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Parametric Study for Structural Performance of Steel Network Arch Bridge Using Finite Element Method

Budhi Ram Chaudhary[1]; Bharat Mandal[2]; Rajan Suwal[3]

[1]PhD Scholar Institute of Engineering, Tribhuvan University, Pulchowk, Nepal
[2]Associate Professor Institute of Engineering, Tribhuvan University, Pulchowk, Nepal
[3]Associate Professor Graduate School of Engineering, Mid-West University, Surkhet, Nepal

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Abstract: Network arch bridges, first developed by Per Tveit, are recognized for their high structural efficiency due to inclined intersecting hangers that reduce bending moments and enhance stiffness. In order to assess the impact of hanger cross-angles ranging from 25° to 90°, this study offers a three-dimensional nonlinear finite element analysis of a 100 m span steel network arch bridge using MIDAS Civil. Using the El Centro earthquake data, the bridge was examined under IRC-based wind loading and nonlinear time-history seismic excitation. To access differences in axial force, bending moment, shear force, and overall structural behaviour, 19 hanger configurations were analysed. The findings demonstrate that dynamic loading controls bridge response, resulting in tie-beam tensile forces close to 430,000 kN and arch compressive forces up to 350,000 kN. While greatly raising hanger strain, increasing hanger cross-angle lowers axial demand in the tie beam and arch rib. While tie-beam axial forces show a high dependency on hanger arrangement, arch bending moments are comparatively resistant to hanger-angle variation. The most balanced structural performance is achieved by hanger cross-angles between 60° and 75°, which combine lower tie-beam tension, less dynamic compression, and a moderate hanger force requirement. The results provide useful recommendations for hanger layout optimization in steel network arch bridges and create the groundwork for further research on hanger loss, robustness evaluation, and structural health monitoring.

Keywords: *Network Arch Bridge, Hanger Cross-Angle, Finite Element Analysis, Time History Analysis, Wind Load Analysis, Axial Force Distribution; Structural Stability; Dynamic Response, Structural Optimization.*

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I. INTRODUCTION

Network arch bridge has become favored for their improved structural economy and appealing aesthetics, particularly for medium-to-long spans, where stiffness and material efficiency are critical. Characteristics such as inclined, multiply-intersecting hangers enhance overall load-carrying performance and fatigue resistance by improving force distribution and reducing bending moments in the deck slab and arch rib (Bruno et al., 2016; Järvenpää, 2007). The iterative behavior of arch, deck, and hanger components produces a statically indeterminate system that can be tailored to meet diverse performance objectives. Originality with Per Tveit in the 1950s, the network arch bridge (NAB) departs from traditional tied-arch forms by employing inclined, intersecting hangers to minimize bending in the arch and promote compressive load transfer. This configuration enables highly efficient structures spanning beyond 400m, from pedestrian to road and rail applications (Zhou et al., 2022; Pipinato, 2016).

However, limited optimization has sometimes led to overconservative designs, premature hanger failures, and inadequate maintenance planning – issues that affect safety and cost-effectiveness (Wang et al. 2024; Deng et al., 2024). Despite demonstrated advantages of crossed-hanger arrangements, several design questions persist. Prior studies using parametric and experimental approaches investigated hanger inclination, density, and connection detailing (Moon et al., 2009; Lonetti & Pascuzzo, 2015), but conclusive optimal strategies remain elusive. Serviceability problems, particularly stress concentrations in hangers that accelerate fatigue and potential failure, indicate the need for more resilient design practices (Eom et al., 2014).

Moreover, current codes and guidelines give limited direction on hanger layouts that ensure durable, elastic response over the long term, especially under loading, environmental degradation, and accidental events. When Tveit (2014) classified network arches, a defining feature was hangers inclined so they cross at least twice, which lowers

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chord bending moments and increases buckling resistance. Teich and Wendelin (2001) reported substantial material saving when concrete ties and prestressing cables were used, reducing steel demand by up to two-thirds. Comparison with conventional tied arches – such as the Åkvik Sound Bridge— show higher stiffness and reduced self-weight for network arches (Tveit, 2013). Schanack (2008) and Brunn & Schanack (2003) argue that appropriate hanger slopes improve fatigue behavior and reduce hanger relaxation. Schanack (2009) suggests simplified buckling checks for long spans that still reflect realistic performance. Erection methods, including scaffolding and floating crane operations, have been shown empirically to significantly affect overall cost (Tveit, 2014).

For road spans of 60–200 m and rail spans of 60–150 m, literature supports the constructability, aesthetics, and economy of network arches. Ongoing research addresses hanger optimization, steel–UHPC composite ties, and life-cycle cost evaluation. Network arch bridges are become popular for long-span transportation infrastructure due to their structural efficiency, resilience against various hanger-loss scenarios, and reduced material consumption. We are motivated to research the most appropriate advanced hanger configuration because there is a practical need to create resilient and optimized hanger systems that enhance structural reliability, increase service life, lower life-cycle costs, and assist sustainable bridge design.

While prior research has examined network arch bridges in terms of structural optimisation, fatigue performance, and stability resistance, there are still a number of significant constraints. Few research assess the combined impact of hanger cross-angle under both wind and seismic events; the majority of existing studies concentrate on isolated geometric features, particular bridge configurations, or static loading circumstances. Regarding the ideal hanger tilt needed to achieve balanced force redistribution and dynamic performance, current design suggestions likewise offer little help. Moreover, there is still little quantification of the connection between hanger shape and important response parameters including dynamic amplification, tie-beam tension, and arch compression. Therefore, in order to generate useful design recommendations for hanger arrangements, thorough nonlinear finite element parametric research is required. By methodically assessing nineteen hanger cross-angle combinations under the same loads and boundary circumstances, the current study fills this gap and offers mathematical proof for choosing structurally sound hanger design in steel network arch bridges.

II. LITERATURE REVIEW

Recent studies employing finite element method (FEM) for parametric assessment of steel network arch bridges have focused on stability, optimization, and nonlinear behavior. The paper "Conceptual design of long span steel-UHPC composite network arch bridge" by Lai et al., Engineering Structures (2023) is a notable example. That work used detailed FEM (Midas Civil) to examine static, dynamic, fatigue, and stability attributes of a 470 m steel-UHPC composite network arch. The authors ran parametric studies on composite section properties, hanger layout, and arch rib arrangement to enhance stiffness and lower CO2 emissions compared with conventional CFST arches. Although centered on a composite system rather than a pure steel NAB, their FEM parametric methodology is highly relevant. A limitation is the single conceptual design examined and modeling assumptions that may limit general applicability. The full article is available in Engineering Structures via Science Direct.

