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A REVIEW STUDYING OF DAMAGES INSPECTION METHODS AND STRUCTURAL PERFORMANCE ASSESSMENT OF BRIDGES STRUCTURES

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ABSTRACT

A bridge can serve as a primary link between highways, railroads, crossroads, two river margins, and between mountains. The design, advancement, and global building of bridges are among the most fascinating and significant achievements in civil engineering. Bridges must be designed and built to be secure, effective, and cost-effective. Evaluation of the bridge structure is a topic that is becoming more and more important in the decision to address the deterioration of the bridge structure. To determine the actual strength of the bridge structure, its service life, and the real load scale, appropriate design and analysis procedures must be adopted. The main purpose of this study is to review the structural performance evaluation, damage inspection processes, different types of damages, static and dynamic analysis, and related studies to evaluate the structural performance of bridge structures.

Keywords: bridge, structural performance, evaluating, load tests, damage, inspection.

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1. INTRODUCTION

Bridges, similar to any other human construction, have progressed and changed over time as to their resources and resistance execution [1]. A most essential element of transportation systems is a bridge. The design, advancement, and global building of bridges are among the most fascinating and significant achievements in civil engineering. Bridges must be designed and built to be secure, effective, and cost-effective [2]. A bridge must be suitable for its situation and then scale, its necessity be designed to be constructed professionally and without needless risk of failure, it must be inexpensive, and its arrival must be prioritized. These characteristics rely on the intangible design's quality design and analysis is regularly used together. Design requires a combination of engineering information, ability, and involvement [3].

Three sections make up the structural component of a bridge. First, it is referred to as a superstructure because it includes a deck, beams or girders, pavement, expansion joints, security barriers, drainage systems, and bearings. Second, it is referred to as a substructure and consists of piers, pier caps, and abutments. It is the structural component utilized to support the superstructure of the bridge and move the superstructure's self-weight and external loads, such as traffic loads, to the foundation of the bridge. Thirdly, a foundation is a structure that incorporates piles and pile caps and is regarded as the part that transmits loads to the soil. Concrete, a material that exhibits varied behavior in compression and tension action, was used to construct every component of the bridge [4-12].

In general, bridges can serve as a primary link between highways, railroads, crossroads, two river margins, and between mountains**.** Bridges' reign applied various structures during history background then multiple ingredients have too been employed to construct those separately substantial consumes gone through it hold evolution and similar is true for all assemblies; a background of Bridges enables therefore remain partitioned hooked on a variety of pasts. Going to depend on their components and rely on their structures, so each past evolved and was established more or less independently of the others. It is complicated, doubt not unthinkable until create the lined background of bridges as we will have to exclude valuable work that is less essential than others and thus not similar [13], [14].

Evaluation of the bridge structure is a topic that is becoming more and more important in the decision to address the deterioration of the bridge structure. To determine the actual strength of the bridge structure, its service life, and the real load scale, appropriate design and analysis procedures must be adopted. Both static and dynamic live loads have the potential to negatively impact the structure of a bridge [15-17].

2. OBJECTIVE OF STUDY

The main objective of this study is to review the structural performance evaluation of bridges structure, damage inspection, different types of damages, static and dynamic analysis, and past related studies to evaluate the structural performance of bridges structure.

3. STRUCTURAL PERFORMANCE EVALUATION OF BRIDGES STRUCTURES

Structural performance evaluation of bridge structures is important to diagnose the damages in bridge structural members and find suitable methods of strengthening and repairing to improve the stiffness of bridge structures. The evaluation process can be done by adopting a theoretical analysis of designed internal forces under static and dynamic loads by using the finite element method which is used in engineering software. Experimental analyses are also used in the evaluation by adopting static and dynamic load tests. To complete the evaluation process, damage inspection methods with field tests such as compressive strength of concrete and leveling of bridge deck (deflection) are adopted.

Bridges' structural integrity is significantly impacted by poor maintenance and retrofitting, which frequently results in load sign-posting, unforeseen bridge closures, and other problems. This can also result in a structural collapse in the worst-case scenario. [18].

Existing bridges may experience structural deterioration owing to the aging of the materials, variable weather conditions, damage from heavy vehicle contact, etc., which lowers their ability to support a given load. A bridge must be tested in the field to see how well it performs when carrying live loads. The response observed in the field and those modeled theoretically still differ, though. The difference between field and analytical replies will be minimized. One strategy would be to calibrate an analytical model to closely match the behavior observed in the field using field (static) response data [19-23].

