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Evaluation of the Structural Adequacy and Strengthening of a Bailey-type Steel Bridge System Under Eurocode Provisions

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Abstract

Legacy modular steel bridge systems, such as the Bailey bridge, remain crucial assets for military operations and emergency civil infrastructure. However, their structural performance under modern, intensified traffic regimes and Eurocodes remains insufficiently quantified in literature, presenting a critical gap between historical design assumptions and contemporary safety standards. This study applies a scientific research methodology based on 3D spatial Finite Element (FE) modelling and Eurocode limit state theory (EC0, EC1, EC3, EC8) to evaluate the structural adequacy of a 24.38 m span Double-Single (DS) Bailey bridge and propose a novel, non-dismantling structural strengthening framework. Through a deductive analytical approach, 115 Ultimate Limit State (ULS) and 115 Serviceability Limit State (SLS) load combinations were evaluated to identify governing failure modes and stress distribution profiles across critical structural members. The numerical investigation revealed significant structural deficiencies under the modern Eurocode load model and heavy military vehicle loading. To address these limitations, a targeted in-situ strengthening strategy utilizing strategically welded steel stiffening plates was developed and evaluated. The application of this method demonstrated a 57,52% reduction in maximum vertical mid-span deflection and restored member utilization ratios below unity across all critical elements. The novelty of this work lies in establishing a standardized, Eurocode-compliant evaluation and strengthening methodology for historical modular steel trusses, providing a scientifically validated, logistically efficient alternative to full structural replacement.

Keywords

Bailey bridge; load-carrying capacity; strengthening

1. Introduction

Bailey bridges [1–4] exemplify a quintessential model of prefabricated, modular military bridges from the twentieth century, engineered for swift erection without reliance on heavy lifting apparatus. Developed during the Second World War by Sir Donald Coleman Bailey [1], they were extensively utilized by the Allied troops because to its versatility, transportability in standardized components, and adaptability to various spans and loading circumstances. The structural system comprises steel truss panels interconnected to create single or multi-truss girders, facilitating the construction of bridges with diverse load-carrying capacities based on the configuration and quantity of structural elements. The importance of Bailey bridges [13], [24], [25] transcends their initial military purpose, as they have

become the model for contemporary rapid bridge deployment systems utilized in emergencies, including natural catastrophes and infrastructure rehabilitation. Their architectural simplicity, coupled with great structural efficiency, has facilitated their use in distant places with restricted accessibility. Nonetheless, their prolonged operation over many decades inside the Greek road network and beyond poses considerable obstacles. Currently, over 54 Bailey bridges are operational in Greece, facilitating crucial traffic connections across towns and communities nationwide.

The primary problem of Bailey bridges is the escalation of internal stresses and structural deformations due to the rising traffic demand and the enhanced load-carrying capability of contemporary vehicles. Under these conditions, the structural components experience heightened stress and deformation requirements, potentially compromising both the load-bearing capacity and serviceability of the bridges. Furthermore, the increased vertical deflections and dynamic vibrations caused by the passage of heavy vehicles may impair the level of serviceability and generate a perception of insecurity among bridge users, even in circumstances when the ultimate structural capacity has not been achieved. Thus, evaluating the structural performance and load-bearing capability of existing Bailey bridges is essential for guaranteeing their safe and continuous operation.

This study examines the load-carrying capacity of a 24.38 m span Bailey bridge featuring a double-single (DS) truss configuration and a reinforced concrete deck slab. A suitable finite element model is built to examine the structural reaction of the bridge under specified design actions and to evaluate the sufficiency of its individual load-bearing components. According to the analytical findings, reinforcement strategies are recommended for the essential segments of the primary structural components, aiming to enhance the bridge's load-bearing capacity and prolong its operational lifespan.

Numerous researchers have investigated the structural behavior and load-carrying capacity of Bailey bridges. Hornbeck [12] examined the effects of military vehicle loading on Bailey bridges. In study [15], the load-carrying capacity of existing Bailey bridges was evaluated through experimental testing and numerical analyses. The static and dynamic responses of the bridges were monitored using accelerometers and strain gauges. King and Duan [16] presented an experimental investigation involving two full-scale load tests on Bailey bridge sections. The experimental results were compared with the predictions obtained from both elastic and inelastic analyses. King, Wu, and Duan [17] conducted experimental tests on 1:6 scale models of the steel truss system of Bailey bridges. Papavasileiou and Raftoyiannis [22] present an investigation based on experimental measurements accompanied by an analytical assessment of the load-carrying capacity of an aging steel Bailey-type bridge that remains in service. The investigation was carried out through in-situ measurements under both static and dynamic loading conditions, supplemented by laboratory experimental results. Papavasileiou et al. [20] investigated the dynamic behavior of a Triple-Single Bailey bridge. The required vibration modes were identified and compared with the corresponding numerical predictions. Prokop et al. [23] examined the application of a Bailey bridge dismantling system and its compliance with current design standards for steel bridges. Webber [27] investigated the fatigue failure of Bailey bridges and examined the influence of transverse floor beams on their fatigue resistance. Similarly, Papavasileiou and Raftoyiannis [21] studied the fatigue behavior of Bailey bridges. The structural behavior of a Bailey bridge with a reinforced concrete deck is presented in [28]. Kakhrimanis [14] investigated the numerical modeling and structural assessment of pin-connected joints in prefabricated steel bridges. Finally, strengthening strategies for improving the load-carrying capacity of Bailey bridges were proposed in study [18].