Another important study, "An analytical methods for out-of-plane stability assessment of network arch bridges" by Jiang et al., (2024) in Thin-Walled Structures, proposes closed-form expressions for out-of-plane buckling resistance and validate them through parametric FEM. The authors varied key geometric parameters – rise-to-span ratio, hanger inclination, and arch stiffness – and concluded network arches exhibit distinct buckling behavior due to overlapping hangers. They warn that ignoring geometric imperfections can produce unconservative predictions and provide simple formulas useful for design, though parts of the deviation assume linear-elastic material response and ideal supports. See Thin-Walled Structures on Science Direct for details.

In "Nonlinear buckling analysis of network arch bridges" (Blonka & Skretkowicz, 2022; Studia Geotechnica et Mechanica), a systematic nonlinear FEM investigation included cable pretension and geometric imperfections in eigenvalue and nonlinear stability analyses of an existing steel NAB in Cracow. They introduced a Unique Global and Local Imperfection (UGLI) modeling strategy to better capture post-critical behavior and showed defect amplitude, arch slenderness, and hanger prestress substantially influence ultimate capacity. This work underscores the importance of geometric nonlinearity in reconciling theoretical and observed stability, though it is focused on buckling rather than fatigue or serviceability. The full text is available via the publisher Sciedo. A.D. Danciu et al.'s 2023 review "A Review of the Network Arch Bridge" (Applied Sciences) consolidates decades of research and, while not itself a parametric FEM study, surveys foundational analytical work and recent numerical investigations of steel NABs. The review outlines numerical modeling techniques, mechanical advantages, and historical development, and highlights trends concerning hanger spacing, inclination, arch geometry, and deck stiffness in stability and fatigue research. Though it contains no new numerical results, it is a valuable resource for locating seminal publications and understanding the theoretical basis for modern parametric FEM studies.

Access via MDPI. Jorquera-Lucerga and Garcia-Guerrero's "Preliminary Design and Parametric Study of Minimum-Weight Steel Tied-Arch Bridges" (Applied Sciences, 2025) emphasizes optimization and iterative parametric FEM to minimize weight while meeting deflection limits. Their exploration of span, rise, and cross-section effects is directly applicable to network arch systems, even though their focus is tied rather than network arches; the approach is adaptable but does not address the complex intersecting hanger patterns unique to network configurations.

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Table 1 Summary of Recent FEM-Based Parametric Studies on Steel Network Arch Bridges

Author(s) & Year	Methodology	Parameters	Key Findings
Lia et al. (2023)	Finite Element Modeling (Midas Civil), static, dynamic, fatigue, and stability analysis	Composite section properties, hanger layout, arch rib configuration, stiffness distribution	Optimized steel-UHPC composite network arch improved stiffness, stability, and reduced CO_2 emissions compared to conventional systems. Hanger arrangement significantly influenced structural performance.
Jiang et al. (2024)	Analytical formulations validated through parametric FEM analysis	Rise-to-span ratio, hanger inclination, arch stiffness, geometric imperfections	Network arches exhibit unique out-of-plane buckling behavior due to overlapping hangers. Geometric imperfections strongly affect stability predictions.
Blonka & Skretkowicz (2022)	Nonlinear FEM, eigenvalue buckling analysis, geometric nonlinear analysis with UGLI imperfection modeling	Arch slenderness, cable pretension, geometric imperfections, defect amplitudes	Geometric nonlinearity, hanger prestress, and imperfections significantly influence ultimate load-carrying capacity and post-buckling behavior.
Danciu et al (2023)	Comprehensive literature review of analytical and numerical studies	Hanger spacing, hanger inclination, arch geometry, deck stiffness, fatigue performance	Identified key factors affecting structural efficiency, stability, and fatigue resistance. Summarized trends in numerical modeling and optimization studies.
Jorquera-Lucerga & Garcia-Guerrero (2025)	Iterative parametric FEM and optimization analysis	Span length, rise ratio, cross-sectional dimensions, structural weight	Minimum-weight bridge designs can be achieved while satisfying serviceability requirements

Finite element modelling has emerged as the primary method for examining network arch bridge behavior, as the examined literature shows. Stability, buckling resistance, weight optimization, geometric flaws, and material efficiency have been the main topics of previous research. However, there are a number of clear limits. First, most studies only assess a narrow range of hanger inclinations or concentrate on certain bridge layouts, which limits how broadly the results can be applied. Second, most published research focuses on stability performance or static behavior, and there are still few thorough analyses that take into account both wind and nonlinear seismic loading. Third, there is disagreement about the ideal cross-angle range that concurrently reduces excessive hanger forces, tie-beam stress, and arch compression, despite the fact that hanger arrangement is acknowledged as a crucial design component. Finally, few studies provide direct comparisons of multiple hanger configurations under identical loading scenarios. Consequently, there remains a need for a systematic parametric study that quantifies the influence of hanger cross-angle on the structural response of steel network arch bridges under realistic dynamic loading conditions. This study aims to fill this research gap through a detailed nonlinear finite element investigation and comparative assessment of nineteen hanger configurations.

III. RESEARCH METHODOLOGY

This research adopts a computational-analytical approach using advanced three-dimensional nonlinear FEM to carry out a parametric investigation of a steel network arch bridge's structural performance. A systematic workflow will ensure appropriate model selection, parameter consistency, and rigorous interpretation of results.

A representative steel NAB studied by Edgar Garcia DA Silva Brito (2009) will be selected as a reference model. Baseline geometric parameters – span, rise-to-span ratio, arch rib cross-section, deck system, and hanger layout – will be chosen based on studied NABs and material parameters based on Rane et al. (2024) article. The structural system comprises steel arch ribs, tie girders, deck beams, and inclined hangers. Three-dimensional models will be developed in the FEM environment Midas Civil. Arch ribs and tie girders will be idealized as beam elements; hangers as tension only truss elements.

Four restraint conditions that do not allow rotation, LRBs that permit longitudinal movement, LRB that accommodate transverse movement, and LRBs designed for multidimensional movement in four edge supports conditions and load scenarios will be prescribed following bridge engineering practice. Loads include self-weight, superimposed dead loads, live vehicular loads, and lateral wind loads. Initial prestress in hangers will be applied to emulate construction conditions. Linear static analysis will be conducted first to obtain baseline responses—displacements, axial forces, bending moments, and stress patterns—verifying model fidelity against structural mechanics expectations.

Stability and ultimate behavior will be assessed using geometrically and materially nonlinear analyses, and nonlinear time-history simulations considering El Centro Earthquake vibration data to determine ultimate capacities and internal force redistribution.