Numerous studies have been published recently to assess the effectiveness of various bridge types using static and dynamic load tests, either in a controlled environment or after the bridge was opened to traffic. To control the finite element model, experimental data from the bridge's static and dynamic load tests were employed. Examining normal service stage, fatigue, and ultimate loads, developing theoretical models to determine the performance of the bridge structural members, and verifying the analytical results by contrasting them with the outcomes of experimental tests are the primary objectives of experimental and theoretical analysis of the bridge structure [24-27].

Computer models with adequate material parameters, boundary conditions, and loads are frequently used in bridge structural analysis. All loads (permanent loads, vehicle live loads, wind loads, and earthquake loads) are proportioned, combined, and factored into members and connection joints by the respective design standards and rules. An analytical model is a simplified representation of the actual structure. A conceptual framework should be as accurate as possible in terms of material characteristics, loading, initial conditions, and structures [28-30].

Generally, the goal of structural analysis is to assess how well a structure will hold up under the influence of specified loads as well as other external factors like support movement and temperature variations. Stresses, strains, axial forces, shear forces, bending moments, support reactions, and deflections are some of the parameters of structural performance. The structural design, on the other hand, entails form-finding, calculating loads, and balancing structural members and parts so that the constructed structure can support the loads within the design limit states [31-32].

3.1 Static Analysis of Bridge Structure

Predicting internal forces and deflections under static load conditions is the basic goal of static analysis. The application of theoretical static analysis and field static load testing can be used to conduct static analysis. The theoretical static analysis comes in two different flavors. The first kind is static elastic analysis, often known as linear analysis, and it can be done manually or with the use of computer algorithms. Sadly, only a small class of bridges can benefit from static elastic analysis. Short bridges with monolithic abutments are included in this class. Static inelastic analysis, also known as non-linear analysis, is the second type and can be performed using specially designed engineering software. Plasticity, stresses, stiffening, significant deflections, strains, hyper-elasticity, contact surface, and creep are characteristics of this type. It is used to assess the current working condition of the bridge structure under static vehicle loads and to measure the internal forces and deflections under the maximum values of bending moments. The static load test is an efficient method for comprehending the behavior and fundamental characteristics of the structural performance of bridges. To determine whether or not the bridge requires strengthening and repair, the results of the theoretical static analysis are compared with those from the field static load test to assess the structural performance of the bridge. For three reasons, including reduced design time, lower construction costs, and increased structural safety, finite element analysis is a useful technique for assessing the static performance of structures [31], [34-40].

3.2 Dynamic Analysis of Bridge Structure

It is thought that the dynamic impacts of moving loads can be taken into account by adding an impact factor to the static load analysis, which is taken into account regardless of the kind of structure or the arrangement and speed of the moving wheel loads. At the resonant peaks, the effects of the maximal dynamic load are felt. When the loading's excitation frequency or a multiple of it corresponds with the natural frequency of the bridge structure, there is a hazard of resonance [41-43].

Due primarily to the dynamic problem's time-shifting nature, dynamic issues are frequently more complex and difficult to understand than their static equivalent. A dynamic load changes in magnitude, direction, and/or position with time. Similar to how a dynamic load responds, a structural response also varies over time. Consequently, unlike a static problem which has a single solution. A succession of solutions to a dynamic problem must be built to correlate to all pertinent points in the response history. Dynamic implies that the elastic resistance force also includes inertia and damping. Inertial forces are created, preventing the structure from accelerating. When a dynamic load is applied to a structure, the outcome is influenced by both the load and inertial forces. As a result, the appropriate internal response in the structure must adjust to both the inertial forces brought on by the structure's accelerations as well as the externally applied forces. [44], [45], [46] The application of theoretical dynamic analysis and dynamic load testing in dynamic analysis allows for the evaluation of the dynamic performance of the bridge structure. Finding out how dynamically responsive the bridge structure is to shifting loads is the major goal of dynamic analysis. These reactions include dynamic acceleration, dynamic displacements, natural frequency, vibration frequency, damping ratio, and impact factor. There are two different types of dynamic analysis, just as static analysis. Firstly, dynamic elastic analysis is known as linear analysis. Engineering software can be used to complete this type of task. While some software allows input motions in three orthogonal directions and combines responses using the appropriate modal combination rule, other software only allows one component of input motion at a time and necessitates the use of an algebraic rule to combine responses from orthogonal input motions. Because elastic analysis improperly accounts for the impacts of nonlinear response on these parameters, local deformation and the distribution of forces cannot be understood well using elastic dynamic analysis. Dynamic inelastic analysis, also known as non-linear analysis, is the second type and is performed using specially created engineering software. Specialized knowledge is needed for choosing the ground motions, conducting the analysis, and deciphering the results. To only allow nonlinear analysis in specific elements (such as the superstructure hinges), specialized software has been developed; this software is probably the most simple to use and interpret. Other software supports both geometric and more widely dispersed material nonlinearities. Additionally, transit dynamic analysis, a method for figuring out how a bridge structure will react dynamically to a time-varying load, modal analysis, an extension of modal analysis that calculates the bridge's natural frequency and mode shape, spectrum analysis, a method for figuring out stresses and strains resulting from response spectra, and explicate analysis, a method for figuring out quick solutions, are all examples of dynamic analysis. [31], [47-50].

