International Journal of Advanced Engineering Research and Science (IJAERS)
Peer-Reviewed Journal
ISSN: 2349-6495(P) | 2456-1908(O)
Vol-10, Issue-1; Jan, 2023
Journal Home Page Available: https://ijaers.com/
Article DOI: https://dx.doi.org/10.22161/ijaers.101.17

A Review on design and analysis of steel bridge with identification of load bearing capacity

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Received: 19 Dec 2022,

Receive in revised form: 16 Jan 2023,

Accepted: 21 Jan 2023,

Available online: 30 Jan 2023

***Keywords*— truss bridges; railway bridges; steel bridges; strengthening.**

***Abstract*— Strengthening old bridges is an increasingly relevant strategy for risk prevention and operation continuity in management of infrastructures. Transportation networks are subjected to progressively stricter environmental and load conditions, leading to a growing number of deficient structures, also due to aging and deterioration. However, employable resources are finite, from both economic and environmental points of view. For these reasons, strengthening opportunities should be considered as a viable option, improving bridges with low economic and environmental impact. With this perspective, a selection of some of the most interesting strengthening techniques for old truss steel bridges is presented. To address effective solutions, the most frequent problems in old truss railway bridges are first presented. Literature analysis and experts' interviews were conducted and compared to results obtained from a representative bridge cluster. Different solutions addressing highlighted problems are then collected and qualitatively evaluated, in terms of efficacy on structural and typical construction requirements. Finally, general remarks and recommendations based on collected evidence are presented.*

I. INTRODUCTION

A bridge is a means by which a road, railway or other service is carried over an obstacle such as a river, valley, and other road or railway line, either with no intermediate support or with only a limited number of supports at convenient locations. Bridges range in size from very modest short spans over, say, a small river to the extreme examples of suspension bridges crossing wide estuaries. Appearance is naturally less crucial for the smaller bridges, but in all cases the designer will consider the appearance of the basic elements, which make up his bridge, the superstructure and the substructure, and choose proportions which are appropriate to the particular circumstances considered. The use of steel often helps the designer to select proportions that are aesthetically pleasing. Bridges are an essential part of the transport infrastructure [1].

II. BACKGROUND

Steel is widely used in building as material. Because of steel have many factors affecting in mechanical properties, availability in a variety of useful and practical shapes, more economy, design simplicity, and ease and speed of construction. In another hand Steel can be produced with a variety of properties by adding many enhancements to suit our different requirements. The principle requirements are strength, ductility, weld ability, and corrosion resistance. Steel design, or more specifically, structural steel design, is an area of knowledge of structural engineering used to design steel structures. The structures can range from towers to homes to bridges. There are currently two common methods of steel design: The first and older method is the Allowable Strength Design (ASD) method. The second and newer is the Load and Resistance Factor Design (LRFD) method.

III. LOADS ON STEEL BRIDGE TRUSSES

Trusses are used in bridges to transfer the gravity load of moving vehicles to supporting piers. Depending upon the site conditions and the span length of the bridge, the truss may be either through type or deck type. In the through type, the carriage way is supported at the bottom chord of trusses. In the deck type bridge, the carriage way is supported at the top chord of trusses. Usually, the structural framing supporting the carriage way is designed such that the loads from the carriage way are transferred to the nodal points of the vertical bridge trusses.

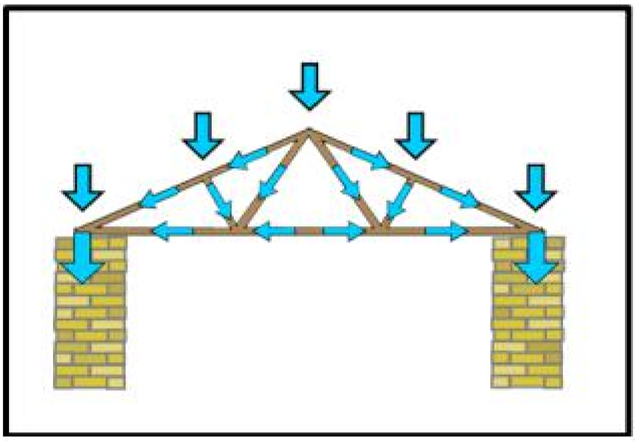

Fig.1: load distribution over a steel truss bridge.