While the geometry and component assembly of Bailey bridges are widely documented in technical manuals, published scientific literature lacks a rigorous, systematic methodology for re-evaluating these historical structural systems under current European structural codes (Eurocodes). Most existing studies treat legacy bridges through historical empirical load ratings or propose full structural replacement when load demands increase.

To bridge this gap, this study offers the following novel scientific contributions:

Methodological Framework: It establishes a reproducible, multi-level numerical modeling and evaluation methodology that integrates historical material specifications (BS 968 steel) with Eurocode limit state verifications (EC0, EC1, EC3, EC8).

Structural Behavior Mapping: It provides an in-depth mechanics-based analysis of internal force redistributions, cross-sectional stress concentrations, and global stability modes (flexural and lateral-torsional buckling) unique to Double-Single modular truss configurations under asymmetric modern traffic loadings.

Non-Dismantling Strengthening Strategy: It introduces and verifies a targeted cross-sectional reinforcement methodology using welded steel plates. This approach optimizes structural capacity and stiffness while minimizing added dead load, offering field engineers a scientifically validated alternative to complete bridge dismantling or replacement.

2. Description of the Bailey Bridge structural system

The bridge investigated in the present study is a Bailey bridge (Figure 1) with a span of 24.38 m, configured as a Double-Single (DS) system (Figure 2), and incorporating a reinforced concrete deck slab. Bailey bridges can be assembled in a variety of structural configurations (Figure 2), depending on the arrangement of the truss panels (Table 2). The term Double-Single (DS) refers to the configuration of the truss panels, consisting of two panels in width and one panel in height. The bridge is modeled as a simply supported structure. The deck is supported by two longitudinal steel truss girders, each comprising two rows of truss panels across the width and a single row of panels in height, extending over the full bridge span of 24.38 m. Each truss girder consists of 8 standard Bailey panels, each 3.05 m (10 ft) long, resulting in the total span length of 24.38 m. The truss girders are of Warren-type configuration, with rhombic web members and parallel straight top and bottom chords.

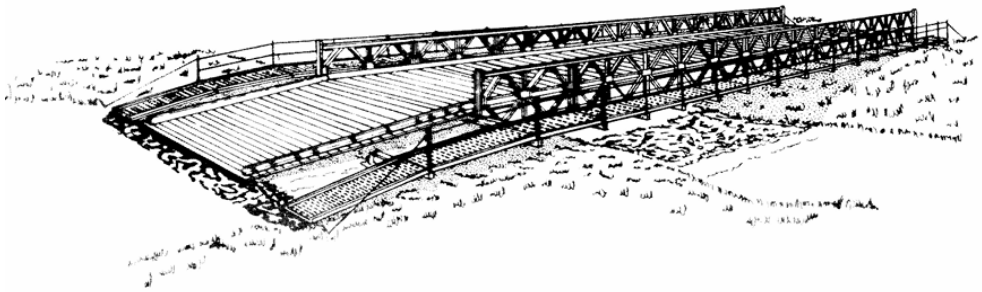


Figure 1. Bailey type bridge [26].

The principal structural components of the Bailey bridge [26] are illustrated in Figure 4 and described below:

a. Panels (Frames): The panel (Figure 3) is the primary load-bearing component of the bridge. It consists of a steel truss assembly with a length of 3.05 m, a height of 1.55 m, and a width of 0.165 m. Each panel weighs 261.72 kg and is designed to be transported manually by six personnel using carrying poles.

b. Transoms: The transoms provide the transverse connection between the longitudinal truss girders. They are rolled steel I-sections with a depth of 0.25 m and a length of 6.07 m. The flange width is 114.3 mm, and the flanges are reinforced with 7.9 mm thick cover plates. Each transom weighs 280.32 kg and can be carried by eight personnel.

c. Stringers: The stringers support the deck system and transfer deck loads to the transoms. Each stringer consists of three welded steel I-sections with a depth of 101.6 mm and a length of 3.05 m, connected through welded splice plates.

d. Chess Panels (Deck Units): The chess panels form the bridge deck surface. They are timber deck units with a thickness of 50.8 mm, a width of 222.3 mm, and a length of 4.22 m. Each unit weighs 29.48 kg.

The Bailey bridge system considered herein comprises structural members fabricated from BS 968:1962 steel, with the corresponding mechanical properties summarized in Table 1; the conventional timber chess panels (deck units) are replaced by a reinforced concrete slab, thereby forming the composite bridge deck considered in the structural analysis.

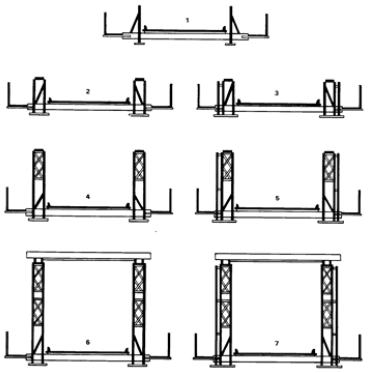


Figure 2. Single, Double, and Triple truss configurations [26].