A systematic parametric study will be executed by varying parameters such as rise-to-span ratio, cross-sectional properties, hanger quantity (kept constant here), and hanger

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cross-angle according to a structured hanger-layout scheme. Parameter ranges is chosen within realistic engineering limits drawn from prior studies. A parameter matrix will be established so each variation is evaluated under identical loading and boundary conditions. Sensitivity analyses will identify the influence of each parameter on peak axial forces, bending moments, shear forces, and stress distribution.

A mesh convergence study will ensure numerical accuracy. Outcomes will illuminate how geometric and mechanical variables govern NAB behavior and stability, informing design recommendations and optimization strategies.

MIDAS Civil is the FEM platform for modelling bridge response to applied loads. The finite element model includes principal bridge components—arch ribs, tie beams, hangers, stringers, cross girders, and bracing—and incorporates the steel material properties to realistically represent structural behavior under the prescribed loading. Axial forces and moments in the tie beam, arch rib, hangers, and other components were extracted to compare 19 hanger configurations with variation of constant cross angles from 25° to 90°. Model details are provided in subsequent sections.

➢ *Materials*

The main materials analyzed for the bridge consist of steel and concrete. For the structural components, Grade E350 steel is utilized for the transverse beam, longitudinal girder (tie beam), plan bracing, and arch beam, while E550 steel is used for the hanger profile. The concrete specification for the deck is M40. Additionally, the tensile strength of the hanger cable is assessed at 1030 MPa.

➢ *Geometry*

The bridge features a span of 100 meters and a width of 13 meters, with a central rise of 17 meters, which is nearly optimal. This design helps reduce material costs since a greater rise would decrease bending moments but require more materials. Cross girders are placed at intervals of 2.5 meters along the length of the bridge to connect the tie beams. The hangers that link the arch ribs to the tie beams form cross angles ranging from 25º to 90º and each model consists of 23 hangers in both right and left skewed in each tie beam. Arch beam placed 10° slope towards center of bridge alignment. Nine rib bracings are situated between the arch ribs, while lateral bracings connect from these ribs to the joints of the arch beam at each panel. Every component of the bridge is engineered in accordance with IRC 6:2017 standards, ensuring they possess specific cross-sectional properties suitable for accommodating applied forces. Fig. 1 shows a 3D view of finite element model, Fig. 2 and 3 showed a bridge plan and elevation respectively.

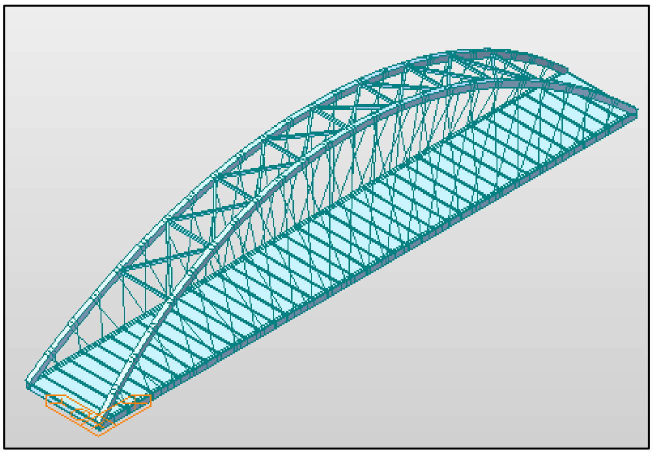

Fig 1 3D View of Finite Element Model

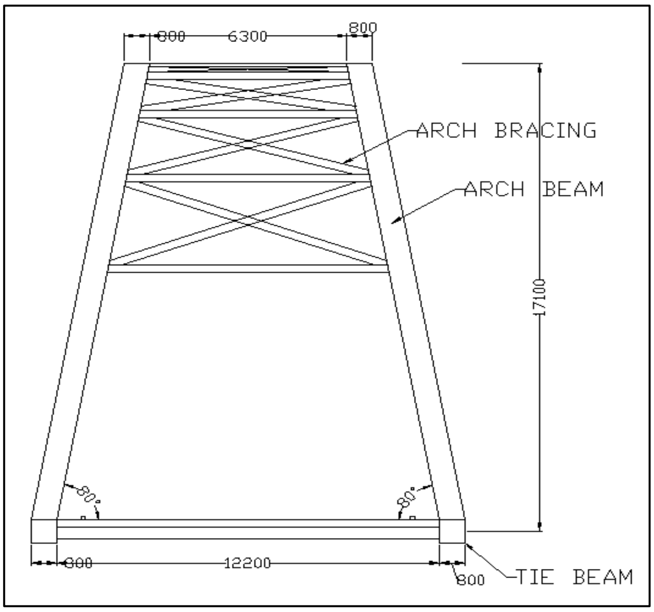

Fig 2 Side View of Bridge

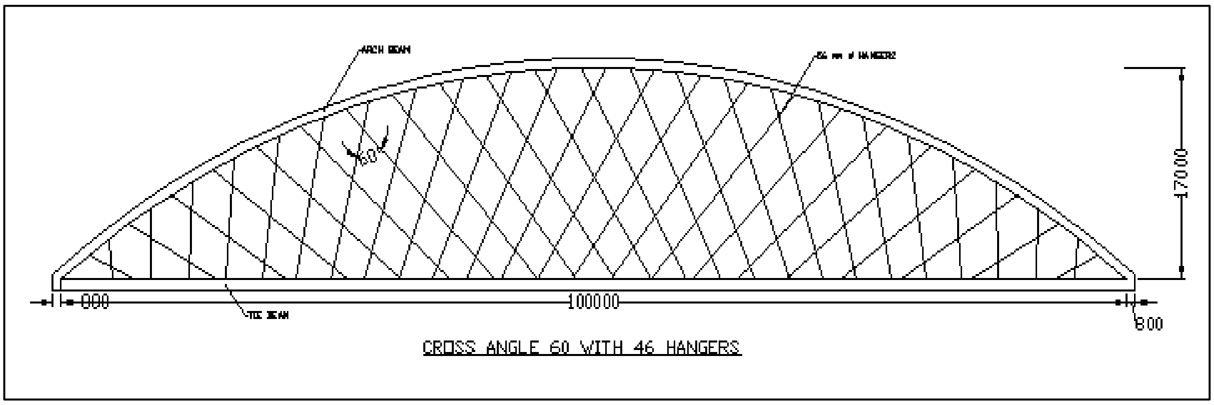

Fig 3 Elevation of Bridge

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The table 1. below presents the geometrical dimensions of various structural members.

