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A Review Study on the Static, Dynamic, and Damages Structural Assessment of Prestressed Concrete and Steel Girder Bridges

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ABSTRACT

Bridges serve as indispensable lifelines in modern transportation infrastructure, linking highways, railways, and geographically complex regions. This study investigates the static and dynamic behavior of concrete highway bridges to enhance structural resilience, with a focus on damage assessment methodologies and advanced rehabilitation strategies. The results show that dynamic loads, like heavy traffic, accelerate the production of cracks by causing stress concentrations to be 15-20% larger than under static conditions. Concrete's compressive strength can be lowered by up to 30% after prolonged exposure to moisture and freeze-thaw cycles. Furthermore, prolonged exposure to moisture and freeze-thaw cycles reduces concrete compressive strength by up to 30%, significantly compromising structural integrity. Retrofitting damaged regions with carbon fiber-reinforced polymer (CFRP) is highly successful; it restores performance while increasing load-bearing capacity by 25-35%. Field investigations identify bridge joints and midspan sections as significant damage hotspots requiring priority maintenance. These findings underscore the need to reduce risk through proactive maintenance procedures and integrated monitoring systems. The proposed framework provides practical recommendations for optimizing sustainable infrastructure management, ensuring safety, and extending bridge service life. This study directly improves the durability and reliability of concrete highway bridges in the face of shifting demands by linking theoretical analysis to practical solutions.

Keywords: Bridge performance; static; dynamic; damage assessment; finite element method

INTRODUCTION

Bridges are key elements of transport infrastructure that connect two parts over an obstacle and therefore have evolved over the years, with improvements in the types of materials used in construction and the ability to withstand forces such as traffic and climatic changes (Man-Chung 2007). Bridges provide an indispensable physical connection between highways, railways, junctions, riverbanks, and mountain ranges and enjoy irreplaceable roles in transportation systems today. One of the most fascinating and complex works in civil engineering, design, planning, and construction of bridges, and this can be attributed to the fact that each stage of the construction of these structures requires the use of engineering, analysis, and risk management skills (Educational Program Innovation Center (EPIC 2010)

Bridges must be constructed so that their safety, cost-effectiveness, and probability of failure are kept to a minimum over a long period. Geographical issues, structural issues, climatic concerns, and projected traffic patterns are some of the typical parameters influencing bridge design (Krejsa & Krejsova 2005). These structures should also resist live loads and other fluctuating loads, the latter of which could compromise the safety and stability of the structures. All these limitations are achieved by the use of improvement design and analysis methods that embrace unique engineering expertise, hands-on training, and experience (Duan 2008).

In a typical bridge, the primary supporting structure is roughly divided into three main parts. Firstly, the superstructure: deck, beams (or girders), pavement, expansion joints, protective railing systems, water drainage facilities, and bearings. This component is the most exposed part of the structure and the most crucial in transferring the loads to other structural parts (Gerard & Nigel 2008). Second, the substructure, which includes piers, pier caps, and abutments, which are wells, connected to the superstructure and aid in carrying the dead weight and live load to the earth (Jim & Chao 2006). Third, the foundation that includes piles and pile caps is the structural element that helps pass on forces to the underlying soil to secure the bridge's structure (Gerard & Nigel 2022). These components are typically made of concrete a material that can withstand any compressive force even though there are some structural considerations on tensile forces making this type of material suitable for many climates of bridge buildings (Ali & Hussam 2020; Neville & Brooks 2010; Giovanna 2006; Benaim 2008).

As the years pass on the evolution of bridge construction and engineering, with the introduction of new materials and artificial structures, so many things have changed. In this context, the assessment of the structural performance of bridges has been gaining more scholarly focus, especially with the maintenance of the bridges and even dealing with the issue of structural deterioration (Ali & Wong 2011). Therefore, the high-level complexity of evaluating structural performance encompasses the complexity of design detailing and construction analysis, which determines the bridge's capacity, its design life, and the various dynamic loads that may be applied to it (Rolands 2015). It is known that while bearing both static and dynamic, the live loads act on the safety and stability of the bridge entirely and therefore need a detailed study to avert the risk of structural failure and enhance the durability of the bridges (Shahid 2017; Ali 2022; Nowak & Hong 1991).

It is also important to state the objective of this research, which aims to assess concrete highway bridges' structural performance by considering both static and dynamic analysis and studying the damage that the structures have received. The goal of the particular study is to examine the sufficiency and reliability of these structures under various loads, as well as how various environmental factors impact the degradation of the structures. Further, the study hopes to provide a review of the repairs carried out on damaged structures and present innovative techniques that will improve the durability and safety of damaged concrete bridges. Most importantly, it aims towards formulating an efficient maintenance policy for the structures whose incorporation will ensure the conservation of the key components of the infrastructure.

STRUCTURAL PERFORMANCE EVALUATION OF DIFFERENT TYPES OF BRIDGES

It is vital to evaluate the structural performance of bridge structures, detect deterioration to different structural elements, and formulate efficient strengthening and repair plans. The objective of this procedure is to improve the overall stability and stiffness of bridge constructions. The assessment can be performed using theoretical analysis, which computes the internal forces under static and dynamic loads. This is typically done by using the finite element method (FEM) with the aid of specialist engineering software. Experiments are used in addition to theoretical approaches, such as load testing conducted in both static and dynamic settings. Additionally, field inspection techniques are used to guarantee a thorough evaluation. These approaches include evaluating deflection by leveling the bridge deck and testing the concrete's compressive strength, inadequate maintenance and improper retrofitting can significantly compromise a bridge's structural integrity, altering its static and dynamic responses. This often leads to load restrictions, unexpected closures, and, in severe cases, structural collapse. Therefore, a thorough assessment of these responses and damage investigation is crucial to ensure safety and prevent further deterioration (Manfi 2023).

TYPES OF BRIDGES

Bridges can be classified according to the materials of construction such as Timber Bridge, steel bridge, concrete bridge, prestressed concrete bridge, Masonry Bridge, and composite bridge. According to the length of the span, such as minor bridge (8-30m), major bridge (above 30m), and long span bridge (more than 120m). According to the function of a bridge, such as an aqueduct (canal over a river), bridge, viaduct (road or railway over valley), pedestrian bridge, Highway Bridge, Railway Bridge, and Pipeline Bridge. According to the types of piers and abutments, supports such as simply supported span bridges, continuous supports span bridges, and cantilever supports span bridges. According to the types of superstructure of a bridge, such as Slab Bridge, girder-to-slab Bridge (I-girders, T-girders, and U-girder), truss bridge, arch bridge, box girder bridge, suspension bridge, and cable-stayed bridge. (Weiwei & Teruhiko 2017; Pipinato 2022; Sagara 2018; Chen & Duan 2014; the Information Architects of Encyclopaedia Britannica, Richard & Jay 2013; Brown 1993; Edwards 1959; Gies 1963). Types of bridges based on span, materials, structures, functions, utility, etc. 2017, Team, D. 2023). Figures 1, 2, 3, 4 and 5.