Table 1. BS 968/1962 Steel Properties

Elastic modulus, E (GPa)	206,8 (30.000 Ksi)
Yield stress, f_y (MPa)	344 (50 Ksi)
Ultimate stress, f_u (MPa)	540 (78 Ksi)

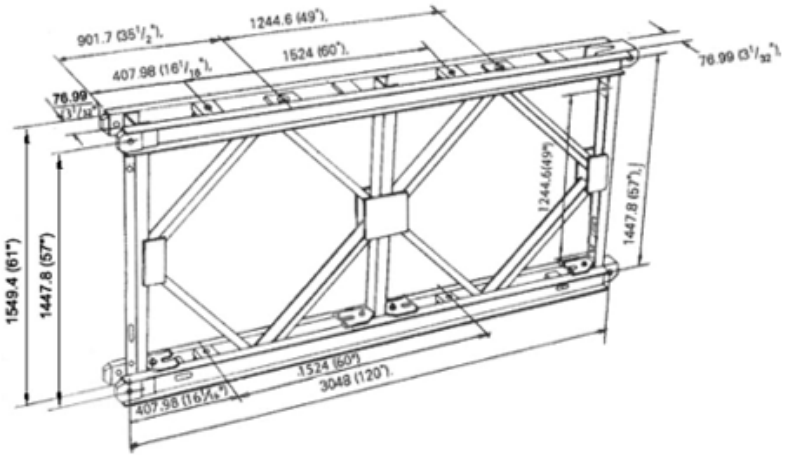


Figure 3. Truss frame of a Bailey bridge [26].

Table 2. Different bridge assemblies [26]

Type		Usual	
Truss	Story	Nomenclature	Description (Abbreviation)
Single	Single	Single - Single	Single-Truss Single-Story (SS)
Double	Single	Double - Single	Double-Truss Single-Story (DS)
Triple	Single	Triple - Single	Triple-Truss Single-Story (TS)
Double	Double	Double - Double	Double-Truss Double-Story (DD)
Triple	Double	Triple - Double	Triple-Truss Double-Story (TD)
Double	Triple	Double - Triple	Double-Truss Triple-Story (DT)
Triple	Triple	Triple - Triple	Triple-Truss Triple-Story (TT)

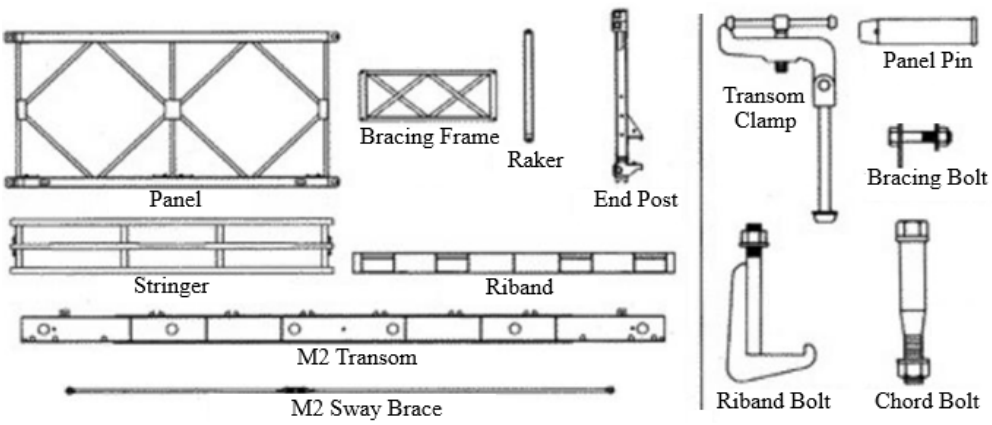


Figure 4. Main load-bearing members of a Bailey bridge [26].

3. Methodology

3.1 Research Problem and Gap

Prefabricated modular steel bridges, such as the Bailey bridge, remain crucial operational assets for both military logistics and emergency civil protection infrastructure. However, modern traffic demands and vehicle Military Load Classifications (MLC) significantly exceed original WWII-era design specifications. Furthermore, structural checks under modern normative frameworks (Eurocodes) frequently identify critical ultimate limit state (ULS) and serviceability limit state (SLS) deficiencies. Existing research primarily focuses either on historical load ratings or complete bridge replacement, leaving a research gap regarding localized, rapid-deployable structural strengthening techniques that maintain operational continuity without full dismantling.

3.2 Research Aim and Objectives

The primary aim of this study is to perform a comprehensive structural adequacy assessment of a 24.38 m span Double-Single (DS) Bailey bridge under Eurocode provisions and to propose and evaluate targeted cross-sectional strengthening strategies. The specific objectives are:

a. To construct a 3D FE spatial model reflecting exact bridge geometries, members, and joint configurations.

b. To compute static and dynamic responses under Eurocode load combinations (ULS, SLS, and seismic).

c. To identify critical failure modes and member demand-to-capacity (utilization) ratios.

d. To design localized steel-plate welding interventions and quantify their effectiveness in mitigating stress concentrations and deflections.

3.3 Research Approach, Reasoning, and Hypotheses

This study adopts a quantitative research approach utilizing numerical modelling and structural simulation. The study follows deductive reasoning, applying generalized structural engineering principles and Eurocode design rules to test specific numerical hypotheses:

Hypothesis 1 (H1): Legacy Bailey bridges configured as Double-Single systems fail to comply with modern Eurocode ULS flexural/torsional buckling and SLS deformation limits under heavy commercial and military vehicle loadings.

Hypothesis 2 (H2): Localized section enhancement via welded steel plates can fully restore structural adequacy across all critical members while reducing maximum vertical deflections by more than 50% without requiring structural dismantling.

3.4 Data Collection and Structural Analysis Methods

Data collection relies on geometric specifications from field manuals [26] and material properties for BS 968:1962 structural steel (f_y=344MPa, f_u = 540MPa). Structural analysis is executed using the finite element software SAP2000 [5]. Frame elements are utilized to model trusses, transoms, stringers, and posts, while deck interactions are accounted for via distributed surface actions and rigid link constraints. A suite of 115 ULS, 115 SLS, and 3 seismic load combinations are evaluated under Eurocodes 0, 1, 3, and 8.

