect of member section on truss economy. Chhasatia et al. [10] and Patel et al. [11] both found that tubular sections allow a reduction in dead weight compared to conventional angle sections, the cost saving was found by Patel et al. [11] to be 15–25%. Yogesh and Koradiya [12] made this comparison for several truss configurations (Howe, Fan, Fink-Fan and N type) and wind zones; and, once again, tubular sections were determined to be more advantageous than angle sections. However, Pradeep et al. [13] determined that for a span of 42 m, the Warren configuration was the most economical truss type in the comparison of the three types—Warren, Howe and N-type—based on the comparison criterion. The Fully Stressed Design (FSD) technique has been applied in optimisation studies to search for minimum weight solutions in a fixed geometry: Jha and Paliwal [14] optimized a Howe truss and they found the weight increases generally with both span and height while Patrikar and Pathak [2] optimized a Fink truss over 81 different combinations of span, height and load and they found that steel take-off does not necessarily increase monotonically with span as simple intuitive expectation. The reductions in member force with external post-tensioning has been explored by Sawant and Vijapur [15] who concluded that it provides a real load reduction, but adds to the complexity of the fabrication process.

Students will develop methods and technologies used.Students will devise methods and technologies used.

2.2 Methods and Technologies Used

The methodologies of the studies reviewed can be categorized into 3 general types. Firstly, code-compliant finite element analysis using commercial software, which in this instance is mainly STAAD.Comparative truss studies, generally using Pro (to a lesser extent SAP2000 and Ansys) and member design checks carried out in accordance with IS 800:2007/AISC LRFD specimen, continue to be the preferred method. Second, physical and field tests, such as non-destructive testing, full-scale cyclic load tests and long-term strain/displacement monitoring have been conducted to validate computational predictions with measured behaviour [5] [8] [22]. Third, there is an increasing amount of recent work that tackles the truss sizing and topology problem using computational optimisation techniques, such as genetic algorithms, reinforcement learning and graph-neural-network surrogate modelling, as detailed in Section III.

2.3 Comparative Summary

The truss geometry most commonly studied in the literature cited above is summarized in table I together with the characteristic force pattern, the typical span range, and the reported relative structural efficiency.

TABLE I summarises the truss geometries most frequently compared in the literature reviewed

Truss Type	Characteristic Force Pattern	Typical Span Range	Reported Relative Efficiency
Pratt	Diagonals in tension, verticals in compression	6–30 m	Efficient for vertical point loads; diagonal member size reduced [14], [19]
Warren	Alternating tension/compression diagonals, uniform triangles	10–42 m	Best for uniformly distributed load; most economical for 42 m span in [13]
K-Truss	Shortened verticals; members reverse force sign between load cases	8–30 m	Improved buckling resistance; more complex member sizing
Howe	Diagonals in compression, verticals in tension	7–28 m	Lowest peak force / deformation among geometries in [1] and Section III

Fink (Flink)	Repeated V-pattern web members, size reduces toward ridge	8–25 m	Highest peak force / weight among geometries in [1] and Section III
King Post	Single central post; struts framing from supports	≤8 m per bay (repeated)	Simple, economical for short bays; intermediate lateral stiffness in Section III

III. CURRENT TRENDS AND DEVELOPMENTS

3.1 Recent Advancements (2020–2025)

A first strand of new research has been focussed on the code basis that is used for calculation of wind loads. Suthar and Goyal [6] did a comparison between the superseded code (IS 875 (Part 3):1987) and the current code (IS 875 (Part 3):2015), and concluded that the current code reduced wind force computed by it by 15.6–25.9% depending upon the direction — the same order as the differences reported in the comparison of wind forces computed for trusses, which depends on geometry and section.

A second strand focusses on the behaviour of long span trusses in service. In an experimental and numerical investigation, Zhang et al. [23] tested a long span composite floor structure subjected to in-plane lateral load, and in a field-monitoring study, Eschenbach et al. [22] instrumented a 54 m long-span steel roof truss and observed it for a prolonged in-service period, which generally validated the behaviour of the structure to be reasonably predicted by design-stage finite element analysis, thus continuing the use of computational models of the type reviewed in Section II for design. Liu et al. [24] and Xu et al. [25] furthered this monitoring and fatigue-assessment approach to the study of long-span steel truss bridges, and both concluded that the local, concentrated stress at truss joints, rather than the global, applied member force, dominates long-term structural performance.