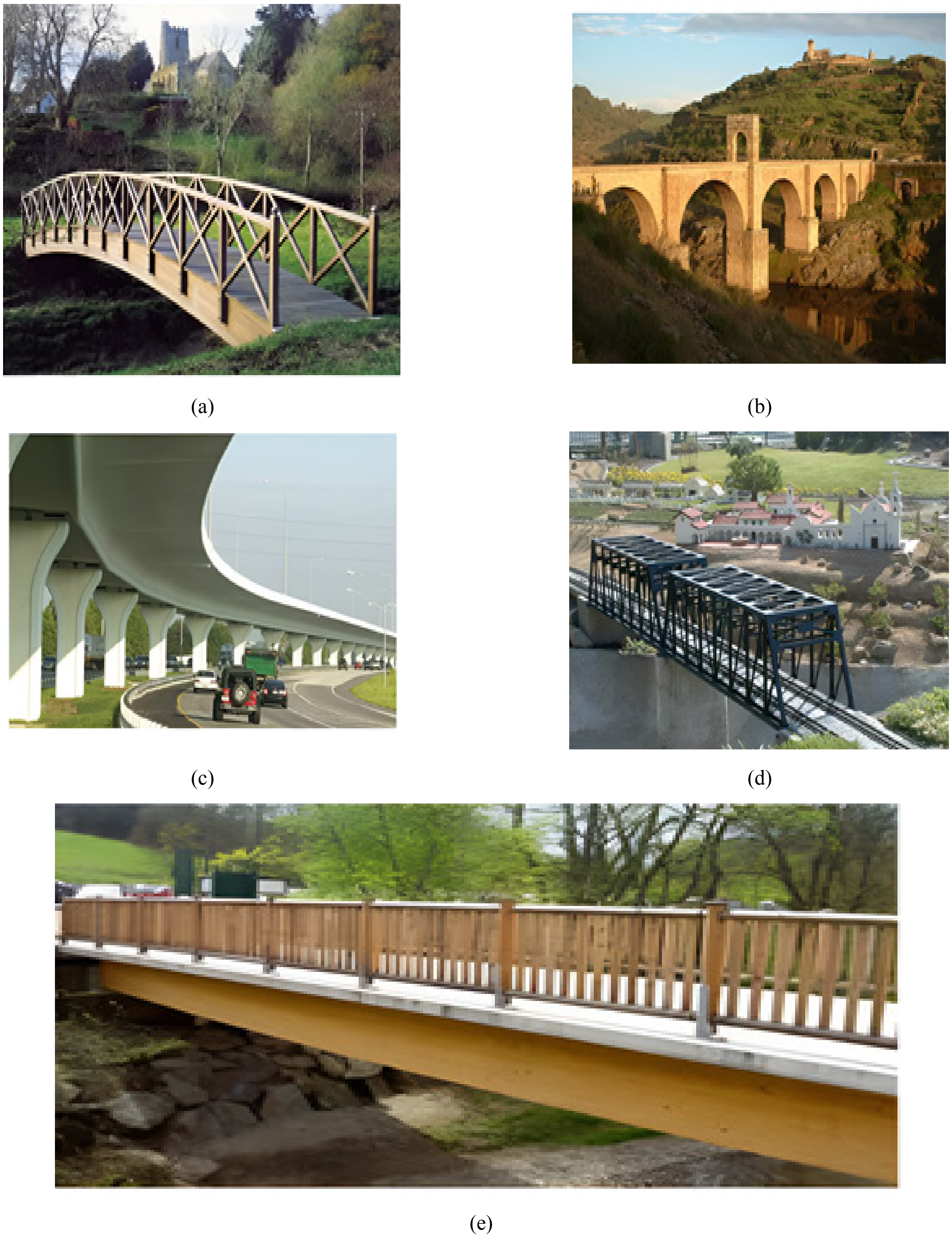
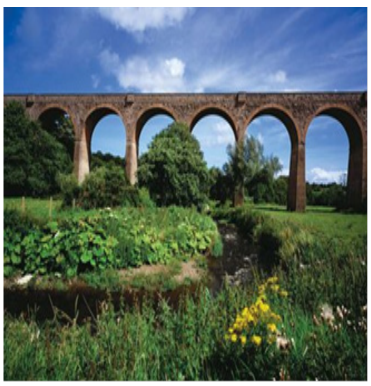


FIGURE 1. Types of bridges according to materials of construction: (a). timber bridge, (b). masonry bridge, (c). the prestressed concrete bridge, (d). steel bridge, (e). reinforced concrete bridge (Sagara 2018)

(a)

(b)

FIGURE 2. Types of bridges according to length of Span: (a). minor bridge, (b) major bridge



(a)

(b)

(c)

(d)

(e)

FIGURE 3. Types of bridges according to function of bridge: (a). viaduct bridge, (b). highway bridge, (c). pedestrian bridge, (d). pipe bridge, (e). railway bridge (Types of bridges based on span, materials, structures, functions, utility, etc. 2017)

(a)

(b)

FIGURE 4. Types of bridges according to types of supports: (a). simply supported bridge, (b). continues bridge

(a)

(b)

(c)

(d)

(e)

FIGURE 5. Some types of bridges according to the type of superstructure of the bridge: (a). slab bridge, (b). arch bridge, (c). truss bridge, (d). cable-stayed bridge, (e). suspension bridge

TYPES OF LOADS APPLIED ON A BRIDGE

Many different kinds of loads are applied to the bridge structure, and their consideration is necessary during the design process. Bridge loads are classified as primary loads and secondary loads. A load's classification as primary or secondary depends on the section of the bridge that needs to be constructed. For example, while planning the main girders, wind loads are secondary loads, and when designing the wind bracings, they are major loads. (Weiwei & Teruhiko 2017; Vardanega 2022; Dong 2020; Andrzej 1993; Wang 1992; Ali 2022; Aggarwal & Parameswaran 2020; Shahid 2017; Ali 2018; Mohamad & Ayad 2006; Ali & Zong 2018; Ali 2021; Abdullah 2024; Davis 2018; Zheng 2007; Martin 2011; Nengguang 2013; Corporation, M. I. (n.d.); Solution, Durand 2022; Kristine 2022).

Primary loads include the dead load, live loads, dynamic load (impact load), and centrifugal forces. Dead load represents the sum of the weight of the attached equipment and the construction of the bridge. Throughout the lifespan of the bridge construction, the fixed load stays in its original location. Another name for this kind of load is persistent load. Conversely, the total weight of all superstructure components (i.e., components above bearings) including the deck, eaves, railings, parapets, stiffeners, and utilities is known as the dead load on a superstructure.

The AASHTO specification from 1944 states that there are five truck categories for a live load: H15-44 (30,000 lb), H10-44 (20,000 lb), H20-44 (40,000 lb), HS15-44 (54,000 lb), and HS20-44 (72,000 lb). AASHTO created the Alternative Military Loading in 1975, which is recognized as the Federal Highway Administration. It is depicted by two axles that are just 4 feet apart and can each support 24,000 lb. The trucks marked H and HS do not depict real trucks that are utilized to move supplies and cargo. These are estimates meant to replicate the highest shear and bending forces produced by real trucks. A loading strategy based on a train of trucks was released in 1935 by the organization that was then known as AASHO. Figure 6.