3.5 Scientific Approach and Theoretical Foundation

Rather than relying on simple technical exposition, this research constructs its scientific approach by synthesizing classical mechanics of materials, finite element formulation, and limit state structural safety theory. The behaviour of the modular truss bridge is evaluated through structural mechanics principles:

Stress and Force Redistribution:

The spatial interaction between the primary longitudinal trusses, transverse transoms, and timber/steel deck elements is mathematically captured using spatial frame elements with 6 degrees of freedom per node.

Buckling and Instability Modes:

Member checks under Eurocode 3 (EN 1993-1-1) account for second-order effects, non-dimensional slenderness, and imperfection factors to rigorously assess buckling resistance rather than assuming nominal yield capacities.

Stiffness Optimization:

The proposed plate-welding strengthening scheme is formulated based on the principle of maximizing the cross-sectional moment of inertia (I_x, I_y) and elastic section modulus (Wel) with minimal mass addition, thereby improving structural efficiency and dynamic response.

3.6 Discussion of Structural Uncertainties and Model Assumptions

While numerical Finite Element modelling provides detailed stress distributions and deformation responses, operational deployment introduces specific physical uncertainties:

Material Degradation and Fatigue: Multi-decade operational history leads to atmospheric corrosion, cross-sectional thickness losses, and localized fatigue damage around connection holes, which may reduce pristine material capacity.

Connection and Joint Behaviour: Pin connections in Bailey bridges are modelled as ideal pins or rigid frame elements; however, in-field conditions exhibit rotational slip, pin-hole wear, and mechanical tolerances that introduce semi-rigid behaviour and dynamic impact factors.

Boundary and Support Conditions: Soil-structure interaction and differential settlement at temporary abutments in military deployments can alter global internal force distributions relative to idealized simple supports.

To mitigate these uncertainties in the absence of direct field destructive testing on this specific span, the Finite Element modelling methodology employed in this work follows calibrated and experimentally validated modelling techniques established in published literature (e.g., King and Duan 2003, Papavasileiou et al. 2022), ensuring conservative limit state estimates.

4. Modeling and analysis of the Bailey Bridge structural system

The bridge's structural model was created utilizing SAP2000 software [5]. The finite element model of the bridge (Figure 5 and 6) was developed following the approach outlined in [19]. The connections among the structural members were represented as either pinned joints, allowing moment release along the major axis, or as fixed connections, contingent upon the particular scenario examined.

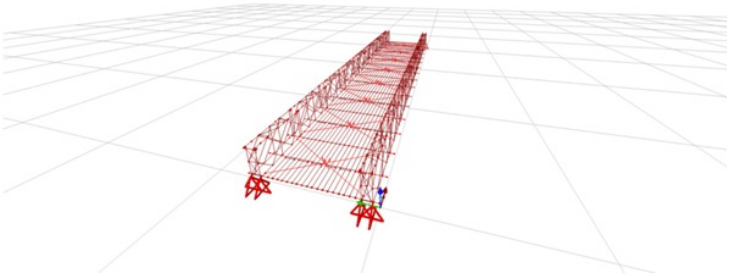


Figure 5. Bailey bridge model.

The design loads are established in compliance with relevant regulatory standards, including Eurocode 1 [7], [8], [11] for permanent and variable actions, and Eurocode 8 [10] for seismic activities. The analyzed loads encompass the self-weight of the structural system, snow loads, wind loads in two directions and both senses, seismic loads in three spatial dimensions, temperature change effects, and traffic loads. Vehicle loads associated with gross weights of 12 t, 20 t, 25 t, 30 t, 35 t, 40 t, 45 t, 50 t, and 60 t were analyzed. A total of 115 ultimate limit state (ULS) load combinations, 115 serviceability limit state (SLS) load combinations, and 3 seismic load combinations were established. Thereafter, the internal force and deformation response of the structural components was assessed.

(a) (b)

Figure 6. Details of a) 3-D design and b) structural model of Bailey Bridge.

A modal analysis was performed to determine the natural frequencies and mode shapes of the steel frame, which are essential for evaluating the structure's dynamic response to seismic excitations in both the x and y directions. The results from the modal analysis due to seismic excitations in the x and y directions are presented in (Figure 7 and 8).

Subsequently, strength and serviceability checks (Figure 9) were carried out in accordance with the provisions of Eurocodes 0 and 3 [6], [9]. The strength checks are performed to ensure that each member of the structural system satisfies the following condition:

$$S_d < R_d \quad (1)$$

where:

S_d: design values of the action effects

R_d: corresponding design values of the resistances

The application of modern design standards [6–11] revealed failures in several structural members, including stringers, transoms, chords, and panel verticals (Figure 9–13). The failure of the aforementioned members is attributed to bending or flexural-torsional buckling, as well as to biaxial bending in the presence of axial force (Table 3).

TABLE: Modal Periods And Frequencies						
OutputCase	StepType	StepNum	Period	Frequency	CircFreq	Eigenvalue
Text	Text	Unitless	Sec	Cyc/sec	rad/sec	rad2/sec2
MODAL	Mode	1	0,479937	2,0836069	13,0916883	171,392302
MODAL	Mode	2	0,339869	2,9423126	18,4870953	341,772693
MODAL	Mode	3	0,267838	3,7336016	23,4589107	550,320493
MODAL	Mode	4	0,242049	4,13139456	25,9583176	673,834253
MODAL	Mode	5	0,213711	4,6792217	29,4004171	864,384523
MODAL	Mode	6	0,193356	5,17180585	32,4954145	1055,95196
MODAL	Mode	7	0,181688	5,50394636	34,5823149	1195,93651
MODAL	Mode	8	0,180979	5,52550491	34,7177713	1205,32364
MODAL	Mode	9	0,160193	6,24247756	39,2226433	1538,41575
MODAL	Mode	10	0,153065	6,53315624	41,0490313	1685,02297
MODAL	Mode	11	0,150487	6,64508538	41,7523028	1743,25479
MODAL	Mode	12	0,147725	6,76932017	42,5328931	1809,04699
MODAL	Mode	13	0,126015	7,93557027	49,8606585	2486,08527
MODAL	Mode	14	0,112308	8,90411978	55,9462346	3129,98117
MODAL	Mode	15	0,111285	8,98595849	56,4604423	3187,78155
MODAL	Mode	16	0,107933	9,2649994	58,2137081	3388,83581

Figure 7. Modal analysis of the Bailey Bridge.