IV. LOADS

1. Dead Loads: The dead load represents the weight of structure itself and any other immovable loads (equipment) that are constant in magnitude and permanently attached to the structure. It consists of the weight of the main supporting trusses or girder the floor beams and stringer of the floor system. Structural design is that the true dead load of the structure that cannot be determined until the bridge is designed and a final design cannot be accomplished unless the true dead load is known. The dead load acting on a member must be assumed before the member is designed; one should design the member of a structure in such a sequence that to as great an extent as practicable the weight of each member being designed is a portion of the dead load carried by the next member to be designed.

2. Live load: The live load for highway bridges consists of weight of the applied moving load of vehicles and pedestrians. Highway bridges should be designed to safely support all vehicles that might pass over them during the life of the structure actually; the traffic over Highway Bridge will consist of multitude of different types of vehicle. It’s not possible for the designer to know what vehicles will be use the structure or what the required life of the bridge will be to ensure the safety of the structure. Some form of the control must be maintained so that the designer has to provide sufficient strength in the structure to carry present and future predicated loads.

3. Wind Loads: Wind loads are caused by the pressure of wind acting on the bridge members. They are dynamic loads that depend on such factors as the size and shape of the structure, the velocity and angle of the wind. For design purposes, AASHTO specifications give wind loads as uniformly distributed static loads. This simplified loading is intended for rigid structures that are not dynamically sensitive to wind; that is, structural design is not controlled by wind loads. It applied as horizontal loads acting on the superstructure and substructure and as vertical loads acting upward on the deck underside. The magnitude of the loads depends on the component of the structure and the base wind velocity used for design.

V. STRUCTURAL ELEMENTS

Truss bridges usually present different features in terms of static scheme, spans, overall length, geometry and so forth. However, they are assembled by the same structural elements such as main trusses, deck elements and connections. As a matter of fact, these are the references for bridge inspection manuals [11-12]. For this reason, the encountered problems for the truss bridge type are organized and presented according to the mentioned scheme. Attention is focused on main trusses, deck elements, connections, in association with the strengthening interventions presented. However, it is good to remember that bracings and bearings may also require strengthening.

VI. LITERATURE REVIEW

YongjianLiu, Advances in the application and research of steel bridge deck pavement: The common diseases of orthotropic steel deck pavement have seriously affected the service life and safe operation of long-span steel bridges. This paper presents an overview on current application and research status of steel bridge deck pavement. Comparations were made on the design requirements of steel bridge deck pavement in several specifications of China, USA, and Japan. The pavement structures, deck stiffnesses and corresponding environmental temperatures were collected from 119 steel bridges around the world. Based on the information collected, the material performance, combination mechanism, technical characteristics and application prospects of various pavement structures were analyzed. Finally, comparison was made on different calculation methods of bridge deck stiffness. Results show that double-layer *EAM*, *GAM* + *SMAM* and *ERS* are the most commonly used pavement structures of steel deck presently. However, for most of application cases, the actual life cannot reach the design service life of 15 years. Rigid base can significantly improve the stress condition of surface pavement and steel top plate [1].

ChaoJiang, Fatigue assessment of fillet weld in steel bridge towers considering corrosion effects: Field inspection shows that the fillet weld in steel bridge towers may be subjected to corrosion and fatigue loading simultaneously. To ensure the structural safety in the service life, corrosion effects on the fatigue life of the fillet weld in steel towers were investigated in this study. A prediction procedure of the fatigue life of the weld was firstly proposed based on the fracture mechanics method and verified by the test results. Three types of corrosion effects, pitting corrosion at the initial crack, pitting corrosion near the initial crack, and the corrosion fatigue crack growth were considered. Three corrosion levels were also defined under different corrosive environments. By taking the Third Nanjing Yangtze River Bridge as an example, a modified finite element (FE) model integrated with the local shell model was established to analyze the stress variation of the fillet weld in steel towers. Based on the stress influence lines, the maximum stress range was obtained under the vehicle load [2].