Table 2 Properties of the Sections.

Component	Cross-Section Type	Flange Plate Details (mm)	Web Plate Details (mm)
Arch Rib	Steel Box Girder	800 x 32 x 2	836 x 32 x 2
Tie Beam	Steel Box Girder	800 x 32 x 2	636 x 32 x 2
Cross Girders	Steel Built up Girder (Single Web)	300 x 16 x 2	700 x 10 x 1
Lateral Bracing	Steel Box Girder	320 x 10 x 2	280 x 10 x 2
Rib Bracing	Steel Box Girder	320 x 10 x 2	280 x 10 x 2
Hangers	Post Tension Bars	56 mm dia.	

➢ *Connection and Supports*

The joints in a steel tied arch bridge play an essential role in facilitating effective load distribution and maintaining structural stability. In this configuration, the majority of the joints are designed as fixed to withstand moments and shear forces. Conversely, the connections for tie lateral bracing are treated as hinged, permitting rotational movement which helps mitigate stress accumulation at these junctions.

Moreover, four distinct types of bearings are employed to manage movements and stresses at the support points. Each of these supports is strategically assigned within the model to ensure that the bridge effectively reacts to thermal expansion, vehicle loads, and various other dynamic influences.

➢ *Loading Cases and Load Transfer Mechanism*

In this analysis, the bridge was subjected to various load cases following the IRC 6: 2017, IRC 114:2018, IRC 83 Part 2:2018 guidelines. The primary load cases considered are Dead Load (DL), Live Load (LL), Moving Vehicle Load (MVL), Wind Load (WL), Earthquake Load (EQ), Temperature Load (TL), Braking Load (BR). Each of these loads was individually and their load combination as per Table B-2 of IRC-6:2017 has been selected for design results. The following parameters and values have been considered in the analysis. Static Wind Analysis, Moving Load Analysis, and Time History Analysis using serve earthquake vibration data of El-Centro under moving load analysis was done considering IRC Class A and 70R loading.

In the steel tied arch bridge, the load transfer mechanism is activated through interactions between the different structural members. The deck, which carries vehicular loads, transfers these loads to the cross girder. Then the cross girder transfers the loads to the tie beams, which distribute the forces to the hangers. The hangers transport these forces upward to the arch rib, which withstands the compressive loads. At the same time, the tie beam at the bottom of the bridge resists the outward thrust of the arch, thus preventing its spread and ensuring the integrity of the structure. Tie lateral bracings and rib bracings are employed in the analysis model as a measure of strength to counter the lateral force that is acting on the structure.

➢ *Finite Element Model Validation*

This study's finite element modelling approach was verified by contrasting it with known analytical behavior documented in earlier network arch bridges. The modelling strategy adheres to the suggestions made by Brito (2009), Lai et al. (2023), and Jiang et al. (2024), in which hangers are modelled as tension-only truss elements and arch ribs and tie beams are represented using beam elements. Geometric proportions, material characteristics, and support conditions were chosen within the ranges frequently documented in network arch bridge studies that have been published.

To guarantee numerical accuracy and stability, a mesh convergence evaluation was carried out. Until the variation in important response parameters, such as displacement and axial force, remained within acceptable engineering tolerance, a number of mesh densities were assessed. Large displacement effects were taken into consideration by incorporating geometric nonlinearity, and realistic building conditions were represented by hanger prestressing. The chosen modelling assumptions are in line with approaches documented in recent literature and offer a plausible depiction of the structural behavior of steel network arch bridges.

➢ *Loading Cases and Load Transfer Mechanism*

Table 3 Load Parameters Considered in the Analysis

Load		Data and References
Dead Load	Self-weight	As modeled
	Wearing course	9.45 kN/m
	Crash barriers	1.25 kN/m
Live Load	IRC Class A and 70R Vehicle	IRC 6:2017
	Pedestrian Live Load	4.25 kN/m
	Braking Load	20% of Vehicle Live Load
Wind Load	Wind Speed	47 m/s
	Exposure Category	C
	Gust factor	2

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	Transverse wind load	0.78 kN/m
	Longitudinal wind load	3.10 kN/m
Earthquake Load	Time History Analysis	El-Centro Earthquake Data
	Scaling Factor	1
	Duration	50 sec
	Time increment	0.002 sec
	Damping Ratio	0.05
	Step Number	5
Temperature Load	Temperature Range (Min. & Max.)	10.05ºC to 30.05ºC

Table 4 Load Combination for Time History Analysis

COMB1	1.1DL + 1.1WC + 1.1PL + 1.1LL
COMB2	1.1DL + 1.1WC + 0.8PL + 0.8LL + 0.8BRK + 0.84TL
COMB3	1.1DL + 1.1WC + 1.2TL
COMB4	1.1 DL + 1.1 WC + 0.7LL + 0.8PL + 0.7BRK + 0.96TL
COMB5	1.1DL + 1.1WC + 0.7PL + 0.7LL + 0.7BRK + 0.96TL
COMB6	DL + WC
COMB7	DL + WC + 0.8PL + 0.8BRK + 0.7TL
COMB8	DL + WC + TL
COMB9	DL + WC + 0.7PL + 0.7 BRK + 0.8TL

Table 5 Load Combination for Wind Load Analysis

COMB1	1.1DL + 1.1WC + 1.1LL
COMB2	1.1DL + 1.1WC + 0.8BRK + 0.8LL + 0.35WL + 0.84TL
COMB3	1.1DL + 1.1WC + 0.8BRK + 0.8LL - 0.35WL + 0.84TL
COMB4	1.1DL + 1.1WC + 0.7LL + 0.96TL + 0.35WL + 0.7BRK
COMB5	1.1DL + 1.1WC + 0.7LL + 0.96TL - 0.35WL + 0.7BRK
COMB6	1.1DL + 1.1WC + 0.96TL + 0.7WL
COMB7	1.1DL + 1.1WC + 0.96TL - 0.7WL
COMB8	DL + WC + 0.8PL + 0.8BRK + 0.7TL + 0.25WL
COMB9	DL + WC + 0.8PL + 0.8BRK + 0.7TL - 0.25WL
COMB10	DL + WC + 0.7PL + 0.7BRK + 0.8TL + 0.25WL
COMB11	DL + WC + 0.7PL + 0.7BRK + 0.8TL - 0.25WL
COMB12	DL + WC + 0.8TL + 0.5WL
COMB13	DL + WC + 0.8TL - 0.5WL
COMB14	1.1DL + 1.1WC + 1.2TL
COMB15	DL + WC + PL
COMB16	DL + WC + TL

IV. RESULTS AND DISCUSSIONS

Midas Civil software has been used to perform finite element analysis to analyze the major structural components for different hangers' arrangements. Results for axial forces, shear, torsion & moment diagrams, and deflection profiles are illustrated below.