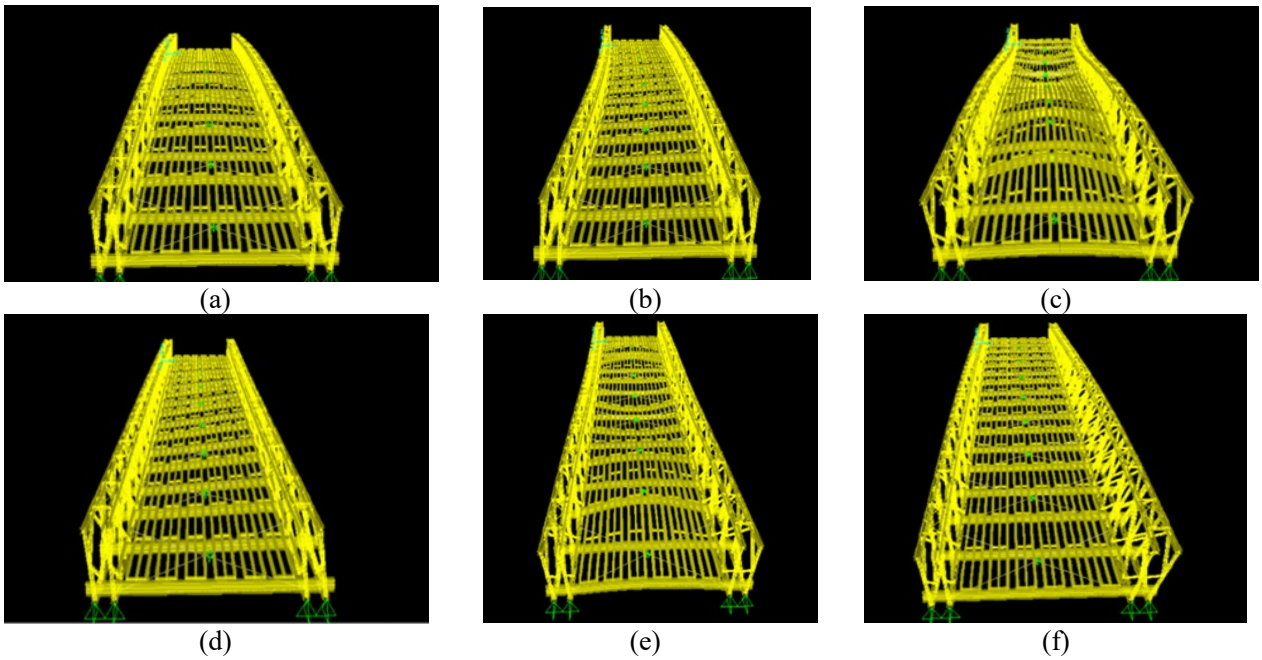


Figure 8. Modal Analysis of the Bailey Bridge a) first, b) second, c) third, d) fourth, e) fifth and f) sixth eigenmode.

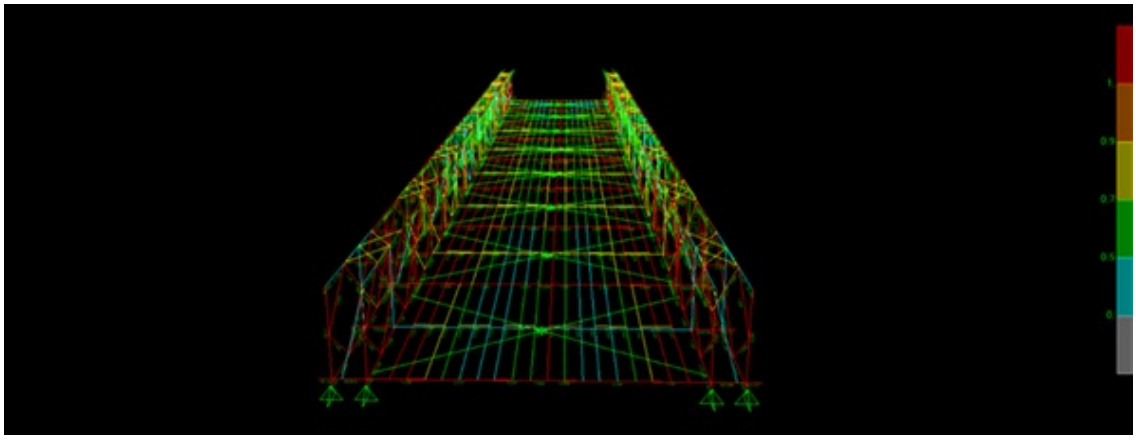
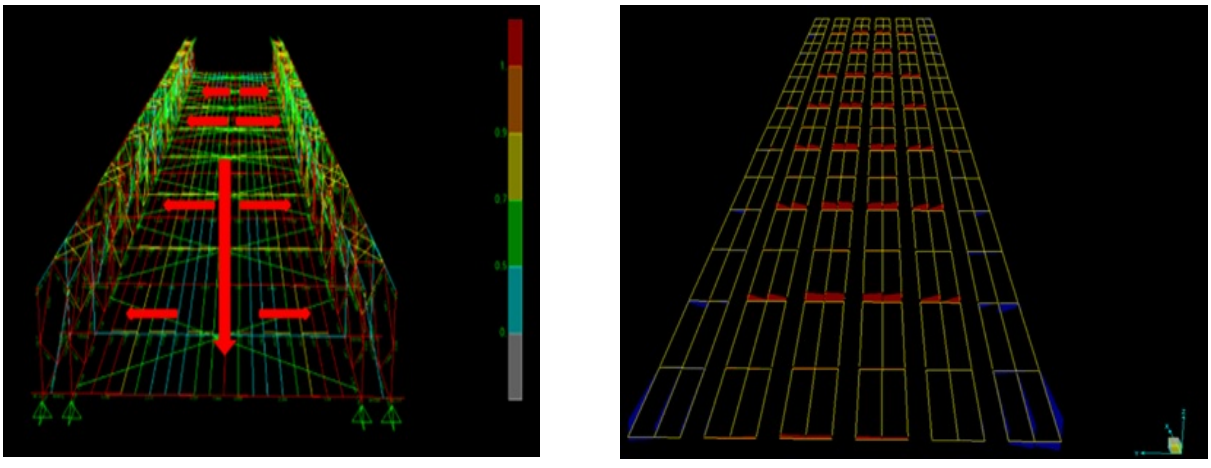