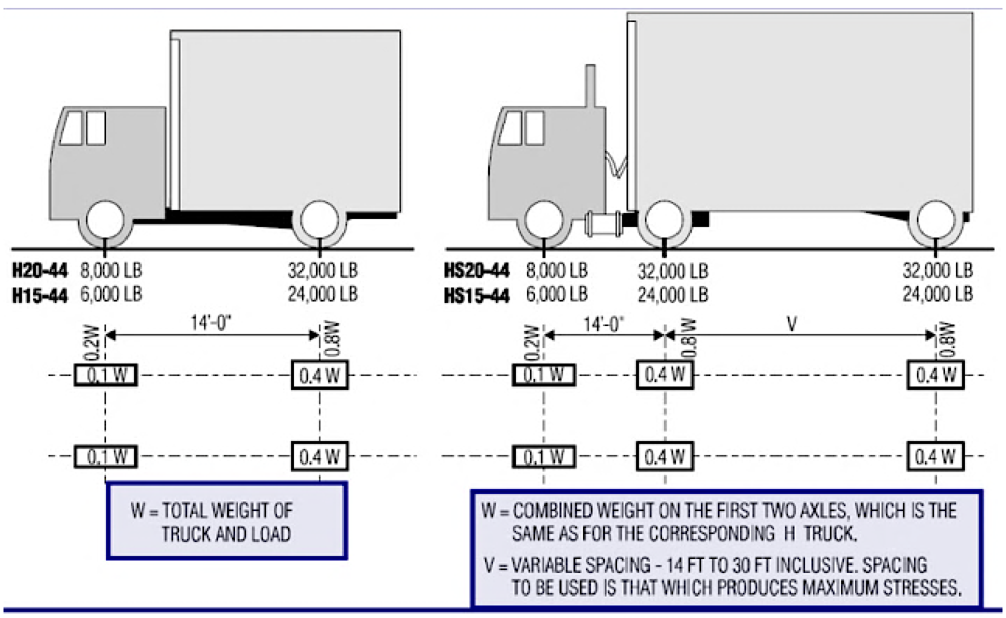


FIGURE 6. AASHO standard H&HS design trucks (Martin 2011)

The dynamic load is the effect of moving loads on a bridge, called impact. It is caused by the possibility that fast-moving trucks will strike the rigid deck with a significant impact or force from many sources, including a pothole or a sizable vertical stair between the approach slab and the rigid deck. For some structural parts, an impact factor is utilized as a Multiplier to account for the dynamic effects of a vehicle passing over the building. The impact factor can be represented as equation 1:

$$I=50/(L+125) \tag{1}$$

Where:

I= impact facto, L= span length

The centrifugal force appears when a vehicle turning on the bridge's curvilinear path generates force perpendicular to the path's tangent. Figure 7 shows the effect of centrifugal force on the vehicle within a horizontal curve.

Secondary loads on the bridge structure include wind load, earthquake action, braking force, temperature effects, friction force, buoyancy effects, and erection loads.

$$I=50/(L+125) \tag{1}$$

$$C=\frac{W\,V^2}{127\,R} \tag{2}$$

Where:

C = centrifugal force in KN, without impact
W = live load in KN, V = design speed in km/h
R = radius of the curve in meters.

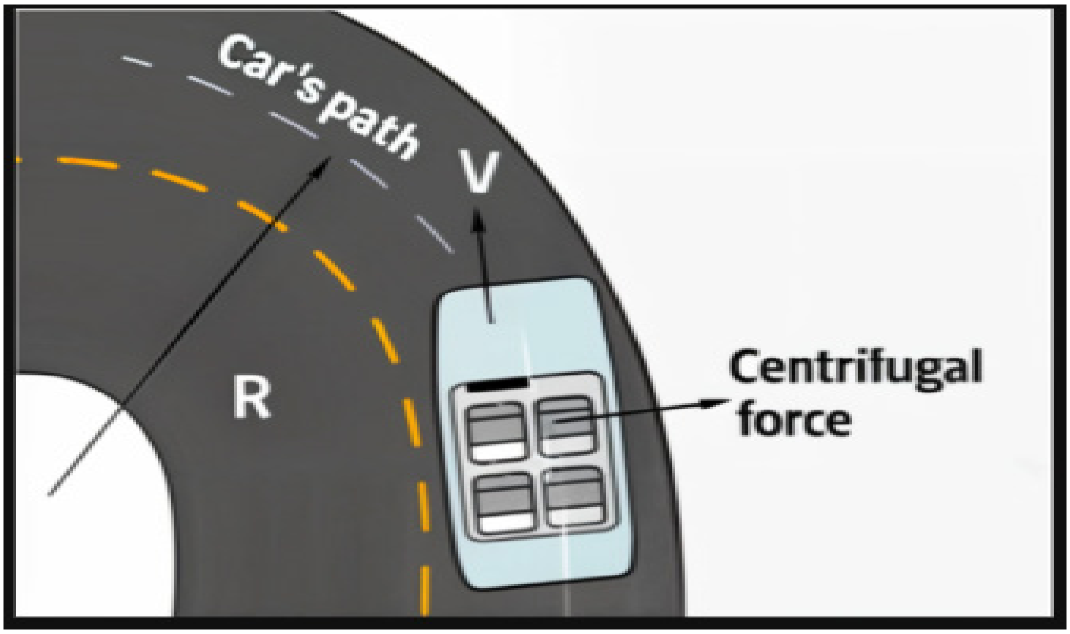


FIGURE 7. Centrifugal force on the vehicle within a horizontal curve

DAMAGES INSPECTION METHODS OF BRIDGES

Many of us do not think about the bridges we drive on every day, but there are millions of them in operation around the world, and they all need to be maintained to avoid severe accidents. There are many bridges in Iraq, and each one must be inspected and maintained regularly to ensure their safety. Practices and regulations vary around the world, but most countries require bridges to be inspected at least every two years. In general, inspectors performing bridge inspections will check for flaws, deficiencies, or possible issue areas that may require maintenance. The ultimate purpose is to uncover problems early on before they become more serious. Bridges are built with safety and longevity in mind, lasting up to 75 years for travelers. Nevertheless, all structural elements decay over time, sometimes prematurely. If they leave without being checked, they will eventually pose a risk to bridge users. Periodic bridge inspections are important to assess structural integrity, identify defects, and extend the bridge's service life. The purposes of damage inspection of bridge components are to evaluate the safety of a bridge structure, identify necessary maintenance, repairs, and strengthening, provide a basis for arranging the funding of any necessary maintenance and strengthening, and inform designers and construction engineers about the aspects that require maintenance. Bridge structures can be inspected for damage using a variety of approaches. The methods are inventory (Initial) inspection, routine inspection, fracture critical inspection, underwater inspection, scour inspection, special feature inspection, Bridge Inspection Truck (UBIT), in-depth inspection, damage inspection, interim inspection, and flood inspection. Figure 8 shows the damage inspection for some parts of the bridge and Figure 9 (Ali & Wang 2011; Moore 2000; Georg 2007; IntPE, M. a. P. P. 2021; Korea infrastructure safety and technology corporation 2017; Ali Abdullah 2023; Robert 2005; Washington State Department of Transportation 2010; Seonghyeon 2020; Vlašić; 2022; Damages Inspection of Bridges - Google Search).

