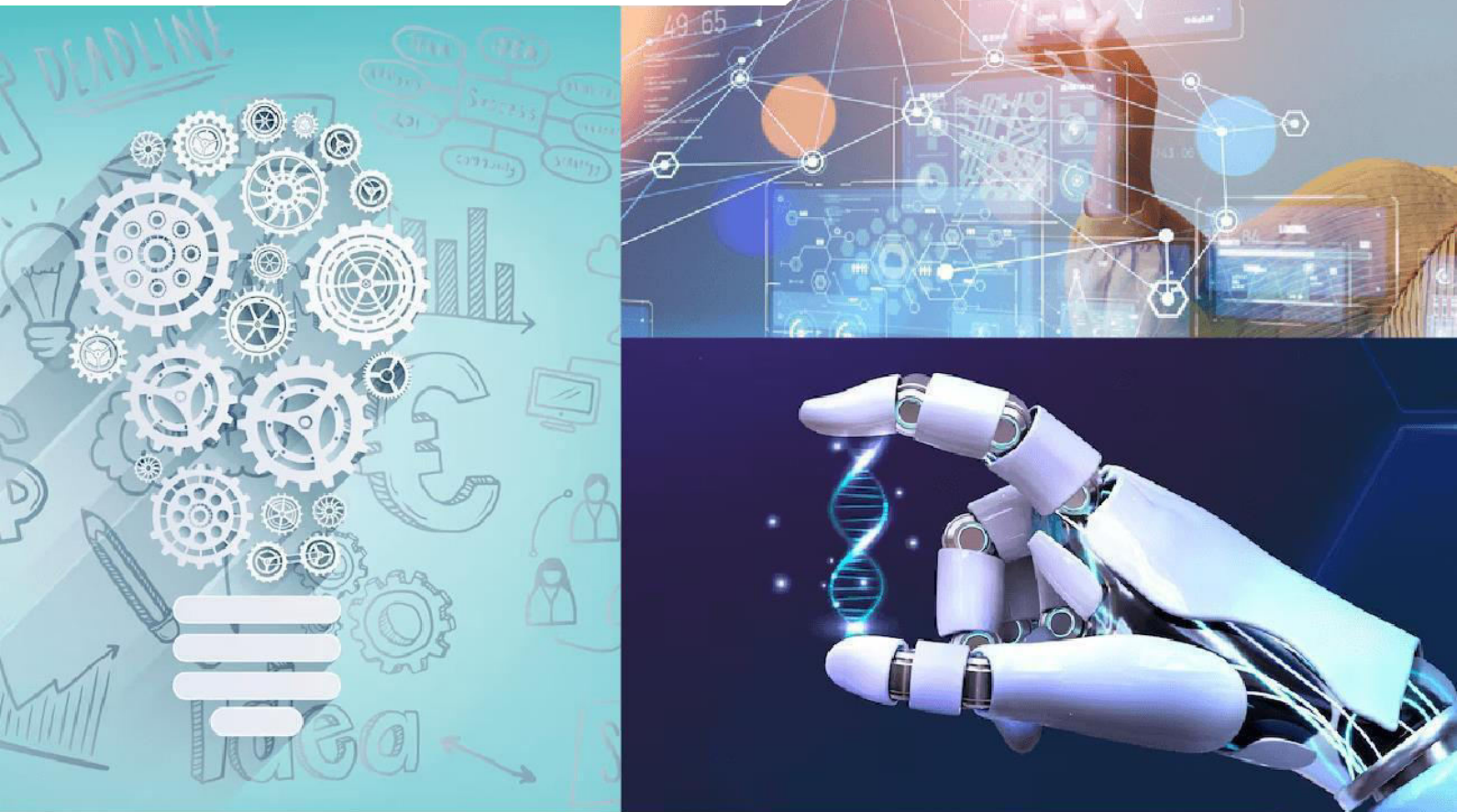




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A Review on Comparative Dynamic Analysis of Stadium Roof Structures with Varying Geometrical Forms

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ABSTRACT: stadium roof structures were among the most challenging and functionally critical components in modern sports facilities due to their large spans, complex geometrical configurations, and susceptibility to dynamic loading. This study focused on the comparative dynamic analysis of stadium roof structures with varying geometrical configurations to assess their seismic performance. Tubular roof systems were designed in accordance with IS 801:2005, ensuring code-based compliance in member sizing, detailing, and connection provisions.

Three roof geometries — Flat, Curved, and Inclined — were modelled and analysed using STAAD Pro. Each configuration was subjected to dynamic loading conditions based on the El-Centro earthquake ground motion record. A time-history analysis was carried out to evaluate the structural response parameters, including displacement, internal member forces, natural frequencies, and modal behaviour.