Figure 9. Members' utilization factors of the Bailey Bridge model.

The failing stringers are those located at the side regions of the bridge, near the truss frames, as well as the central stringer in the bridge deck (Figure 10). The failing truss panel flanges are located along the longitudinal axis of the bridge, both in the top and bottom chords of the panels (Figure 11). The failing transoms are located along the longitudinal axis of the bridge (Figure 12). The failing panel verticals (posts) are located on both sides of the bridge's central axis and in the first two panels of the structural system (Figure 13).

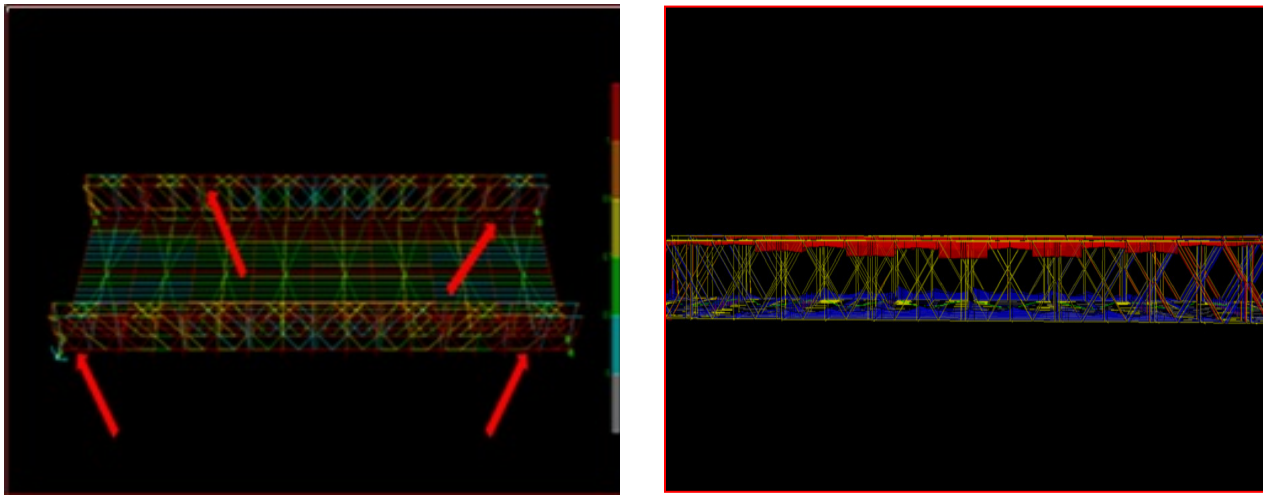
Table 3. Load-bearing members and the corresponding load combinations leading to failure

Structural member	Load combination	Strength check
Stringers	1,35(D+SD)+1,50DT+0,90Q+0,90WP0	$\frac{N_{Ed}}{N_{b,Rd}} < 1{,}0$
Truss panel flanges	1,35(D+SD)+1,50Q+0,75S+0,90WP0 +0,90DT	$\frac{N_{Ed}}{N_{Rd}} + \frac{M_{y,Ed}}{M_{y,Rd}} + \frac{M_{z,Ed}}{M_{z,Rd}} \leq 1$
Transoms	1,35(D+SD)+1,50Q+0,75S+0,90WP0+0,90 DT	$\frac{N_{Ed}}{\frac{x_y N_{Rk}}{\gamma_{M1}}} + k_{yy}\frac{M_{y,Ed}+\Delta M_{y,Ed}}{x_{LT}\frac{M_{y,Rk}}{\gamma_{M1}}} + k_{yz}\frac{M_{Z,Ed}+\Delta M_{z,Ed}}{\frac{M_{z,Rk}}{\gamma_{M1}}} \leq 1$
Panel verticals (posts)	1,35(D+SD)+1,50Q+0,75S+0,90WP0	$\frac{N_{Ed}}{\frac{x_y N_{Rk}}{\gamma_{M1}}} + k_{yy}\frac{M_{y,Ed}+\Delta M_{y,Ed}}{x_{LT}\frac{M_{y,Rk}}{\gamma_{M1}}} + k_{yz}\frac{M_{Z,Ed}+\Delta M_{z,Ed}}{\frac{M_{z,Rk}}{\gamma_{M1}}} \leq 1$