➢ *Maximum Shear Forces Due to Superstructure*

Across wind and time history analysis, the maximum and minimum shear forces in the superstructure vary only slightly as the hanger cross-angle changes, indicating limited sensitivity to cross angle and a dependence on hanger inclination. Overall, shear demands are well distributed, the hanger system performs stability under static and dynamic loading, and cross-angle variations produce only minor shear fluctuations.

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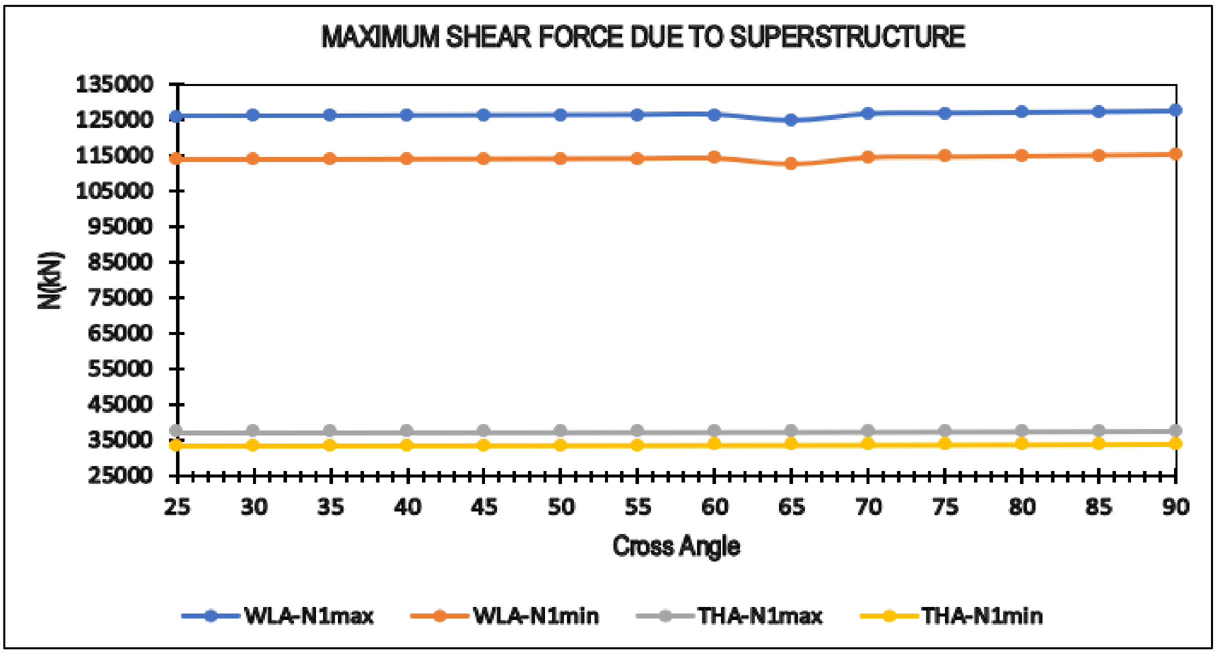

Fig 4 Maximum Shear Force Due to Superstructure

➢ *Maximum Axial Forces in the Hangers*

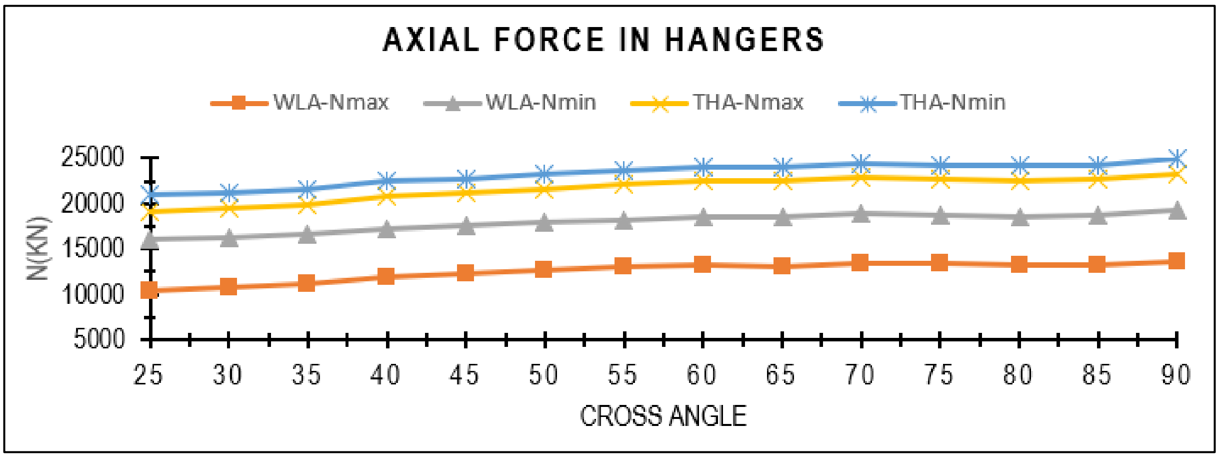

Fig 5 Maximum Axial Force in Hangers

Hanger axial forces increase as cross-angle goes from 25º to 90º. Initial Hanger prestressing force was taken as 1 kN for each hanger. Wind loading produces the highest peak tension – up to about 13,548 kN at 90° - highlighting wind's significant role in hanger design. Seismic actions also raise hanger forces with angle but to a much lesser extent than wind. Minimum tensions vary within a narrow band, particularly under seismic loading, suggesting earthquakes do not cause wide variations in hanger tension. Overall, cross-angles near 80° - 90° generate large peak forces, implying higher capacity requirements for near-vertical hangers and confirming the direct impact of cross-angle on force distribution and structure efficiency.

The network arch system's shifting load-transfer mechanism can account for the observed rise in hanger tension with increasing cross-angle. A greater percentage of the vertical deck load is transferred straight through the hangers to the arch rib as the hangers get steeper. This lowers force demand in the tie beam and boosts axial load transfer efficiency, but it also raises tensile demand in the hanger system. Moon et al. (2009) and Lai et al. (2023) revealed similar results, noting that steeper hanger arrangements increase structural rigidity but necessitate a larger hanger capacity. The current findings support the idea that excessive cross-angles that approach vertical orientation may not always be ideal since the ensuing rise in hanger tension may have a negative impact on fatigue. The current findings support the idea that large cross-angles that approach vertical orientation may not always be ideal since the ensuing rise in hanger tension may negatively impact fatigue performance and susceptibility in situations involving unintentional hanger loss.