FIGURE 8. Damage inspection for some parts of a bridge (IntPE, M. a. P. P. 2021, Damages Inspection of Bridges - Google Search)

FIGURE 9. Damage inspection with non-destructive tests (Moore 2000, Bridge Testing in Nondestructive Testing)

DAMAGES OF BRIDGE STRUCTURE

Damage refers to changes in material properties, section geometry, boundary conditions, and system connectedness. Bridges, like other civil engineering constructions, can sustain damage over time. Poor workmanship and a lack of awareness of damage mechanisms lead to poor performance of concrete structures, resulting in inadequate design and inaccurate estimation of environmental effects. Both environmental conditions and material resistance to aggressive chemicals determine the durability of materials and buildings. Several factors can affect the durability of bridge structures. Bridge structure damage can occur due to aging, poor design and construction, lack of maintenance, accidents involving heavy vehicles and ships, fire, tiredness, and conceptual or computational errors. Damages can be classified: according to affected level which are four categories of damages. These are affected damages, minor damages, large damages, and destroyed damage. For example, the Jiamusi Highway Bridge in China has cracks and corrosion in its reinforced concrete girders. To solve these difficulties, the structure was reinforced using steel plates and external tendons (Ali & Wang 2011). Similarly, the Bata Bridge in Iraq experienced expansion joint degeneration and reinforcing corrosion. The rehabilitation method included the use of external tendons to increase load-bearing capability (Abdullah 2023). According to the nature of decay such as chemical deterioration

Which refers to the chemical and physical properties of cement, as well as alkali reactions, electrolytic attacks, fungoid growth, and mechanical deterioration factors that include shrinkage failure, temperature and moisture strains, internal tensions, hydraulic gradient, freezing and thawing, abrasion, fatigue, and shock waves. Damages also can be classified according to the location of decay in the bridge such as deteriorating the bridge foundations due to unanticipated displacements, affecting the entire structure, and bridge superstructure damages include fractures, exposed horizontal surfaces, steel corrosion, infiltration, carbonation, porous and permeable concrete, deck abrasion, increased deformations, vibrations, unintentional damage, and chemical degradation. Figure 10 (Bjørn 2020; Chung 2008; Manaf 2000; Osama 2004; Steven 2003;Norman 2000; Fares 2013).

FIGURE 10. Different types of bridge damages

FIELD LOAD TEST

Normal service stage, fatigue, and ultimate loads are routinely assessed; theoretical models are established to calculate the performance of bridge structural components; and analytical results are validated through comparison with experimental test data. These are the primary goals of both theoretical and experimental bridge structure analysis. Field load testing is an important tool for assessing the structural performance of bridges. They allow us to compare the actual behavior of the bridge during stress tests to theoretical forecasts. Static and dynamic load tests are the two types available (Bridge Testing in Nondestructive Testing, Ali 2013; Jica, Study 2007; Lantsoght 2017; Xiang 2023).

STATIC LOAD TESTS

Static load tests are performed when government authorities or the bridge's designer request them. During a static load test, the vertical deflections, stresses, strains, and bending moment must be measured at the points where the greatest effects are expected (middle of spans, quarter of spans). Every test condition consists of two test runs. The average of the two-time loads is the final value of the tested location. Before testing, the tested point's initial value is first recorded. Following that, the loading vehicles are positioned under the intended loading position. After 20 minutes, the loading value is noted. After the video, the cars drive off the bridge fully. After a further 20 minutes, the unloading value is also noted in (Petra 2018; Miguel 2014; Support, C. 2017) Figure 11.

FIGURE 11. Static load test on bridge structure (Support, C. 2017)

DYNAMIC LOAD TESTS

Normally, dynamic load tests are only used once static load tests have been completed and shown acceptable bounds in behavior. Bridges will experience vibration states when they are subjected to dynamic vehicle traffic loads. When a vehicle is traveling across a bridge, it creates stresses and deflections that are often higher than when the same vehicle loads are applied statically. The dynamic performance of bridge structures is a key indicator for determining the bridge's carrying capacity and operational status. The primary goal of a bridge's dynamic load test is to assess whether the bridge structures are in safe vibration functioning condition. The dynamic load test consists of measuring the bridge structure's dynamic responses, which include the natural frequency, vibration frequency, damp ratio, dynamic acceleration, dynamic deflection, dynamic strain, and impact factor, and then comparing them to the theoretical value to evaluate the bridge's dynamic performance. Three steps of dynamic load test analysis are used. The first stage includes an investigation of the bridge structure's natural frequency when no traffic passes over it. The second stage involves testing the dynamic responses of the bridge structure using vehicles with specified weights and measuring the dynamic response at different speeds. The dynamic response statistics are recorded at all speeds. The third stage entails recording data on dynamic responses when the bridge is opened to all traffic loads. The dynamic response of the bridge structural tested members includes the dynamic strain of the pier box girder of the structure, the dynamic acceleration of the section in the corbel at different speeds, the natural frequency, vibration frequency, the damping ratio, dynamic displacement, and dynamic deflection (SIA 169. 1987; Mandirola 2022; Wang 2022; Naser & Wang 2013) Figures 12 and 13.

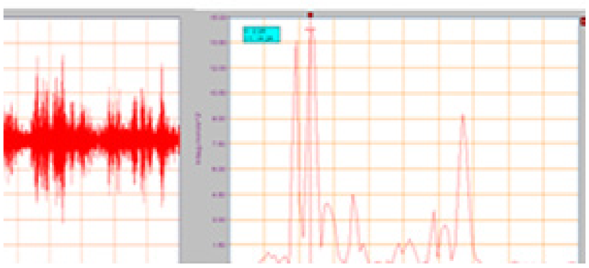


FIGURE 12. The spectrum analysis of measured natural frequency and dynamic acceleration for the first stage of the dynamic load test of a bridge (Ali 2013)

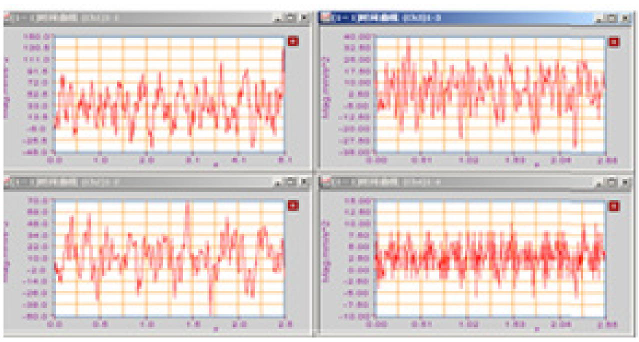


FIGURE 13. Dynamic acceleration time-history curve of a bridge (Ali 2013)

BRIDGE DECK LEVELING TEST

The bridge structure's deck system exhibits upward and downward deflection as a wave, resulting in an uneven deck line shape. The bridge deck's leveling is measured using a total station. Figure 14.