ZheZhang, Fatigue performance and optimal design of corrugated steel–concrete composite bridge deck: Orthotropic steel bridge deck (OSD) has been widely used in long and medium span bridges. However, traditional OSD with U-ribs is prone to fatigue cracking at the deck-to-rib welded joint. Corrugated steel–concrete composite bridge deck (CSCCBD) composed of corrugated steel plate, concrete layer and perforated plate shear connectors was proposed recently to improve the fatigue performance of the bridge deck. In this paper, comparing of the fatigue performance of OSD and CSCCBD was conducted through finite element (FE) analysis. The results showed that the stress amplitude of deck-to-rib welded joint of CSCCBD was reduced by more than 90 % compared with OSD. The fatigue problem of deck-to-rib welded joints can be solved fundamentally. It is further studied that distribution of fatigue vulnerability details of CSCCBD. The most unfavorable fatigue vulnerability details are located around the diaphragm-to-rib weld. The fatigue life of CSCCBD was evaluated based on the linear cumulative damage theory [3].

ShuailingLi, Ultra-low cycle fatigue fracture initiation life evaluation of thick-walled steel bridge piers with microscopic damage index under bidirectional cyclic loading: Strong earthquakes can cause ultra-low cycle fatigue (ULCF) fracture in steel bridge piers. This paper examined the fracture behavior of two thick-walled square section steel bridge piers subjecting to horizontal bidirectional cyclic loading. In addition, a microscope damage index for evaluating ULCF fracture initiation life of steel bridge piers was proposed. The findings show that ductile cracking firstly appeared at the junction between the stiffened base plate and bottom weld at the corner position of steel bridge piers under bidirectional cyclic loading, and that initial crack growth did not reduce the strength capacity [4].

HuiyunXia, Preparation and performance of durable waterproof adhesive layer for steel bridge deck based on self-stratification effect: In view of the shortcomings of the existing steel bridge deck waterproof adhesive layer (WAL), such as poor durability, high construction cost and long construction period, a new preparation method of waterproof coating with self-stratification effect is proposed. In this paper, poly butyl acrylate-methyl methacrylate–styrene block copolymer with lower glass transition temperature was synthesized by free radical solution polymerization, and 5 kinds of self-stratification coatings were obtained by mixing it with epoxy resin at different mass ratios. The glass transition temperature, thermal stability and chemical composition of acrylic resin were characterized by DSC, TGA, and FT-IR. The self-stratification behavior of the coatings was confirmed by FT-IR, SEM, and water contact angle test. The basic performance and road performance of above self-stratifying waterproof coatings were tested according to specific standards [5].

JiaSun, Structural optimization of steel bridge deck pavement based on mixture performance and mechanical simulation: The upper layer of modified SMA mixture (SMAM) and the lower layer of epoxy asphalt mixture (EAM) is a steel bridge deck pavement (SBDP) structure with application potential, but there is a lack of systematic research on it. In this study, the pavement material and structure of SMAM + EAM were optimized using mixture performance tests and finite element analysis, which provided guidance to facilitate its promotion and application. Firstly, the pavement performance and dynamic properties of SMAMs and EAMs prepared with different binders were compared to preferably select the appropriate SBDP material. Secondly, the dynamic modulus master curves of the mixtures were established to provide material parameters for pavement structure design. Finally, the FEA method was applied to comparatively analyze the dynamic mechanical response of the pavement structure for different structures, thickness combinations, and temperatures to optimize the SBDP structure purposefully. The results demonstrated that EAM had better high-temperature rutting resistance than SMAM, while SMAM had superior moisture damage and skid resistance [6].

Qing-ChenTang, Hybrid control of steel-concrete composite girder bridges considering the slip and shear-lag effects with MR–TMD based on train-bridge interactions: With the speed of trains higher and bridge structures towards larger spans with lighter weight, the train-bridge resonance will become fairly pronounced. Therefore, to ensure the safety of bridge structures, research on vibration control is of far-reaching significance, especially for steel–concrete composite girder bridges with mechanical properties, such as slip, and shear lag. Therefore, based on a magnetorheological tuned mass damper (MR–TMD), this paper proposes a hybrid control strategy for the steel–concrete composite girder bridge considering whether the trains are either on or off the bridge, and applies it to a numerical example, reducing vertical dynamic responses of a railway steel–concrete composite girder bridge based on train-bridge interactions [7].