The third and emerging promising field is computational optimisation for sizing and topology of trusses. Kumar et al. [26] used genetic algorithms for discrete-variable truss sizing, Delyová et al. [27] applied combined sizing/topology optimisation and Mahmood et al. [28] reported up to 21% weight reductions when compared with the conventional section-based sizing approach with the MATLAB genetic algorithm and AISC 360-16. More recent work has turned towards machine learning approaches: Nourian et al. [29] proposed a graph-neural-network surrogate model and particle-swarm optimisation to limit the computational costs associated with repeated finite-element evaluations; Kupwiwat et al. [30] used a graph representation of the truss to formulate the design as a multi-objective reinforcement-learning problem without the need for external labelled training data; and Mai et al. [31] developed a deep unsupervised-learning framework that minimises the weight of the structure directly, using a custom loss function without the need for external labelled training data.

A 4th strand draws on optimisation as part of digital design processes: Yavan et al. [32] introduced a Building Information Modelling (BIM) environment with visual programming, optimisation using genetic algorithms and life-cycle assessment, assessing truss designs simultaneously on structural, economic and environmental criteria; comparative studies of conventional versus pre-engineered building (PEB) framing [33] and [34] and the use of the Grasshopper optimization tool for the sizing of large-scale structural steel frames [35] indicate that optimisation-driven design of trusses and frames is increasingly automated while simultaneously considering multiple criteria.

3.2 Emerging Technologies Illustrated by a Representative Case Study

To demonstrate the effect of these trends on measurable structural results, Fig. 4 shows the relative lateral stability index that was calculated for a representative 9 configuration STAAD.Normalised and benchmarked to Howe truss (100%) for pro case study (Fink, Howe and King Post trusses – angle and channel and ISMB – plan 35 m × 25 m – basic wind speed 39 m/s – IS 875 (Part 3):2015 wind loading). As previously noted in Harod and Pahwa [1] the Howe truss has the largest index, the King Post truss has an intermediate value and the Fink truss has the lowest value, which corresponds with its relatively high

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maximum member forces when subjected to lateral loads.

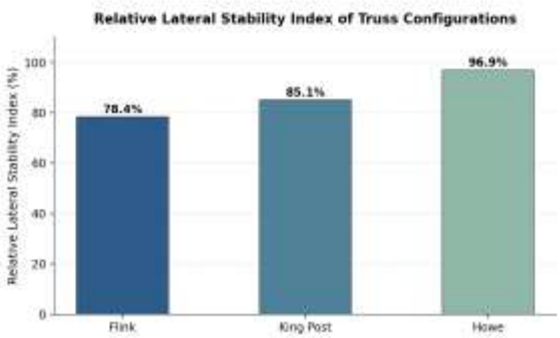

Fig. 4. Relative lateral stability index of Fink, Howe and King Post truss geometries, derived from a representative nine-configuration STAAD.Pro case study.

The same quantity-based cost comparison is shown in Fig. 5, which has been calculated by multiplying the total quantity of steel (kN) with a representative unit rate. The Howe truss with ISMB (beam) section is the least expensive of the nine, while the Fink truss with channel section is the most expensive, as found in [33], [34] that for the case considered the geometry and section combination identified as the most structurally efficient is also the most cost effective.

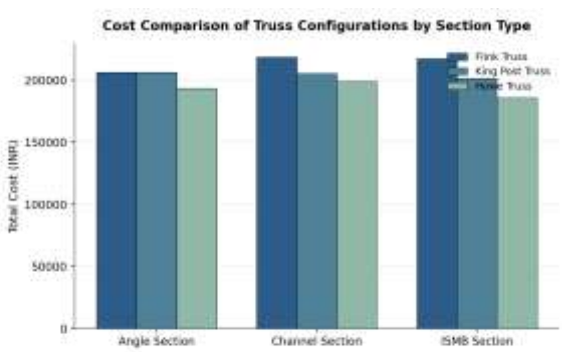

Fig. 5. Cost comparison of the nine truss–section combinations by section type, derived from the representative STAAD.Pro case study.

Both figures are based on the computation of the design wind force that is calculated from the standard code expression, for each of the structural elements.

$$F = (Cpe - Cpi) \cdot A \cdot Pz \quad (1)$$

where Cpe and Cpi are the external and internal pressure coefficients respectively, A is the surface area of the element, and Pz is the design wind pressure at height z as defined in IS 875 (Part 3):2015 [6]. Because Cpe and Cpi both vary with roof slope and truss geometry, Eq. (1) itself provides a first-principles explanation for why truss geometry affects lateral load response independently of member section.