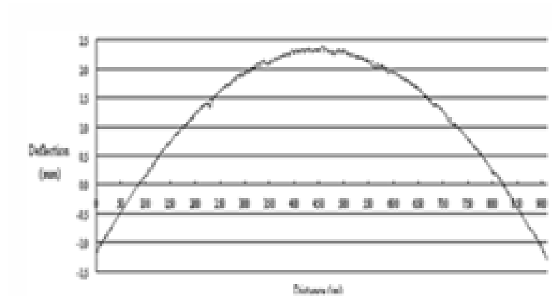


FIGURE 14. The results of the leveling test of the bridge surface (Ali 2013)

CONCRETE CARBONATION TEST

When carbon dioxide enters the concrete and reaches the steel-concrete interface, the steel bars lose the concrete's protective coating and corrode. As a result, increasing concrete carbonation reduces concrete strength, resulting in the loss of a bridge's practical effective section. The drilling method is used to determine the depth of concrete carbonation on the interior and outside webs of box girders and piers. Each portion contains two test sections, each with three holes (Naser & Wang 2013, Abdullah 2023). Figure 15.

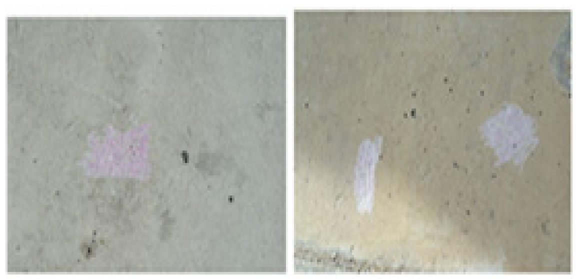


FIGURE 15. Carbonation test of concrete for bridge structural parts (Ali 2013)

CONCRETE COMPRESSIVE STRENGTH TEST

The compressive strength test of concrete can provide immediate information about its quality. In this study, the Rebound method is used to evaluate the quality of concrete during batch sampling inspections.

CORROSION OF STEEL REINFORCEMENTS TEST

The main factor contributing to the deterioration of structural concrete is the corrosion of steel reinforcement. The Scribe digital reinforcement rust instrument is used in this test. To evaluate the corrosion of the steel reinforcement, two sections are selected from the top of the box girder (Naser & Wang 2013; Abdulla 2023) Figure16.

Table (4.7) The standard values of potential level of corrosion state

Potential level	0 to -100	-100 to -200	-200 to -300	-300 to -400	>-400
Corrosion state	No corrosion	Middle corrosion	There corrosion	Corrosion >90%	Serious corrosion

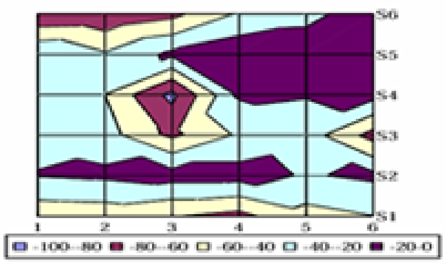


FIGURE 16. The result of the steel corrosion test (Ali 2013)

LITERATURE REVIEW OF RELATED STUDIES

Enright & Frangopol (2000) tried to investigate how and why concrete structures, in particular bridges, continue to fail over time and also seek to pinpoint the most likely areas to undergo wear to plan effective maintenance and inspection operations. Analyzing a significant number of bridges, it was established that the water leaking from the surface closure joints is the most contributing factor to the corrosion of the embedded steel reinforcement. It was ascertained that the degradation is mainly localized to the girders and the pier, with these members being more deteriorated than the other regions of the bridge. The research also found that there was spalling and random cracking in the concrete of some bridges, while other parts of the same bridge were in satisfactory condition. In terms of structural investigation, the purpose of the study comprised the analysis of the damaged bridges in static, dynamic, and thermal loading. It was established that the dynamic stresses and deflections in structures due to lateral loading did not exceed the limits allowable according to AASHO, thus these parameters cannot account for the observed cracks. It was also demonstrated that compressive and tensile stresses could not account for most of the damages, meanwhile, the tensile stresses induced by temperature variations occurred as the depth of the girders increased and these contributed to some of the damage.

Fry 2001, focused on the load testing and assessment of several road and railway bridges in the Czech Republic and Slovakia. The investigation featured static, dynamic, and monitoring tests on bridges, which were conducted to determine the operational state, its future changes, and possible damages. As an illustration, a test was performed on a three-span prestressed concrete bridge after the left-hand side of the superstructure had moved out of its cushion bearings resulting in deforming the joints between segments, The results from static load tests showed that the altered substructure suffered a vertical deflection error of 5.4% of the original, where the undamaged part was located. Dynamic tests revealed a five percent error in the vibration modes measured in the damaged and the undamaged test sections. Nevertheless, both static and dynamic tests indicated that the repaired structure behaved as the undamaged one. The results addressed the necessity of the undertaken repairing works as well as the usefulness of load testing for searching possible defects that occurred in structures and protecting them from being over. Strength. Fig.17 & 18

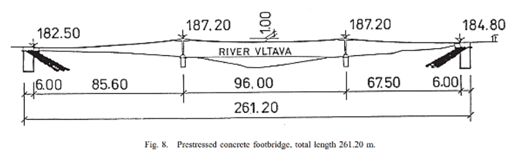


FIGURE 17. A prestressed concrete footbridge measuring 261.20 meters in length (Fry 2001)

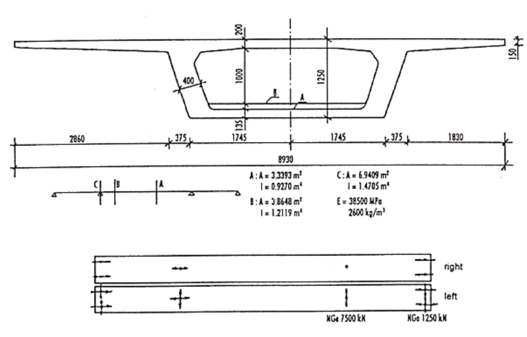


FIGURE 18. One of the bridges' cross sections, a view of both buildings and the bearings' movements (Fry 2001)

Awad & Swailem 2003 examined both static and dynamic effects along with damage inspection for a concrete bridge. The purpose of the research was to study the structural behavior of the structure affecting the bridge under different traffic loads. The damage investigation report illustrated that the severest damage was seen in girders and piers due to water infiltration and corrosion of the reinforcing steel, which comprise the structure. A Finite Element Method (FEM) model was developed to evaluate the load condition response of the bridge. Vehicle-induced dynamic deflections and deformations were recorded. It was established that the girder response did not exceed design constraints but that dynamic responses increased greatly with load and speed. In addition, static load tests were carried out on the bridge. The values derived from the maximum deflection of the specific damaged old bridge indicated strains as within allowable limits. However, an enhancement of maintenance and repair strategies is recommended since the structure requires rehabilitation. Many suggestions were offered to improve maintenance and repair techniques in light of the analysis outcomes.