O.Bouzas, A holistic methodology for the non-destructive experimental characterization and reliability-based structural assessment of historical steel bridges: Nowadays, several historical steel structures present damage and an advanced deterioration state induced by human or natural actions, causing fluctuations in geometrical, physical, and mechanical properties that dramatically affect their mechanical behavior. Due to the economic, cultural, and heritage value, these constructions must be comprehensively assessed to verify their current condition state. This work presents a holistic methodology aimed at the non-destructive experimental characterization and reliability-based structural assessment of historical steel bridges. It comprehends from the experimental data acquisition to the finite element model updating and the probabilistic-based structural assessment to obtain the reliability indexes of serviceability and ultimate limit states. Several sources of information are considered in the evaluation process, thus, results are more realistic and accurate and can be used for optimal decision-making related to maintenance and retrofitting actions. The feasibility of the methodology has been tested on O Barqueiro Bridge, an aging riveted bridge located in Galicia, Spain. The study first involved a comprehensive experimental campaign to characterize the bridge effectively at multiple levels: geometry, material, and structural system by the synergetic combination of different tools and methods: in-depth visual inspection, terrestrial laser scanner survey, ultrasonic testing, and ambient vibration test [8].

Tadesse G.Wakjira, Explainable machine learning based efficient prediction tool for lateral cyclic response of post-tensioned base rocking steel bridge piers: This study presents a novel explainable machine learning (ML) based predictive model for the lateral cyclic response of post-tensioned (PT) base rocking steel bridge piers. The PT rocking steel bridge pier comprises a circular tube with welded circular base plate that is pre-compressed to its base by means of gravity loads and/or a PT tendon. The input factors were column diameter, column diameter-to-thickness ratio, column height-to-diameter ratio, cross-sectional area of tendon-to-column ratio, tendon initial post-tensioning ratio, dead load ratio, base plate thickness, and base plate extension. Response variables were column residual drift, column shortening, ratio of degraded stiffness to initial stiffness, maximum lateral strength to uplift force ratio, and lateral strength reduction ratio. Nine ML techniques that range from the simplest to advanced techniques were used to generate the predictive models [9].

TomaszMaleska, Effect of the soil cover depth on the seismic response in a large-span thin-walled corrugated steel plate bridge: The common use of corrugated steel plate (CSP) bridges and culverts has been increasing in recent years. Despite the growing popularity of these objects, there is very scarce research concerned with the response of such structures to seismic excitation. Therefore, the aim of the study is to determine the effect of seismic excitation on a CSP bridge with span exceeding 17 m and a variable depth of the soil cover above the steel shell (from 1.0 to 5.0 m). The obtained results demonstrate that the depth of the soil cover has a significant impact on the response of the bridge [10].

DaoyunYuan, Fatigue damage evaluation of welded joints in steel bridge based on meso-damage mechanics: Welding is a rapid and flexible connection that facilitates the use of a broad range of steel bridge. However, fatigue cracks initiating from various welded connection details are common problems in steel bridges. Therefore, it is vital to accurately evaluate the fatigue damage evolution and fatigue life of welded joints in steel bridge. In this study, a fatigue damage evolution model based on the *meso*-damage mechanics was proposed to evaluate the fatigue damage of welded joints in steel bridge. The number density of micro-cracks was adopted as the damage variable in the fatigue evolution model. Finite element modelling and user material subroutine (UMAT) in ABAQUS were combined to simulate fatigue damage evolution of welded joints in steel bridge. The fatigue damage evolution model was embedded in UMAT while the UMAT was coupled with the finite element model of the welded joints under cyclic loading [11].