IV. CHALLENGES AND LIMITATIONS

4.1 Technical Issues

- The sensitivity to the wind-code (WC) edition of the computed lateral forces is illustrated by [6] that indicates that results from studies conducted based on superseded and current code editions may not necessarily be directly comparable unless corrected.
- Idealisation of joint behaviour: most of the studies reviewed assume that truss joints are idealised pins that carry only an axial force, but field-monitoring data [22], [24] show that local stress concentration at actual semi-rigid joints can dominate long-term behaviour and is not represented by this idealisation.
- The limited coupling of geometry and section variables: Most comparative studies (Section II) alter one or the other variable, but not both at the same time in a consistent, parametrically modelled study, which makes it difficult to determine the contribution made by each of the variables to overall structural performance.
- The computational cost of the optimisation methods: some methods based on genetic-algorithm and machine-learning need a lot of computational time or a large set of training data to achieve substantial potential material savings, and may be difficult to fit into the routine use of design offices.

4.2 Research Gaps

- The number of the studies that compare the structural performance with the quantity-based cost comparison of different combinations of the truss–sections under a common lateral load regime is limited.
- Despite the fact that there are a number of current wind codes, and various sections of the span, little documentation exists with which to compare the wind load behaviour of Fink, Howe and King Post

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trusses of long-span scale (span length > 25 m plan dimension).

- Practical gains in using the simpler, code-compliant approach to section-selection that is still the norm in conventional design office practice, have not, in general, been directly compared with the more recent studies that focus on optimisation, and the actual size of the improvement to be gained in regular design office conditions is not yet well established.
- Although the practical significance of combined wind-seismic lateral loading of long-span truss geometries is also significant in seismically active regions, there has been much less comparative attention to this combination of loading.

V. FUTURE RESEARCH DIRECTIONS

5.1 Potential Improvements

(I) Development of joint models that capture realistic semi-rigid behaviour, but that are calibrated against field-monitoring data similar to that found in [22] and [24] to improve the fidelity of lateral-load predictions beyond the idealised pinned-joint assumption found throughout the reviewed literature.

(II) Systematic comparison of code-compliant section selection methods with the optimisation methods based on metaheuristic and machine learning approaches [26]–[32] to arrive at appropriate conclusions on the practical opportunities of material and cost savings in regular design practice.

(III) Inclusion of quantity based cost comparison in the assessment of full life-cycle cost and embodied-carbon assessment which includes fabrication, transportation, erection and maintenance cost, based on the integrated BIM–LCA model adopted by Yavan et al. [32].

5.2 Opportunities for future work

(I) the same lateral load is applied to additional geometries – Pratt, Warren and K-truss – which are then compared to the Fink, Howe and King Post geometry geometry discussed in Section III.

(I) Development of combined wind and seismic lateral loading to assess the performance of the truss to address research gap identified in Section IV-B.

(II) Field instrumentation and long term monitoring of new long-span truss roofs, in the spirit of [22] to validate computation and to gather a larger empirical database connecting to models developed at design stage and to the behaviour in service.

(III) Extension of the scope of the geometry–section interaction studies of this review to include investigation of the effect purlin spacing, roof slope and bracing arrangement has on the lateral stability of long span truss geometries.

VI. CONCLUSION

This review has summarised research into the structural behaviour of long-span steel roof trusses under gravity and lateral load up to present day, categorising the work between fundamental studies (2004–2019) and recent developments in wind-code refinement (2020–2025), structural health monitoring (2020–2025) and computational optimisation (2020–2025). For all the studies analysed and the representative nine configuration STAAD.For the long span industrial roofs of the scale under consideration, the Howe truss geometry with rolled steel beam (ISMB) sections is in overall a more structurally efficient and economical design as compared to the Fink and King Post designs and to channel and angle designs when compared to the case studies discussed in Section III.

Meanwhile, the review has found that there are significant gaps in the literature, such as the lack of research that has considered varying truss geometry and member section at the same time under a given lateral loading regime, the lack of benchmarking of new computational optimisation techniques against traditional design, and the relatively few studies in which simultaneous consideration of combined wind–seismic loading has been given. The research directions outlined in Section V provide both opportunities to further optimise the structure and confidence for adopting new optimisation and monitoring technologies in the design of long-span steel truss structures by code.

The key recommendations from this review are: (i) designers need to check the wind code that underlies any comparative truss study before using its conclusions; (ii) the Howe truss with ISMB sections is a good default design for long span industrial roofs of the scale studied here, subject to project-specific verification; and (iii) research with combined geometry–section parametric studies and life-cycle cost assessment should be given priority to close the main gap identified in Section IV-B.

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