Ahmed 2004 studied road and bridge diagnosis and treatment in distressed concrete work in the state of Mississippi. The investigations sought to focus on the factors that contributed to structural degradation, namely: corrosion, leakage, spalling, and cracking. The purpose of the research was to formulate and justify recommendations on how to choose the correct materials and techniques that will be employed by the Mississippi Department of Transportation (MDOT). According to the evaluation process, it was determined that the majority of areas that were damaged were primarily located in the girders and the piers, where the internal components were prone to damage due to environmental factors resulting in deterioration. Using diagnostic tools and diagnostic techniques, the condition of the concrete was diagnosed and remedial measures were proposed including resin-based and cementitious repair materials. Laboratory experiments showed that those materials enhanced the bond between the original concrete and repair materials. Then in the study, it was noted that it is necessary to consider the issues of selection of optimal methods and materials for repair to increase durability of the bridges in the future. The study conclusions were directed toward enhancing MDOT's maintenance practices and prolonging the service life of the repaired facilities (Figure 19).

FIGURE 19. Concrete plaques were grooved at a 30-degree angle.

In Reference (Azlan 2006), the authors proposed a technique for nondestructive testing as an alternative to the usual physical examinations of bridges. The study revealed a strong interrelation between the visual estimates and the rebound hammer measurements. The tests revealed that the compressive strength of the abutment concrete was 19 N/mm² (this is sloppy work, very poor condition), the deck was 55 N/mm² (sound condition) and the pier was 35 N/mm² (moderate condition). The rebound hammer can be considered the first reaction for the condition evaluation of the bridge.

Gheorghiţa 2009 applied a four-degree-of-freedom system in which the vehicle was treated as a moving inertia encompassing linear suspensions and elastic tires. The bridge was simplified to a uniform Euler-Bernoulli beam, which was supported at either end. Vehicle load-induced cracking models of the bridge's T-section reinforced concrete beam were instigated using a dynamic field load test on the beam to see how these cracking models responded to vehicle loads. Further comprehension into the factors which include the vehicle speed and the road surface roughness was also focused to understand the impact of these factors on the dynamic behavior of the bridge. Dynamic deflection adjustment, the alteration of relative and absolute frequencies, relative frequency change (RFC), absolute frequency change (AFC), and their phase plane plots and the analysis of their responses were the areas of concentration in this analysis. These results indicated that in the event of structural damage to the bridge structure, there is a sharp rise in the deflection, suggesting such an indicator is critical in determining damage to bridge structures. In addition, the reaction frequency of structural elements and the vehicle frequency reaction ratio had a clear significant effect on the RFC and AFC while the tarmacked road's surface effects on the deflection and the response's phase plane plots were minimal. In addition, both the vehicle weight and motion itself were qualitatively and quantitatively measured as parameters influencing both the RFC and AFC.

Ali & Wang 2011 inspected the damage experimentally and assessed its repair and retrofitting with the improvement of the Jiamusi Highway Prestressed Concrete Bridge in the country of China. The investigators' primary objective in this study was to make a structural inspection of the bridge after repairs, to evaluate the effectiveness of the strengthening techniques employed. This study presented various methods: observing the structure and performing static loading tests. The results showed that the state of such structural elements as cantilever beams, and bonded steel plates, were acceptable. No fresh cracks were noted over the ermine mending zones, which simply put showed how good the mending was done. From static load tests, it was concluded that the average compressive strength of concrete was about 46.31 MPa, which was standard and Adhered to the requirements. On the other hand, Experimental values of deflection and stress developed whilst loading up the bridge were relatively less than the computed figures, which showed that the bridge had enough strength and was stiff enough to meet the safety requirements. In general, the results of this investigation validated that bridge performance after enlargements on the repair were positive, where none in width and length of the previous crack changed due to strengthening of shrinkage than traffic. The work focuses on the determination of appropriate procedures for thorough inspection and repair of damages.

Ali & Wang (2011) presented a hydraulic model of the bridge over the Yangtze River in China. The study was rapid under the limitation that theorization did not deviate from its intended purpose. Conversation analysis was employed to examine the damage sustained by the box girder and the T-section concrete beam of the bridge under investigation. A software program created for this research was Dr. Bridge V.3.0, which is used to provide finite element analysis. The report of structural inspection suggests a satisfactory structural performance of the bridge, but it was established that Bridge No. 10 shall be reinforced as its structural integrity is in jeopardy. The analyses proved that the box-girder condition was in good status and no major impacts were visible.

In this document of Reference (Li 2011), stresses due to temperature effects and shrinkage in a 20 m section of a box girder are theoretically analyzed. The objective was to determine the reasons for longitudinal cracks that develop in the web and bottom region of the girder. Several longitudinal cracks appeared in the surface and bottom slabs, particularly in the web of the edge beam where the distresses were noticed most largely. A two-dimensional cross-sectional Finite Element Model was created, and temperature stresses consequent to the inside and outside temperature differential of the box was estimated along with moisture diffusion-derived shrinkage stresses using 'Ansys' software. Findings revealed that in more than three times colder conditions than normal, both the web and the outer surface of the bottom slab contract while internal pressure is exerted on heat-insulating foam. If concrete reaches a particular age, the Fu tendon does not induce cracks despite this tensile stress. Such shrinkage stress upon the degree of moisture gradient increases remarkably within 15 days and keeps reducing with the age of the concrete. In the early stages, due to low tensile strength, cracking occurs on the surface as drying and exposure strengthen the concrete. Adding vents to reduce the temperature difference can prevent cracking, while reinforcement and internal vapor venting grooves can aid in the early prevention of shrinkage issues. Fig.20

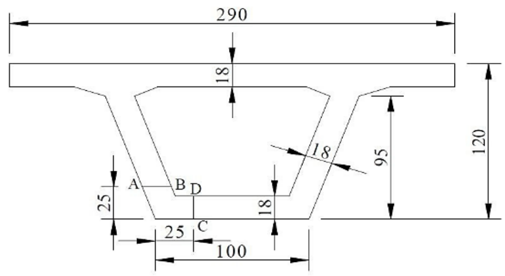


FIGURE 20. Mid-span cross-section

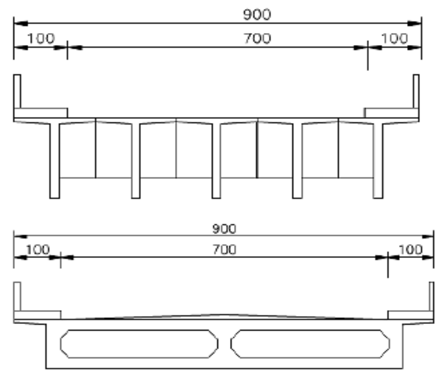


FIGURE 21. The bridge superstructure consists of a simply supported T beam and a pre-stressed continuous box girder (unit cm).

Zhang 2011 used testing of the shear stiffness of the segmental joints of cantilever-casting concrete bridges. These types of bridges need some special attention in design and during construction, as the structural connections are built in such a way that there is a structural discontinuity in between, which leads to a reduction in connection strength and stiffness, making the bridge vulnerable to a large amount of vertical bending towards the underside. The different areas of these criteria used included monolithic regions, roughened joints with a shear key, roughened joints without a shear key, and roughened joints. The investigation demonstrated that the jointed parts have less stiffness than the non-jointed sections. The design of cantilever-casting concrete bridges is strengthened when a shear key is employed in the joint zone because it increases the joint area's shear strength and stiffness.

