

A Review on Optimization of Steel Truss Stadium Roof Frame Using Parametric Staad. Pro Models and Genetic Algorithms

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Abstract—Large-span stadium roof structures are highly susceptible to dynamic and seismic effects, where structural performance is significantly influenced by roof geometry. This study focuses on the comparative analysis and optimization of steel truss stadium roof systems with different geometrical configurations, namely flat, inclined, and curved roofs. Parametric models of all roof types are developed and analyzed in STAAD.Pro as per IS 801:2005. Dynamic analysis is carried out using El-Centro earthquake time history data to evaluate important response parameters such as fundamental time period, displacement, member forces, and stresses. A comparative study is performed to identify the influence of roof shape on seismic behavior and structural efficiency. Further, a Java-based Genetic Algorithm (GA) is developed and implemented to optimize the roof structure by minimizing structural weight while satisfying design constraints related to stress, displacement, and safety requirements. The optimization results are compared for all roof configurations to determine the most economical and efficient stadium roof system. The study provides an integrated approach combining parametric modeling, dynamic analysis, and optimization for safe and cost-effective stadium roof design.

Index Terms—Stadium Roof Structure, STAAD.Pro, Genetic Algorithm, Structural Optimization, Dynamic Analysis.

I. INTRODUCTION

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.

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.

While any shape is possible, common shapes are flat, ridge, hip-ridge, barrel and dome. A residence might incorporate one or more 3' by 5' retractable; a bar or restaurant a retractable roof measuring 20' by 30'; and a meeting hall a 50' by 100' bi-parting-over-stationary.

Stadium roofs are generally used in locales where inclement weather, extreme heat, or extreme cold are prevalent during the respective sports seasons, in order to allow for playing of traditionally outdoor sports in more favorable conditions, as well as the comfort of spectators watching games played in such weather. Unlike their predecessors, the domes built primarily during the 1960s, 1970s, and early 1980s, retractable roofs also allow for playing of the same

traditionally outdoor sports in outdoor conditions when the weather is more favorable.

Another purpose of retractable roofs is to allow for growth of natural grass playing fields in environments where extreme hot and/or cold temperatures would otherwise make installation and maintenance of such a field cost prohibitive. Installations throughout the world employ a variety of different configurations and styles [11]



Fig 1 The First Stadium Roof- Civic Arena, Built In 1961

The first retractable roof sports venue was the now-demolished Civic Arena in Pittsburgh, Pennsylvania, United States. Constructed in 1961 for the Pittsburgh Civic Light Opera, the arena was home to minor-league and NCAA D-1 basketball and ice hockey teams before becoming the home of the NHL's Pittsburgh Penguins in 1967, as well as hosting over a dozen regular season NBA games in the 1960s and 1970s. The arena's dome-shaped roof covered 170,000 square feet (16,000 m²) and was made up of eight equal segments constructed from close to 3,000 tons of steel, in which six segments could retract underneath the remaining two, supported by a 260-foot (79 m) long exterior cantilevered arm.

B. Genetic Algorithms

Genetic Algorithms are optimization techniques inspired by the principles of natural selection and genetics. They are widely used to solve complex engineering problems where traditional optimization methods become difficult or inefficient.

In structural engineering, GA is particularly useful for optimizing parameters such as member sizes, weight, cost, and geometry of structures like steel trusses and stadium roofs

II. STATE OF DEVELOPMENT

The literature review presents an overview of previous research and studies related to the structural behavior and design of stadium roofs. It explores various roof systems such as fixed, retractable, cantilever, and tensile structures and their performance under different environmental and loading conditions. This chapter summarizes key findings from national and international studies, focusing on aspects like material selection, load distribution, architectural efficiency, and cost-effectiveness. The review helps identify the existing research gaps, provides a theoretical foundation for the current study, and supports the selection of suitable roof types for modern stadium design.