➢ *Maximum Axial Forces in Arch Beam*

Arch axial forces remain compressive across conditions and show limited sensitivity to hanger cross-angle. Under wind loads, N_{1max} is about −130,000 kN and remains roughly constant between 25° and 90°, indicating substantial axial

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compression largely independent of hanger inclination. Wind-related N_{2max} ranges between −225,000 and −235,000 kN, with a slight decline at steeper angles. Time-history loading produces much larger compressive forces: THA-N_{1max} approaches −270,000 kN and THA-N_{2max} reaches −310,000 to −350,000 kN. These THA results suggest compression reduces noticeably at higher cross-angles as geometric efficiency improves and dynamic axial demand falls. In summary, THA-N_{2max} governs arch axial behavior, and increasing hanger angle tends to reduce dynamic compressive demand on the arch.

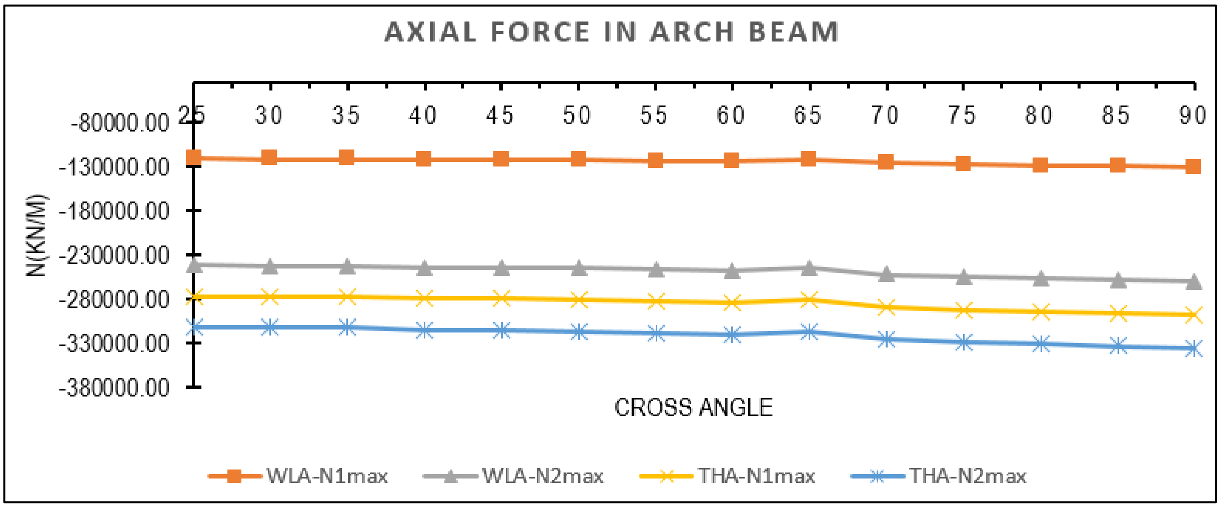

Fig 6 Maximum Axial Force in Arch Beam

* *Maximum Bending Moment in the Arch Beam*

Arch bending moments (M_1 and M_2) under wind and seismic loading vary with hanger cross-angle from 25° to 90°, but the arch beam's bending response is not strongly affected by angle. Wind M_{1max} lies roughly between 11,000 and 13,000 kN·m, while dynamic amplification under THA raises moments substantially—THA-M_{1max} around 35,000–38,000 kN·m and THA-M_{2max} reaching 44,000–47,000 kN·m. Thus, bending is largely driven by dynamic loading, especially in the M_2 direction, whereas hanger cross-angle exerts a smaller influence.

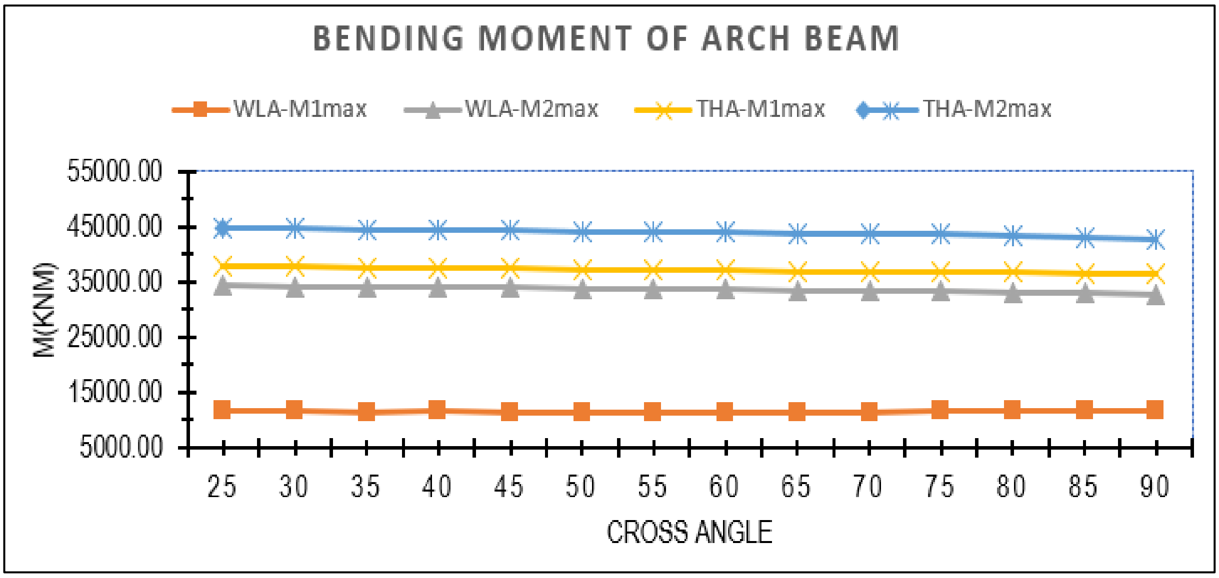

Fig 7 Maximum Bending Moment in Arch Beam

* *Maximum Axial Forces in the Tie Beam*

Tie beam axial forces show greater sensitivity to hanger cross-angle than do bending moments. WLA-N_{2max} ranges about 315,000–340,000 kN and decreases as hanger angle increases. Under THA, THA-N_{1max} is roughly 360,000–390,000 kN and THA-N_{2max} is about 400,000–430,000 kN, the highest observed values. Compared with arch bending, tie axial forces decline with steeper hanger angles, suggesting steeper hangers reduce axial demand on the tie. THA-N_{2max} consistently governs tie design under dynamic loading. Overall, hanger cross-angle markedly affects tie axial efficiency in dynamic scenarios.