In the paper of Hussain 2011, the behavior of the Qing Shan Concrete Bridge was evaluated under static load tests with an emphasis on its structure and its load-bearing capacity. The observations led to the conclusion that most of the structural components of the bridge are in good condition, with no serious deterioration recorded. For the static load tests, the T-beam girders as well as the prestressed concrete box girders showed negligible data variances from the assumptions made under the applied loads. This conformity with theoretical values illustrates an adequate safety allowance in terms of the load-carrying capacity of the bridge elements. The load-carrying capacity of the bridge was regarded as satisfactory in general; however, particularly in span No. 10, showed stress levels approaching the maximum design limits, indicating a need for reconstruction. Additionally, some parts revealed minor hairline cracks, which were reasonably well within acceptable limits. Under load, these cracks in parts of the bridge were likely to experience stress within reasonable amounts. The work, therefore, recommended minor interventions, which, in the long term, would further improve the load capacity of the bridge. Fig.21

This Reference (Ali & Wang 2013) by evaluating the static and dynamic characteristics of a pre-stressed concrete box girder bridge following restoration and strengthening, investigates the bridge rehabilitation approach. The emphasis will be on clarifying these procedures while investigating the responses of the structure due to these treatments and determining their dominance. The repairs in the bridge consisted of putting an additional 10 cm of slab to the deck, strengthening the web and bottom floors with steel plates, application of external pre-stressing tendons as a means of enhancing the whole structure, and treatment of existing fissures. It was observed that tensile stresses and vertical deflection were minimized following the strengthening, while compressive stresses were increased. There were no tensile stresses, which implied that the member at the mid portion possessed efficient crack-resisting capacity and that the load-bearing capacity had been boosted. Modal analysis indicated an increase in the natural frequency of the bridge from 1.64 Hz to 2.09 Hz, thus corroborating increased stiffness. The evaluation proposes that for structural evaluation purposes, external pre-stressing tendons and intended materials be utilized to enhance the strength of the structure and its fatigue resistance (Ali & Wang 2013).

A generalized assessment by Ali & Wang 2013 was made of a skewed pre-stressed concrete box girder bridge that was subjected to strengthening techniques. It was prescribed that there would be a more detailed examination of the static and dynamic structural responses following these methods. The repairs included crack-filling, web thickening of the box girders over the length of the bridge, internal pre-stressing tendons, and beam and column-type reinforcements across the girders. From theoretical analysis, it was revealed that allowing more composite strength resulted in compressive stress never exceeding limits, while tensile stress was often reduced below the required limits. Furthermore, a reduction in vertical deflection values and an improvement in natural frequencies were observed, indicating that the structures were stiffer and experienced less vibration. The paper concludes that the methods for enhancing the bridge had a significant effect on the bearing capacity of the structure, its lifespan, and overall performance conditions.

Mohammed 2014 investigated the dynamic amplification factor for bridges with simple supports and continuous loads imposed as moving loads. The dynamic and static maximum total load effects divided by the static maximum load effect are known as the Dynamic Amplification Factor (DAF.). Three simply supported and continuous beams with different lengths and widths were experimentally tested under a constant moving load with varying speeds. In particular, the sagging and hogging moments of the continuous beams and mid-span bending moments of the simply supported beams were of interest. Most importantly, the study found that the FDAF (Full Dynamic Amplification Factor) is often greater than DAF for both bridge types. For example, FDAF for the sagging moments in continuous bridges was 12% larger than in simply supported bridges. On the other hand, the FDAF for hogging moments in continuous bridges was found to be 16% higher than that of the sagging moments. This implies that there is more dynamic amplification for continuous bridges, particularly in the hogging regions. It was also suggested that more emphasis should be focused on the effects of dynamic loading on the design of continuous bridges. This is because compared to the conventional simply supported structures, the continuous beams were liable to magnify dynamic behavior, which necessitated the need for accurate simulation and design for safety purposes.

Conducted research on the Nondestructive Testing of bridges through 40 state Departments of Transportation (DOT). The study's main purpose (Lee & Kalos 2015) was to determine what NDT techniques were used and how effective and practical they were in reality for reinforced concrete and metallic structures. It was found that NDT methods were preferred in special and damage inspections while these were less often used in routine or baseline inspections. Typical methods of these bulk structures were ultrasonic testing and magnetic particle inspections for steel structures, while ground radar and smart concrete were used for concrete. However, the changeover to some advanced methods was hampered by the expensive costs and complicated instruments. On the other hand, an underwater examination that is usually done by subcontractors was indicated to be difficult because in some instances sonar would not be useful. Lastly, the study pointed out the varied extent of NDT usage by various states due to differences in skill sets and infrastructure availability.

Addressed the issues related to bridge maintenance inspection and gave solutions to enhance these practices through the use of automation. The (Hüthwohl 2016) remarks that bridges as structures are complex components, not just that, but also calls for more accurately done inspections and maintenance of hygiene. There are several challenges that current inspection methods are faced with, like the bias of the inspections, whereby it is done manually, the maintenance comes at a costly price, and dangers involved in inspecting areas that are out of reach. Examples of manual inspections that are impossibly dangerous for non-use of protective equipment are common. Such issues are rectified by enlarging the review of the literature to cover automated visual inspection, addressing algorithms, machines, and bridge damage detection. These novel methods offer better quality and speed by incorporating sensors, cameras, and software for the analysis of collected data to achieve automatic detection of various defects on the bridge, including cracks and spalling, without human effort. The study warrants that presently available procedures for inspecting bridges leave a single mode of inspection that can look at such offenses of damage inspection or look at over-based or under-based elements.

Ali 2017 further highlights the impact of varying girder cross-section shapes on the static properties of bridge models in the study. The methodology deployed was the finite element method, where ten bridge models with different girder shapes including T-girders, I-girders, box girders, and flat slabs were constructed and compared. Its main focus was on optimizing the chosen girders for bridges supporting heavy traffic loads. Vertical displacement, bending moment, shear force, tensile and compressive stress were evaluated for this purpose. The findings of this study showed that box girders, commonly constructed with curved and sloped external webs, performed better than other girders, especially in terms of vertical displacement and stiffness, hence applicable for high-traffic volume-related bridges. On the other hand, those models that used flat slabs and T-girders showed extension in vertical displacements and tensile stresses and seemed unable to withstand dynamic loads. Hence, the study concludes that box girders should be integrated into the designs of new bridges that are likely to experience high loads.