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., & Dikicioğlu, A. (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., Huang, A., & Li, J. 2023 Current structural design practices lack a unified standard for long-span lightweight stadium roof structures. This study performs linear static analysis

to identify critical members and carry out preliminary sizing in accordance with AS 4100:2020. Linear and nonlinear buckling analyses are conducted to evaluate critical loads and structural stability. Key parameters such as displacement, principal stresses, buckling loads, and load factors are assessed. The study aims to establish a clear design roadmap for stadium roofing systems subjected to combined loading conditions.

Muslikh & Iman, Miftahul. (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, Q., Sun, Z. (2024)

Aftershocks following major earthquakes can significantly intensify damage to building structures. This study evaluates the seismic vulnerability of concrete-filled steel tube (CFST) frames and CFST frames with buckling-restrained braces (BRBs) under main shock and main-aftershock sequences using Midas 2022. Results indicate that structural vulnerability is considerably higher under main-aftershock loading than under a single main shock. Compared to conventional CFST frames, BRB-equipped structures show reduced displacement and hysteretic energy, lower plastic deformation risk, and improved seismic performance. The inclusion of BRBs significantly reduces collapse probability and enhances overall structural stability.

Sunil Kumar Yadav & Rahul Kumar Satbhaiya (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)

Although trussed-tube systems offer significant structural advantages, current codes lack specific seismic design provisions, leading designers to rely on conventional methods. This study evaluates the seismic performance of a tall building with a trussed-tube system using the performance-based guidelines of ASCE 41. The structure was initially designed using response spectrum analysis and later verified through linear time-history analysis with spectrally matched ground motions. A three-dimensional nonlinear static analysis at two hazard levels was conducted to assess component performance. Results indicate that the code-conforming design fails to meet performance objectives, with single braces and lower-storey columns identified as the most critical elements requiring redesign.

Joseph, J. R., Henderson, J. H. (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., Zanni, J., Riva, P. (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.

Cheon, D.-J., Lee, S.-H., & Kim, H.-J., (2021)

Dome roof cladding, commonly made of lightweight membrane materials, is highly susceptible to wind damage, especially in open or retractable domes. This study investigates wind pressure characteristics of a dome with a central opening through wind tunnel experiments by evaluating external and internal pressure coefficients. Based on the results, peak net pressure coefficients suitable for cladding design were proposed. External peak pressure coefficients on leeward regions showed minimal variation with height–span ratio and turbulence intensity, while internal pressures were predominantly negative and largely insensitive to geometric changes. These effects resulted in increased upward and downward peak net pressures acting on the dome cladding.

Tahmasebinia, F., Chen, E., Huang, A., & Li, J., (2023)

This study examines the wind pressure characteristics of elliptical-plan retractable dome roofs using wind tunnel experiments. Models with varying wall height-to-span ratios (0.1–0.5) and roof opening ratios (0–50%) were analyzed. The peak pressure coefficients of closed elliptical domes were compared with the AIJ-RLB (2015) wind load code and with previously proposed values for spherical retractable domes. Based on the comparative analysis, appropriate positive and negative peak pressure coefficients were proposed for the cladding design of elliptical retractable dome roofs.

Zhen, W., et al., (2024)

Ground-motion intensity measures (IMs) play a vital role in seismic risk assessment and the design of large-span structures. This study proposes a novel IM based on the velocity spectrum that accounts for multiple vibration modes and period elongation due to seismic isolation. The efficiency of 37 different IMs was evaluated against engineering demand parameters using far-field ground-motion records. The proposed IM was first examined using a planar lumped-mass model and later validated on a numerical model of the Beijing Workers' Stadium. Results show that the proposed IM exhibits satisfactory adequacy and superior efficiency compared to other IMs for multiple engineering demand parameters.

Rizzo, F., et al., (2022)

Aeroelastic wind tunnel testing of flexible hyperbolic paraboloid cable-net roofs presents significant challenges due to their low mass, strict scaling requirements, and closely spaced natural frequencies. This study proposes a systematic approach for investigating wind–structure interaction of such roofs by addressing aeroelastic scaling, model construction, dynamic identification, and FEM-based numerical modeling. Hyperbolic paraboloid roofs with square, rectangular, and circular plans and varying curvatures were analyzed. Advanced modal identification techniques, including Welch's method, RDT, TVF-EMD, and FDD, were employed to capture closely spaced modes. Results confirm good agreement between experimental and prototype responses, demonstrating the reliability of the proposed aeroelastic modeling approach.