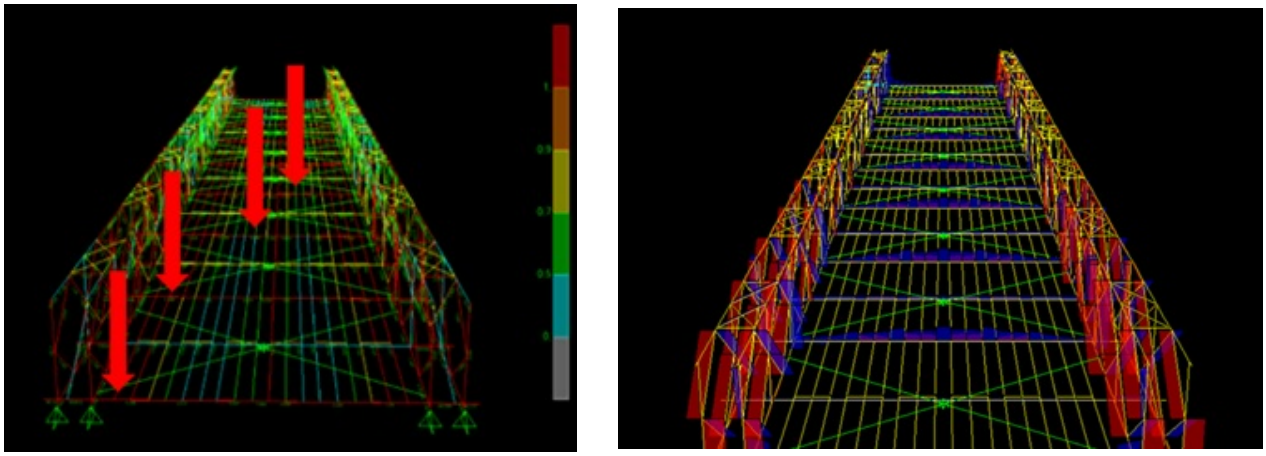
(a) (b)

Figure 10. (a) Stringers, members with failure issues, (b) normal stresses.



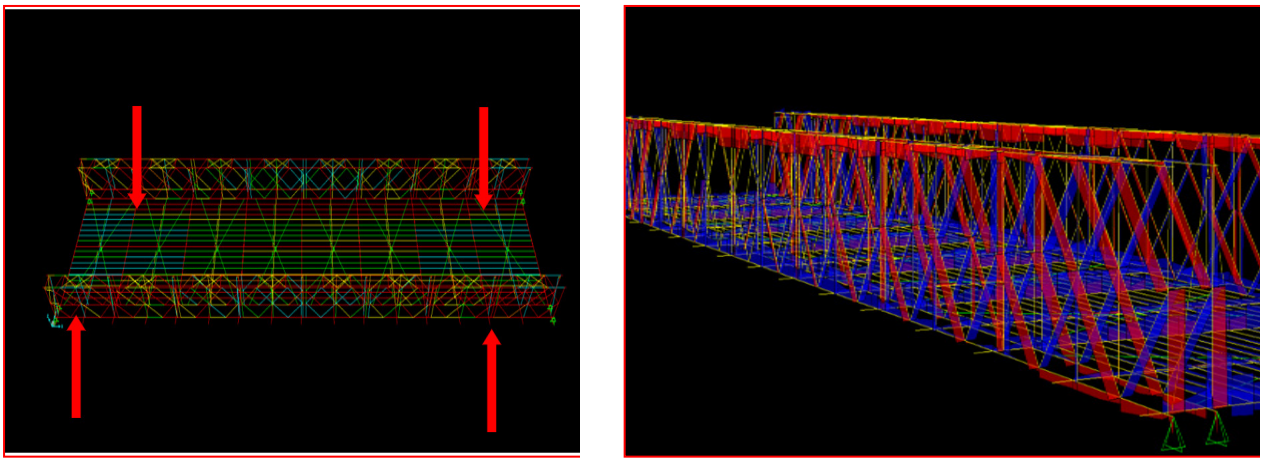
(a) (b)

Figure 11. (a) Truss panel flanges with failure issues, (b) normal stresses.



(a) (b)

Figure 12. (a) Transoms, members with failure issues, (b) normal stresses.



(a) (b)

Figure 13. (a) Panel verticals (posts) with failure issues, (b) normal stresses.

5. Proposals for enhancing the load-carrying capacity of the Bailey Bridge

It was proposed to strengthen the member cross-sections by welding steel plates of appropriate thickness. This strengthening technique aims to enhance the structural performance of the existing elements by improving their stiffness and load-carrying capacity without requiring complete dismantling of the bridge. An alternative solution would be the replacement of the existing members with new elements having suitably designed cross-sections, in order to avoid failure under the checks imposed by current design standards. However, this approach would introduce significant construction and logistical difficulties, particularly in bridges that remain in service, and could potentially alter the original design philosophy and load distribution mechanism of the structural system.

Consequently, the first solution was selected, focusing on improving the relevant inertial properties of the member cross-sections through local or global strengthening interventions, such as increasing the area, depth, or width of the sections, depending on the specific cause of failure (Table 4). This approach ensures compatibility with the existing structural system while providing the required increase in resistance and serviceability performance under modern design loading conditions.