Cui 2018 enumerated Fatigue Performance and Evaluation of Welded Joints in Steel Truss Bridges explores the fatigue performance of welded joints, as it is particularly important for the service life of steel truss bridges. It was noted that stress concentration as well as residual stress of welds were the main sources of fatigue damage. To improve fatigue performance through the reduction of stress concentration and residual stresses in the joints, tests with corner-fillet profile (CFP) and ultrasonic impact treatment (UIT) were conducted. Experimental tests revealed that fatigue resistance was improved, and using CFP increased it by 24% while increasing fatigue resistance with the help of UIT increased it by 36%. The application of these methods in combination has increased the fatigue resistance of the joints by 60%. Three techniques were employed in the evaluation of fatigue performance, namely the nominal stress method, effective notch stress method, and peak stress method. Among them, the peak stress method was the most accurate. The data presented in this study confirms that CFP and UIT are useful techniques for enhancing the fatigue resistance of steel truss bridge joints, as well as the choice of efficient methods for the accuracy of results.

The paper of Marcheggiani 2019 highlighted the necessity of assessing the highway bridge's condition using a range of static and dynamic techniques, or "combined methods. The present study examined a multi-span bridge located in Northern Italy and employed operational modal analysis (OMA) and experimental modal analysis (EMA) to provide a broad framework for evaluating the targeted structure under diverse conditions. It was expected in this research that the structure could be characterized by key parameters such as natural and structural frequencies, mode shapes, and damping factors under excitation from traffic and seismic activities. The study revealed that dynamic load testing was a good complement to static load testing since it provided information that could not be obtained from the static tests alone. The report also established that there was a need to apply appropriate material and structural parameters in numerical modeling to make reliable assessments of the bridge's behavior. It was demonstrated that such a combination of static and dynamic test data would improve structural health assessment capacity, which is important for both new structures and existing ones. The authors recommend the use of these techniques separately and together, as they help to improve test conditions, performance, and durability.

The article by Mansoor & Awad 2019 pointed out the extreme deficiency that is there in the Al-Anbar governorate of Iraq, which is the Inspected and evaluated concrete bridges, especially because of war-induced deterioration. This attempts to create a KBS, which optimally assesses the damage while effectively saving time and resources. The author puts forward an Inspection System for Damaging Concrete Bridges, which was further specified in this study to apply to the Palestine Bridge of Al Anbar. The KBS utilizes the knowledge of the experts to formulate correct answers for the maintenance of various parts of the bridges in the twinkling of an eye. The damage could be fractures, delaminations, and rusting of corroded surfaces, and can be classified into minor, moderate, and severe based on the degree of damage. As one of the limitations of conventional methods, it is noted that the system incorporates knowledge, requires low interaction effort by the end-users, and offers innovative solutions to support timely inspection and maintenance of structures. The study was able to assess that the ISDCB system is efficient, satisfactory, and accurate in structural abnormalities diagnosis, possibly with the knowledge base being upended for further accuracy enhancement.

Dong 2020 examined and was concerned with the bridge load test for live load distribution, load rating, serviceability, and dynamic behavior evaluation. Dynamic and static testing was undertaken of an in-service concrete Highway Bridge in Florida that had previously been delaminated but fully rehabilitated to determine its performance. The emphasis of the static tests was on deflection-based live load distribution factor (DF), load rating factor (RF), and serviceability evaluation factors. The dynamic tests were conducted to determine structural frequencies, and mode shapes as well as impact factor (IM) under varying truck loads and speeds. As per the study findings, it was clear that the AASHTO specifications were very conservative when compared to experimental results and the finite element model (FEM). The deflection of the bridge was demonstrated to be within allowable ranges while the impact factors were less than the AASHTO values. It was also established that there was no need to post load restriction notice or load further retrofitting as the modified bridge was fully capable of sustaining heavy trucks. Besides, the information borrowed or the framework in the study is suitable to be used for other bridges constructed in similar conditions.

Hidayat & Suryatama 2023 did a dynamic analysis for a continuous box girder bridge and examined the response of the bridge under the effects of Light Rail Transit (LRT) loading. The research applied the finite element method for the analysis and modeling of the bridge structure, geometry, support, and materials. Three conditions were analyzed: the bridge under existing conditions (without LRT), with a single LRT trainset, and with two LRT trainsets. The results showed that there was a decrease in the natural frequencies of the bridge structural members as the LRT loading was increased. The highest natural frequency was depicted in the bridge without LRT, followed by the bridge with one LRT trainset, and the lowest was noted when two LRT trainsets were deployed on the track. This means that the increase of LRT loads indeed decreases the structural stiffness of the bridge. On the other hand, the results of dynamic testing of the structure were compared to the results of the finite element analysis, the prediction of bridge natural frequencies showed 2.567% less values, which means that the actual rigidity of the bridge was slightly higher than estimated. It emphasizes the importance of carrying out further dynamic analysis as a critical part of the work in bridge design, in particular of continuous box girder bridges, as it determines the behavior of the structure under different loads.

Abdullah 2024 focused on the study of the evaluation of field damage and performance of a precast prestressed concrete I-girder bridge for a static loading case basis. The case study chosen for this research was the Bata Bridge located in Babylon, Iraq. The main objectives include but are not limited to identifying damage to the structures, internal forces analysis at design and service intervals, and making assessments on the bridge under various loads such as dead load, prestressed load, moving traffic loads, temperature effect, and load combinations. It is concluded that bridge rehabilitation works are typically required for some elements such as those made of steel, concrete deck, bearing pads, expansion joints, and abutments. On static analysis, span No. 1 recorded the highest values of positive bending moment, tensile stress, and downward vertical deflection for the superstructure, albeit compression stress and negative bending moments were lower. However, more than 50% of vertical deflection after prestressed tendon improvement had been achieved, improving the structural performance of the bridge. The study ends by stating that such a method of external prestressing tendons can easily be adopted by rehabilitation works of the old bridge making it better able to resist loads and stresses that may be applied to it in the future.

CONCLUSION

This study highlights the necessity of a comprehensive evaluation approach that integrates both static and dynamic analyses for concrete highway bridges to determine the causes of deterioration. Field load testing, finite element modeling (FEM), and on-site inspections were employed to identify critical structural issues, enabling targeted modifications to enhance resilience. Onsite evaluation, experimental load tests, and finite element modeling analysis (FEM) uncovered crucial structural defects. The results indicate that the presence of dynamic loads, such as heavy traffic, increases the stress concentration by 15-20% from the static conditions, which leads to faster crack propagation. Also, prolonged relative humidity and freeze-thaw cycles can reduce the compressive strength of concrete by 30%, leading to the loss of structural stiffness. The repair to the damaged zones with carbon fiber reinforced polymer (CFRP) lowered the stiffness but increased the load-carrying capacity by 25–35%, whilst maintaining structural integrity. Despite the results being interesting, the research was seriously flawed. The results can be questioned because they are relative to the behavior of concrete bridges under a specific set of loads and climatic conditions, which does not consider the behavior of steel or composite bridges along with the effect of harsh weather. The development of blended rehabilitation strategies combining CFRP and ultra-high-performance concrete for bridge strengthening should be explored further. The application of adaptive machine learning models that dynamically optimize maintenance and damage prognosis for these methods could enhance their effectiveness. By moving the attention to seismic risk and fatigue damage, a complete risk assessment methodology would be possible. These methods will lead to frameworks for proactive maintenance of critical assets of transport infrastructure to guarantee their safety and usability during the changing environmental and operational conditions.

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