3.3 Field Load Test

An essential technique for assessing the structural performance of the bridge structure is to undertake field load testing on the bridges. They enable comparisons between theoretical presumptions and the actual behavior of the load-tested bridge. Static and dynamic load tests are two different forms of load tests. Figure-1 shows the load test flow chart. [31], [51-53].

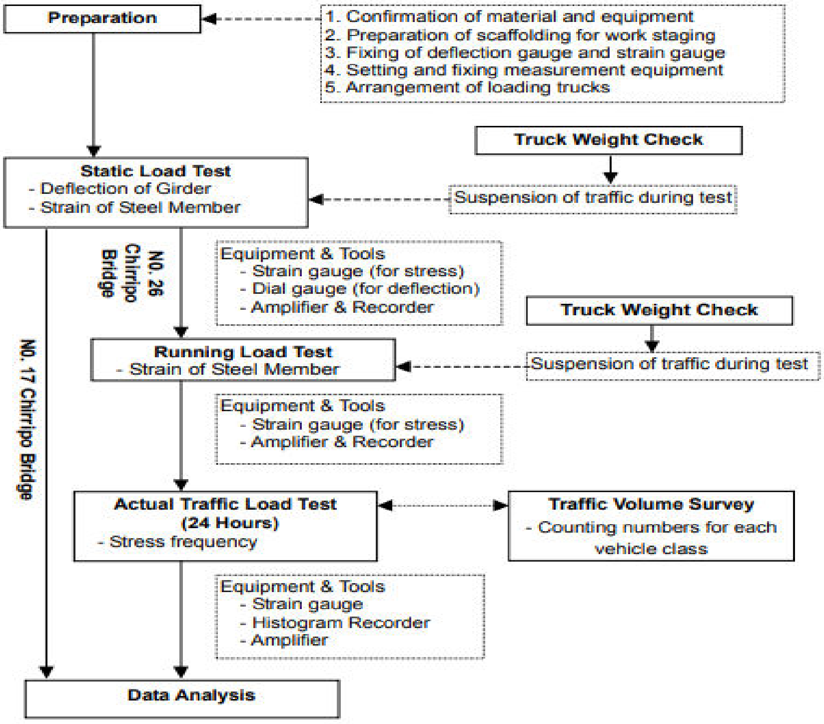

Figure-1. Load test flow chart.

3.3.1 Static load test

If required by governmental authorities or the bridge's designer, static load tests are conducted. It is required to quantify the vertical deflections, stresses, strains, and bending moment at the locations where the greatest effects are anticipated during a static load test (in the middle of spans, in the quarter of span) [31]. Static load tests are used to determine the elasticity for constant or rising loads or to validate the experimental behavior to compare it with the theoretical behavior. Depending on whether the bridge is a road or a railroad bridge, the load is applied using trucks or locomotives. Tanks filled with water are utilized for pedestrian walkways. Differential transducers fitted on telescopic rods carried to the bottom of the structure allow for real-time arrow observation on computers. Figure-2 shows the static load test on the bridge [54].

Figure-2. Static load test on the bridge [55].

The static system, support, loads, and degree of external prestressing of the structure alter throughout construction. Under both dead and live load, the entire segment is still in compression. It is crucial to maintain safety standards and to guarantee the final needed alignment of the bridge so that stresses and deformation at each construction stage are accurately assessed. Bridge load testing enables the investigation of the genuine behavior of the structure under brief loading. A load test can be supplemented by bridge monitoring. It could identify unusual behavior when the bridge was being built, during its use, and as it deteriorated. Other factors, such as rapid foundation settlement, ground movement, high traffic, or failing post-tensioning tendons, can also create structural problems [56].