OskarSkoglund, A numerical evaluation of new structural details for an improved fatigue strength of steel bridges: Fatigue is often the decisive design factor when designing steel bridges and improving the fatigue strength of critical details can reduce the amount of steel material used. In this paper, the fatigue strength of four different structural detail solutions are investigated and compared through numerical simulations. Two of the evaluated structural details have not been used before in bridge construction. The most promising structural detail managed to improve the fatigue strength by more than 25% compared to the conventional solutions used today. The numerical studies were performed as a preparation for future testing [12].

AlirezaGhiasi, Damage detection of in-service steel railway bridges using a fine k-nearest neighbor machine learning classifier: Minor areas of surface corrosion in steel railway bridges can grow progressively and lead to localized section losses and structural failure over time. This paper proposes a novel combined damage detection approach for the classification of various extents and degrees of cross section losses due to damages like corrosion using a k-Nearest Neighbor (kNN) machine learning classifier. A Finite Element (FE) model of an in-service railway bridge is developed and validated using vibration data from field testing and these combined FE-field data are trained and tested to classify various corrosion cases following the Australian Standard AS7636 [13].

JeonghwaLee, Improved design of intermediate diaphragm spacing in horizontally curved steel box bridges: Eccentric live loading acting on the steel box girders induces cross-sectional distortion in the steel box sections. In particular, the distortional behavior in horizontally curved steel box bridges can be significant compared to that in straight ones; the reason is that the curvature effects of horizontally curved steel box bridges can provide additional distortional behavior due to gravity and live loads even without eccentricity of the applied loadings for every construction sequence (self-weight for non-composite and live loads for composite box sections). Therefore, to control the distortional warping normal stresses induced by the distortional behavior, it is necessary to install intermediate diaphragms in the box sections for straight and horizontally curved box bridges [14].

DorinRadu, Residual life of a historic riveted steel bridge - engineering critical assessment approach: Sustainability has become an increasingly important component of requirements for the rehabilitation of bridge structures. Responsible use of our limited natural resources is essential for future generations, so the whole bridge rehabilitation process must be taken into account, in terms of structural integrity. The environmental impact for these types of structures is major – demolition and reconsideration of e.g. reinforced concrete structure being examples of poor management of resources and energy. On the existing roads and railways network steel bridges with more than 100 years in service lifetime are numerous. The in-service safety assessment of these structures is a complex problem. This article emphasizes the importance of rehabilitating the structure of existing steel bridges, considering the historical monument character of these structures, as well as the reuse of existing structures, part of sustainable development. The paper is presenting a study case for an historical riveted steel bridge build in the beginning of twentieth century, with an assessment method considering the structural integrity by means of fracture mechanics [15].

VII. CONCLUSIONS

In this paper, different possible strengthening solutions for old steel truss Steel bridges have been proposed. Their choice is generally motivated by different aspects, such as structural efficacy, construction times, required traffic interruptions and maintenance ease. First, the analysis of material and structural features has outlined that strengthening requirements: (1) are related to brittleness and low-redundancy characteristics of truss steel bridges; (2) are mainly associated to problems localized in deck elements, namely stringers, cross beams, and connections. Literature review, interviews and direct examination of a target bridge cluster also suggest that often problems are not present on a single element only but interest a whole class of structural components. For this reason, it is opportune to assess whether a global strengthening solution can be more effective that a set of local interventions. Being the latter better known and more extensively adopted, an examination of global strengthening strategies is conducted and presented through real case studies. The overview highlights that: (1) load bearing capacity for main trusses is generally not a problem, however a global intervention can reduce fatigue sensitivity in main trusses connections and increase the overall structural robustness and safety; (2) extensive interventions on the deck can not only solve the phenomena localized in single problematic elements, but improve the overall behaviour of the structure, in terms of deformations, sensitivity to brittle failures, vibrations and maintenance. We believe that there are many more smart, innovative solutions that have been used, but they are not always reported in the literature, since bridge designers and bridge owners are normally not so interested in producing papers for conferences and journals. Thereof, strengthening may not always be the best solution for deficient old truss railway bridges. However, an updated knowledge of available techniques and a creative approach can expand the upgrade possibilities for existing bridges, increase their lifetime and safety with low economical and environmental impact, while preserving our historical heritage.

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