Structural analysis of the bridge was performed, and all required strength and serviceability checks were carried out in accordance with the provisions of the Eurocodes, fully satisfying their requirements. The utilization factors of the load-bearing members demonstrated a significant improvement in the load-carrying capacity of the bridge (Figure 14), indicating that the strengthened configuration performs more efficiently under the considered loading conditions. In particular, after the implementation of the proposed strengthening measures, the demand-to-capacity ratios were substantially reduced, confirming the effectiveness of the intervention in enhancing structural safety and overall performance.

Table 4. Proposed strengthening of load-bearing member cross-sections

Member	Strengthened cross-section region	Initial dimensions (mm)	Final dimensions (mm)	Percentage change (%)
Stringers	flange (t_f)	6	12	100
	web (t_w)	6	12	100
Truss panel flanges	flange (t_f)	10	30	200
	web (t_w)	8	24	200
Transoms	flange (t_f)	12	36	200
	web (t_w)	7,5	22,5	200
Panel verticals (posts)	flange (t_f)	7	21	200
	web (t_w)	4	12	200

Furthermore, the strengthening of the Bailey bridge through cross-sectional enhancement of its load-bearing members also led to a notable reduction in structural displacements (Table 5), thereby improving serviceability conditions and overall structural response under service loads.

(a) (b)

Figure 14. Utilization factors of load-bearing members (a) initial structure and (b) strengthened Bailey bridge configuration.

Table 5. Displacements of the Bailey bridge structural system before and after strengthening intervention

Minimum structural displacement (mm)		
Initial structure	Strengthened structure	Percentage change (%)
1,397	0,660	-52,75%
Maximum structural displacement (mm)		
Initial structure	Strengthened structure	Percentage change (%)
-156,472	-66,472	-57,52%

6. Discussion

6.1 Operational implications and logistical trade-offs

From a military engineering perspective, the decision between structural strengthening and asset replacement in forward or contested environments involves trade-offs among operational continuity, logistical footprint, speed, and cost.

Time-to-strengthen vs. time-to-replace: Replacing an existing operational Bailey bridge requires establishing temporary bypasses, heavy crane equipment, extensive labour, and structural dismantling, often taking several days to weeks. Conversely, localized plate-welding interventions can be executed incrementally beneath or alongside active traffic. Critical member reinforcement can be completed in a fraction of the time (hours to days), minimizing operational downtime.

Logistical footprint in active environments: Modernizing legacy bridges in-situ significantly reduces transport requirements. Transporting raw steel plates and portable welding units requires minimal airlift or ground transport capacity compared to shipping full replacement bridge sets or concrete deck superstructure components into logistically constrained or active combat zones.

Economic and life-cycle efficiency: Strengthening extended-service legacy bridges provides a highly cost-effective extension of operational life, preserving capital resources while maintaining readiness for rapid deployment elsewhere.

6.2 Study limitations, assumptions, and uncertainties

While the developed 3D Finite Element model provides detailed insights into stress distribution and structural response, several inherent modeling assumptions and physical uncertainties should be noted. First, structural joints and panel pins were modeled using idealized boundary conditions (pinned/rigid connections). In practice, joint tolerances, pin-hole wear, and rotational slip can introduce semi-rigid behavior, potentially affecting global deflection and internal force redistribution. Second, the material properties adopted in this study correspond to pristine BS 968 steel; however, multi-decade operational history and environmental exposure may induce localized corrosion, cross-sectional loss, or fatigue damage not explicitly captured in the current FE framework. Finally, perfect simple supports and rigid abutment conditions were assumed, neglecting potential soil-structure interaction or differential support settlements. Although these assumptions align with established guidelines and conservative limit state procedures, future experimental validation and field instrumentation (e.g., dynamic strain monitoring) would further refine the numerical observations.

Conclusion

This study presented a comprehensive, Eurocode-compliant structural evaluation and targeted strengthening methodology for historical Bailey-type modular steel bridges, which continue to serve as critical transport links in remote and disaster-prone regions. By integrating classical mechanics of materials, 3D spatial Finite Element (FE) modeling, and modern limit state theory [6], [9] [10], the research bridged the long-standing gap between WWII-era empirical design standards and contemporary structural safety requirements.

The numerical load-demand investigation under modern traffic actions and dynamic environmental effects revealed that key structural components of the unstrengthened system failed to meet current verification criteria, particularly under combined Ultimate Limit State (ULS) flexural-torsional load actions and Serviceability Limit State (SLS) displacement constraints. To address these vulnerabilities without requiring structural dismantling, a non-

destructive strengthening strategy was formulated based on targeted cross-sectional enhancement via strategically welded steel stiffening plates. The quantitative evaluation of this intervention demonstrated a significant redistribution of internal stresses, a dramatic reduction in critical member utilization ratios below unity, and a 57,52% reduction in maximum vertical mid-span deflections.

Beyond addressing the specific structural deficiencies of the evaluated bridge configuration, this research offers broader scientific utility and enriches the specialized literature on infrastructure rehabilitation in several fundamental ways:

Validation of Modular Infrastructure Longevity: It demonstrates through a rigorous analytical framework that historical modular steel trusses can be successfully upgraded to satisfy stringent modern Eurocode performance criteria without compromising their primary operational advantages of rapid field execution and modularity.

Optimization of Rehabilitation Strategies: It proves that targeted, localized cross-sectional stiffening is scientifically and economically superior to full structural replacement or global over-design, establishing a quantifiable optimum between structural reliability, material efficiency, and logistical footprint in forward or remote environments.

In summary, the developed methodology establishes a standardized, scientifically backed assessment framework that enables field engineers to extend the operational life of vital modular bridge assets safely, efficiently, and in full compliance with modern structural codes.

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