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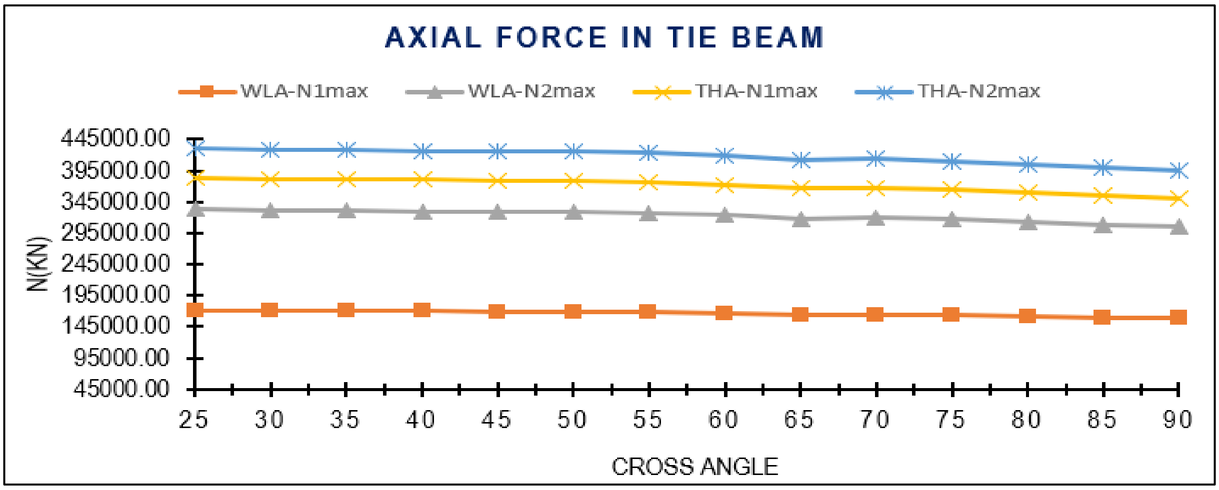

Fig 8 Maximum Axial Force in Tie Beam

➢ *Maximum Bending Moment in the Tie Beam*

Tie beam bending moments are modest relative to the arch. WLA-M_{1max} attains 24,000–26,000 kN·m and decreases as cross-angle increases from 25° to 90°. WLA-M_{2max} remains fairly constant at about 10,000–11,000 kN·m. Under THA, bending moments are significantly lower: THA-M_{1max} ~7,000–8,000 kN·m and THA-$_{M2max}$ ~3,000–4,000 kN·m. In general, tie bending reduces slightly with higher cross-angles, confirming the tie functions primarily as a tension member with secondary bending effects across hanger layouts. Y- and Z-axis behavior of tie elements differs visibly with hanger cross-angle.

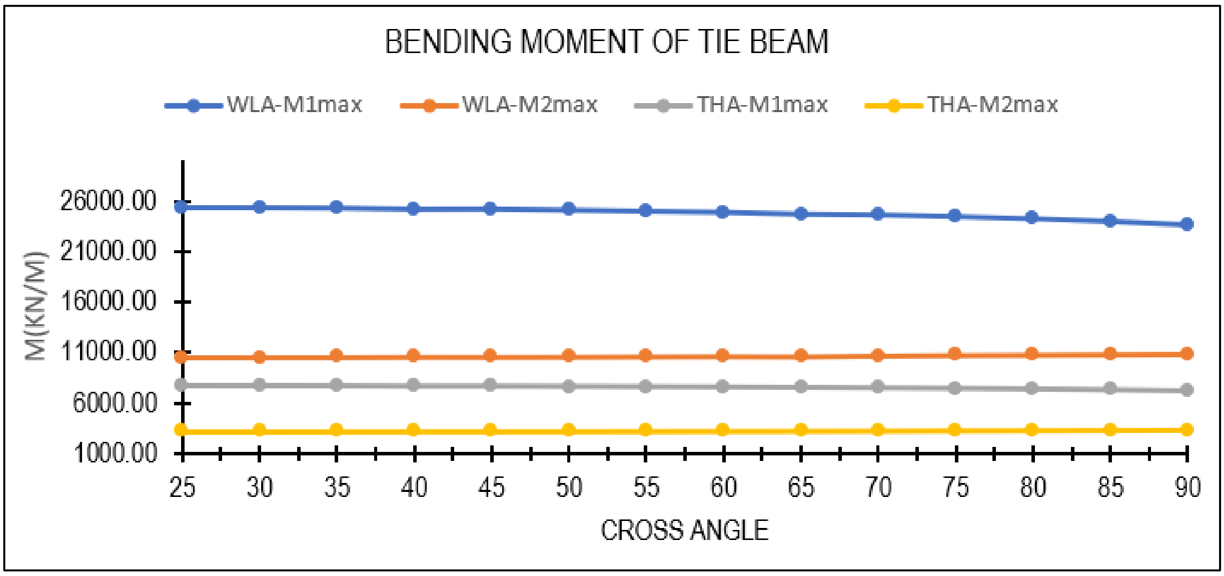

Fig 9 Maximum Bending Moment in Tie Beam

V. CONCLUSION

This study used three-dimensional nonlinear finite element analysis to examine the impact of hanger cross-angle on the structural behavior of a 100-meter steel network arch bridge. Nineteen hanger layouts with angles ranging from 25° to 90° were assessed using nonlinear seismic time-history analysis and IRC-based wind loading.

The findings show that dynamic loading causes far larger force demands than static wind loading and controls the bridge's structural reaction. Increasing the hanger cross-angle often results in lower tensile forces in the tie beam and compressive forces in the arch rib, suggesting better force redistribution and structural efficiency. On the other hand, steeper hanger designs result in significantly higher hanger tension, especially when there is wind loading. While tie-beam axial forces strongly depend on hanger geometry, arch bending moments are largely insensitive to hanger-angle variation.

Hanger cross-angles between 60° and 75° offer the best balance between hanger force requirement, tie-beam tension, and arch compression among the configurations examined. While avoiding the severe hanger forces connected to near-vertical configurations, this range provides better dynamic performance. For steel network arch bridges exposed to combined wind and seismic effects, the study suggests the 60°–75° range as a feasible design interval.

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This study's main contribution is the quantitative assessment of hanger-angle effects under nonlinear seismic stress and wind utilising a consistent finite element methodology. The results set a standard for future research on structural robustness, hanger loss scenarios, and structural health monitoring applications. They also offer useful advice for designers looking for effective hanger configurations.