The post-dynamic performance of each roof system was assessed in terms of structural safety, serviceability, and energy dissipation capacity. Furthermore, analytical validation using simplified dynamic methods was performed to verify the accuracy and reliability of the STAAD Pro results. The comparative findings demonstrated the significant influence of roof geometry on the overall dynamic response and provided design recommendations for selecting optimal roof forms that enhance seismic resilience and structural efficiency in large-span stadium structures.

KEYWORDS: Stadium roof structures, Dynamic analysis, Tubular truss, Earthquake ground motion, STAAD-Pro.

I. INTRODUCTION

A stadium roof is a roof system designed to roll back the roof on tracks so that the interior of the facility is open to the outdoors. Retractable roofs are sometimes referred to as operable roofs or retractable skylights. The term operable skylight, while quite similar, refers to a skylight that opens on a hinge, rather than on a track. Stadium roofs are used in residences, restaurants and bars, swim centers, and other facilities wishing to provide an open-air experience at the push of a button.

Stadiums are iconic structures that represent not only engineering excellence but also architectural innovation. Among their various components, the roof system plays a crucial role in ensuring both functional and structural performance. Unlike conventional building roofs, stadium roofs typically span large areas, adopt complex geometrical forms, and are required to provide unobstructed visibility, weather protection, and long-term durability. These demands make them structurally more vulnerable to dynamic actions such as wind and earthquake loading. Dynamic analysis of stadium roof structures is essential for understanding their behaviour under seismic ground motions. The geometry of the roof strongly influences parameters such as stiffness, natural frequency, and load distribution. Tubular truss systems are widely adopted in long-span structures because of their light weight, high strength-to-weight ratio, and architectural versatility. However, their behaviour under real earthquake excitations varies significantly with roof form, making comparative analysis an important research need.

A. History

The United States Patent and Trademark Office (USPTO) shows that David S. Miller, founder of Rollamatic stadium Roofs, filed a patent in August 1963 for a movable and remotely controllable roof section for houses and other types of buildings. As Rollamatic was founded five years earlier, the first installation of a motorized retractable roof must be between 1958 and 1963.

II. STATE OF DEVELOPMENT

Ahiwale, D., Shaha, P., Palaniyandi, K. et al. (2021)

The effects of vertical seismic excitations have a considerable destructive potential for long-span structures, particularly for near-field earthquakes. A quantification analysis is carried out in this paper to describe the response of a 25-m long trapezoidal truss frame with a height of 9 m under Vertical Ground Motion (VGM) with the help of eight near-field seismic excitations. Linear analysis of earthquake load combinations, including VGMS, has been conducted. The VGMS are leading the design of the long-span roof truss rather than the wind load. The time history analysis is therefore performed for horizontal ground acceleration and horizontal plus vertical acceleration using SAP 2000.

Tüfekci, M., Tüfekci, E., & Dikicioglu, A. et. al. (2020)

This study investigated the failure of the roof, with steel truss construction, of a factory building in Tekirdag in the northwestern part of Turkey. The investigation includes detailed numerical modelling of the truss roof system, identification of weak links in the structure and examination of possible failure modes under loads. It is found that design deficiencies, material non-uniformity, incorrect assumptions in load paths, and local buckling are probable reasons for collapse. The results suggest that better design practice, especially considering realistic loadings, stability issues and proper connection detailing, is essential for safety.

Tahmasebinia, F., Chen, E., et. al. (2023)

The current structural engineering practical standards are unable to offer an universal structural design standard for long-spanning lightweight stadium roofing structures. Linear static analysis will then be undertaken where critical members will be identified within the model. Based on this, preliminary member sizing and design feasibility checks will be conducted in order to ensure structural stability and compliance to the Australian Steel Structure code AS4100:2020. A linear buckling analysis is also conducted based on the selected sizes from the initial stage to determine critical loads. Advanced analysis including non-linear buckling computation is comprehensively managed. Some of the crucial parameters such as maximum displacement, maximum/minimum principal stresses, critical buckling loads, as well as load factors are examined. The main novelty of this study is to determine a clear road map to design stadium roofing systems subjected to a combination of different types of the loading.

Muslikh & Iman, et. al. (2025) There were many incidents of cold-formed steel roof truss structures in the last 5 years in Indonesia. Various kinds of allegations have been addressed to cold-formed steel material applications especially in the case of seismic resistance. Some of them concern the authenticity of the steel material itself and the selection of cold formed steel material. On the other hand, recently, people have installed (assembled) cold-formed steel trusses without involving a certified cold-formed steel applicator. The study aims to examine such failures, perform seismic load and buckling analyses on cold-formed steel truss roofs, and identify critical failure modes. The paper concludes that improper material selection, inadequate member design, and lack of consideration for buckling under seismic effects are key vulnerabilities.