Yuan, Y., et al., (2024)

STFE (structural, transparent, fluorinated, envelope) membrane material is a newly developed transparent architectural membrane that effectively combines high transparency with adequate tensile strength, overcoming the limitations of conventional membrane materials. This study evaluated the tensile strength of STFE membranes using different testing methods, including clamping, winding, and dumbbell-shaped tests, and analyzed the causes of variation in the results. The winding-type test with smooth surface contact provided the most accurate and highest strength values, while clamping tests, dumbbell-shaped tests, and winding tests with rough contact surfaces resulted in reduced strength due to specimen slippage, stress concentration, and material damage, respectively. The measured tensile strengths were 4241 N/5 cm in the warp direction and 4335 N/5 cm in the weft direction, confirming that STFE membrane material possesses sufficient strength for application in tensile membrane structures.

Yuan, Z., et al., (2023)

Stadiums are highly wind-sensitive structures and are particularly vulnerable to tornado-induced damage. In this study, a Ward-type tornado simulator was used to investigate the wind load characteristics of a stadium under tornado conditions, and the simulation results were validated by comparison with experimental data. Wind pressure coefficients, wind speed distribution, and vorticity characteristics on the upper and lower surfaces of the stadium were

analyzed for different swirl ratios. The effects of wind profile, uniform inflow conditions, and varying ground roughness on wind speed, wind pressure, vortex core radius, and vorticity development were also examined. The results identify the most vulnerable regions of the stadium and the most unfavorable influencing factors, demonstrating that swirl ratio, ground roughness, and wind profile significantly affect stadium wind loads under tornadoes. The findings provide useful guidance for disaster prevention and wind-resistant design of stadium structures.

Cheon, D.-J., (2021)

Wind-tunnel study of elliptical/retractable dome roofs showing that opening state and roof plan shape strongly influence pressure distributions; recommends design margins and operational wind limits for retractable systems.

Rizzo, F., (2024)

This study examines wind direction and Reynolds number effects on flexible roof behavior. Results show that nonlinear FEM based on static wind loads underestimates roof-center displacements compared to aeroelastic tests. To address this, ANN-based machine learning models are used to correct displacement predictions from simplified rigid-model tests. The approach improves representation of fluid–structure interaction and supports both preliminary design and wind tunnel model development.

Song, W., et al., (2024)

Conventional wind tunnel studies on tensile membrane structures use rigid models and ignore the influence of large membrane deformations on pressure coefficients. This study investigates how membrane displacements affect wind pressure distribution. Wind tunnel tests were carried out on two rigid models representing the initial and deformed membrane shapes. The deformed shape was obtained using the dynamic relaxation method under wind loading. Results indicate that membrane deformation significantly alters peak pressure coefficients. Considering the deformed shape improves the accuracy and reliability of wind analysis for tensile membrane structures.

III. CONCLUSION

- The reviewed literature indicates significant advancements in the analysis of long-span

stadium roof structures subjected to wind and seismic loads, with emphasis on tubular systems and numerical modeling techniques. However, most studies primarily focus on structural analysis using software tools, with limited efforts toward systematic comparison of different roof geometries under identical seismic conditions.

- There is a lack of integrated research that evaluates the influence of roof shape such as flat, inclined, and curved configurations on dynamic response parameters including time period, displacement, and stress distribution. Furthermore, very few studies incorporate optimization techniques such as Genetic Algorithms to enhance structural efficiency and achieve economical design solutions.
- Additionally, the linkage between analysis results obtained from software like STAAD.Pro and advanced optimization methods is not adequately explored. This creates a gap in developing a combined framework of parametric modeling, dynamic analysis, and optimization for stadium roof structures.
- Hence, there is a need for a comprehensive study that not only compares different roof geometries under seismic loading but also applies Genetic Algorithm-based optimization to identify the most efficient and cost-effective stadium roof configuration.

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