The findings should be evaluated in light of the bridge shape, material characteristics, support circumstances, and loading assumptions that were examined. The analysis should be expanded to include various span lengths, arch-rise ratios, traffic loading patterns, gradual hanger-loss scenarios, and experimental validation of finite element predictions in subsequent research.

FUTURE RESEARCH DIRECTIONS

In order to evaluate structural robustness, future studies should examine network arch bridge performance under multiple damage scenarios, gradual collapse, and sudden hanger loss. To confirm the applicability of the suggested 60°–75° hanger-angle range, more research with varying span lengths, rise-to-span ratios, hanger densities, and geometric shapes is advised. To gain a better understanding of long-term structural behavior, advanced seismic analysis utilising numerous earthquake records, wind-induced vibration studies, and fatigue assessments should be carried out. Additionally, incorporating machine learning methods, experimental validation, and structural health monitoring (SHM) will boost confidence in finite element-based design recommendations and increase damage detection capabilities.

REFERENCES

[1]. Belevicius, R., Juozapaitis, A., & Rusakevičius, D. (2018). Parameter study on weight minimization of network arch bridges. Periodica Polytechnica Civil Engineering, 62(1), 48-55.
[2]. Błonka, A., & Skrętkowicz, Ł. (2022). Nonlinear buckling analysis of network arch bridges. Studia Geotechnica et Mechanica, 44(2), 123-137.
[3]. Brunn, B., & Schanack, F. (2003). Calculation of a double track railway network arch bridge applying the European standards. Germany: TU-Dresden.
[4]. Bruno, D., Lonetti, P., & Pascuzzo, A. (2016). An optimization model for the design of network arch bridges. Computers & Structures, 170, 13-25.
[5]. Bruno, D., Lonetti, P., & Pascuzzo, A. (2018). A numerical study on network arch bridges subjected to cable loss. Int. J. Bridge Eng, 6(2), 1-19.
[6]. Danciu, A. D., Guțiu, Ș. I., Moga, C., Dragomir, M. L., Ciotlăuș, M., & Marusceac, V. (2023). A review of the network arch bridge. Applied Sciences, 13(19), 10966.
[7]. De Zotti, A., Pellegrino, C., & Modena, C. (2007). A parametric study of the hanger arrangement in arch bridges. In ARCH'07-5th International Conference on Arch Bridges (pp. 475-482).
[8]. GARCIA, E. (2009). DESIGN OF NETWORK ARCH BRIDGES.".
[9]. Islam, N., Rana, S., Ahsan, R., & Ghani, S. N. (2014). An optimized design of network arch bridge using global optimization algorithm. Advances in Structural Engineering, 17(2), 197-210.
[10]. Järvenpää, E., & Laaksonen, A. (2023, October). Form-finding of constant stress arch in network tied-arch bridge. In International Conference on Arch Bridges (pp. 325-332). Cham: Springer Nature Switzerland.
[11]. Järvenpää, E., Laaksonen, A. (2025). Form-Finding of Constant Stress Arch in Network Tied-Arch Bridge. In: Briseghella, B., Contento, A., Liu, J. (eds) Proceedings of ARCH 2023. ARCH 2023. Structural Integrity, vol 32. Springer, Cham. https://doi.org/10.1007/978-3-031-83508-7_36
[12]. Jiang, Z., Xiao, R., Song, C., Sun, B., Tong, S., & Ma, Y. (2024). An analytical method for out-of-plane stability assessment of network arch bridges. Thin-Walled Structures, 204, 112289.
[13]. Jorquera-Lucerga, J. J., & García-Guerrero, J. M. (2025). Preliminary Design and Parametric Study of Minimum-Weight Steel Tied-Arch Bridges Obtained According to a Maximum Allowable Deflection Criterion. Applied Sciences, 15(18), 10022.
[14]. Lai, Y., Li, Y., Huang, M., Zhao, L., Chen, J., & Xie, Y. M. (2023). Conceptual design of long span steel-UHPC composite network arch bridge. Engineering structures, 277, 115434.
[15]. Lonetti, P., & Pascuzzo, A. (2020). A practical method for the elastic buckling design of network arch bridges. International Journal of Steel Structures, 20(1), 311-329.
[16]. Naess, A. (2014). System Reliability Analysis of Slender Network Arch Bridges.
[17]. Olaszek, P., Świercz, A., Wyczałek, I., & Kołakowski, P. (2025). Monitoring and numerical analyses of the steel railway arch bridge: a case study. Journal of Bridge Engineering, 30(1), 05024007.
[18]. Pettersen, E. F., & Hovde, R. H. (2024). Dynamic Analysis of Network Arch Bridge Subjected to Train Traffic.
[19]. Rane, P. R. (2024). Analysis of long span steel tied arch bridges. *International Journal for Research in Applied Science and Engineering Technology*.
[20]. Schanack, F. (2009). In-plane arch buckling of network arch bridges. Paper for the 2009 World Steel Bridge Symposium.
[21]. Schanack, F., & Brunn, B. (2009). Analysis of the structural performance of network arch bridges. Indian concrete journal, 83(1), 7-13.
[22]. Selvam, E., Antony, C. B., & Kumar, S. V. (2024). Structural optimization of hangers in network arch bridges. *International Refereed Journal of Engineering and Science*, *13*(2), 34–44.
[23]. Tetougeni, C. D., Maiorana, E., Zampieri, P., Pellegrino, C., & Briseghella, B. (2023, October). Structural Integrity of Tied Steel Arch Bridges After Loss Hanger Scenario. In International Conference on Arch Bridges (pp. 218-225). Cham: Springer Nature Switzerland.
[24]. Tetougueni, C. D., Zampieri, P., & Pellegrino, C. (2019). Lateral structural behaviour of steel network

ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/26aug1601

arch bridges. In Proceedings of the 7th ECCOMAS Tematic Conference On Computational Methods In Structural Dynamics And Earthquake Engineering (pp. 5834-5841).
[25]. Tveit, P. (2014). *Systematic thesis on network arches*. University of Agder.
[26]. Whelan, M., Salas Zamudio, N., & Kernicky, T. (2018). Structural identification of a tied arch bridge using parallel genetic algorithms and ambient vibration monitoring with a wireless sensor network. Journal of Civil Structural Health Monitoring, 8(2), 315-330.
[27]. Zampieri, P., Tetougueni, C. D., Maiorana, E., & Pellegrino, C. (2021). Post-buckling of network arch bridges subjected to vertical loads. Structure and Infrastructure Engineering, 17(7), 941-959.