Zhang, C., Li, J., Liu, Y., Cheng, et. al. (2024) Earthquakes are often followed by higher-intensity aftershocks, which tend to aggravate the accumulated and more severe damage to building structures. The seismic vulnerability of concrete-filled steel tube (CFST) structures under major aftershocks is more complex. In this paper, a CFST frame and a frame with buckling-restrained braces (BRBs) are studied, and the finite element analysis software Midas 2022 is used to analyze the seismic vulnerability of the two types of structures under main shock and main-aftershock. The results show that the structural vulnerability of the two structures is significantly higher under the main-aftershock sequences than under the main shock alone. Compared with the CFST structure, the structure with BRBs can effectively reduce the structural displacement and the hysteretic energy, decrease the plastic deformation risk of the structural components, and improve the seismic performance. The structure with BRBs can significantly reduce the probability of structural collapse under the main-aftershock sequence and can provide a reliable guarantee of the stability of the building.

Sunil Kumar Yadav et. al. (2025)

This study provides a comprehensive analysis of the design of a multifunctional stadium constructed of reinforced concrete (RCC) using STAAD.Pro software. The primary focus is on how the structure behaves under various stresses, including seismic, wind, dead, and live loads. The stadium's geometry and material properties were modelled using STAAD. The primary focus is on wind and seismic loads and how they impact the structural behavior of the stadium. STAAD.Pro was used to model a 21-meter stadium structure, including all of the material properties, boundary conditions, and intricate geometry.

Masoud Babaei, Kamran Asemi et al. (2025) Despite the many advantages of tube systems with braces, known as trussed tubes, no specific seismic design criteria exist in the current regulations to design them, and practitioners utilize common methods used for common building structures to deal with designing such systems. In the current study, the seismic performance of a code-conforming tall building with a trussed-tube system has been investigated using the performance-based instructions of the ASCE 41 standard. The structure has primarily been designed using code-based response spectrum analysis. Moreover, the adequacy of the final design has then been rechecked through the application of a linear time–history analysis with an ensemble of seven pairs of spectrally matched earthquake records. To assess the performance of the designed structure, a three-dimensional nonlinear static analysis has been employed at two different hazard levels to examine whether the steel structural components, including the braces, columns, and beams, meet the acceptance criteria at the specified performance objective. Based on the obtained results, it has been observed that the code-conforming structure does not satisfy the performance objectives at either of the two hazard levels. Single braces, as well as columns at lower stories, have been found to be the most critical elements requiring reconsideration in their design.

Joseph J. R., et. al. (2023)

This paper reviews the existing literature and applications of concrete-filled steel tube truss girders. Key aspects covered include design approaches, structural behaviour under load, fatigue, buckling, and composite action between concrete infill and steel tube. The review synthesizes findings from experimental, analytical, and numerical studies, highlighting gaps such as behavior under dynamic loads and seismic performance of such girders in long-span roof and truss structures.

Labò S., Marini A., Giuriani E. P., et. al. (2024) This paper presents a case study dealing with the seismic risk mitigation of a long-span historical building, focusing on the roof-box structure composed of wooden elements. The study involves retrofitting strategies to improve seismic performance while preserving architectural and historical features. Through numerical modelling and historical structural analysis, the roof box's behavior under earthquake loads is evaluated, and interventions are proposed aiming to reduce damage during seismic events, considering both structural safety and heritage conservation.

III. CONCLUSION

The review of existing research highlights that considerable work has been carried out on the seismic and dynamic performance of long-span roof structures, trussed systems, and tubular members. Studies emphasize the influence of roof geometry, slenderness ratio, buckling effects, and material properties on the overall seismic response. Advanced methods such as nonlinear time-history analysis, response spectrum analysis, and performance-based approaches have been widely applied to capture realistic behavior under earthquake loading. Research also points out that vertical ground motions, often neglected in conventional design, can be critical for long-span roof structures. While tubular truss systems are recognized for their efficiency and light weight, they remain vulnerable to instability and local buckling under severe seismic effects. Computational tools like SAP2000, STAAD.Pro, and MIDAS are frequently employed, with partial validation against analytical or experimental approaches. Overall, the literature establishes the importance of dynamic evaluation in ensuring the stability and safety of large-span roof systems.

Gap Identification

- Design of stadium roof as tubular structure: While tubular truss systems are widely used for long-span roofs, few studies have focused on designing stadium roofs specifically according to Indian standard IS 801:2005, considering member sizing, connections, and overall geometry.
- Dynamic analysis under multiple ground motions: Many studies analyze seismic response under a single or simplified ground motion. There is a lack of comprehensive dynamic analysis of different stadium roof geometries subjected to multiple recorded earthquake ground motions using time-history methods.
- Post-dynamic behavior assessment: Most research focuses on immediate seismic response (displacement, internal forces) but does not sufficiently explore the post-dynamic performance, such as residual stresses, deformation patterns, and structural stability after seismic excitation.

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