3.4 Dynamic Load Test

An essential step in the acceptance process for new bridges is dynamic load testing. Dynamic tests provide valuable information about the real behavior of the bridge during traffic in addition to static load tests. Analytically, this information is typically challenging to ascertain due to the complexity of the actual structure. For the management of the structure, the impact of pavement deterioration on the dynamic response of the bridge is particularly crucial. A dynamic test can readily and realistically provide this information, which the highway authority can then utilize to plan pavement maintenance. The goal of the dynamic load test is to identify the variables that will affect the bridges' dynamic behavior. The basic vibration frequency, the dynamic amplification factor, and the logarithmic decrement are the structure's primary dynamic properties. Typically, these characteristics are not thoroughly examined during the design stage of small and medium-sized structures. At the time of design, several parameters, such as the dynamic amplification factor or the logarithmic decrement, can only be tentatively estimated. These characteristics, though, are reasonably simple to measure experimentally and can provide useful data for the use and upkeep of the bridge [57], [58].

One of the key evaluation markers of bridge health is the dynamic effect of moving vehicles on bridges, which is typically regarded as a dynamic load allowance (or dynamic impact factor). The stress cycles that cause bridge component fatigue can be overestimated if the dynamic effect is not appropriately taken into account. In addition to the maximum span or the natural frequency, the dynamic load allowance (DLA) depends on a wide range of additional factors that were challenging to assess with adequate accuracy. The ratio of the maximum static response (Yst) under the same vehicle load to the maximum dynamic response (Ymax) on a bridge is known as the dynamic amplification factor. The dynamic amplification factor (DAF) and the DLA (u) differ by one [59], [60], [61].

Only when the static load testing has been completed and has demonstrated structural behavior within acceptable bounds are dynamic load tests often applied? The vibrating state of the bridge will occur when it is subjected to dynamic vehicle traffic loads. The deflections and strains produced by a moving vehicle on the bridge are often larger than those produced by the same vehicle loads applied statically [31], [60].

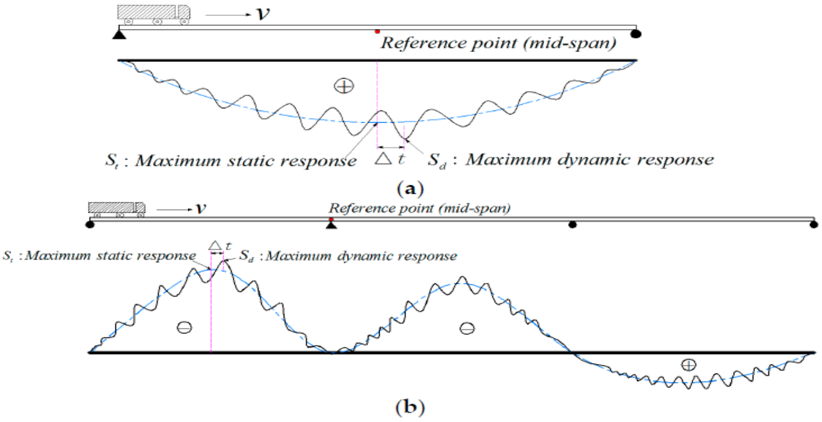

Figure-3. The time history curve of static and dynamic responses under vehicle load (a) simply supported bridge, (b) continuous bridge [59].

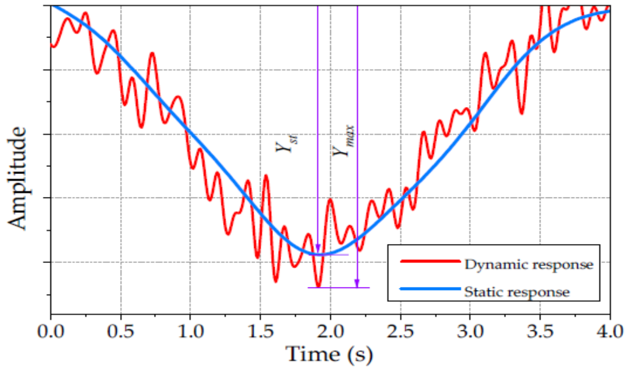

Figure-4. The principle of conventional DLA [59].

3.5 Damages Inspection Methods of Bridges

Due to the critical role that these infrastructure components play in the highway and railway transportation system, integrity, safety, and serviceability of bridges and viaducts are all key targets that need to be guaranteed throughout their lifetime. The guidelines document's inspection methods and techniques are based on a multi-level approach with varying levels of complexity, intricacy, and prioritizing that aims to define so-called attention classes, through the use of inspection forms and digital Bridge Management Systems. The conventional methods of bridge inspection and monitoring, which mostly rely on visual techniques, are technically and logistically challenging, time- and resource-intensive, expensive, and if carried out on a damaged structure in an emergency, even dangerous for the inspectors themselves. Figure-5 depicts the bridge structure examination process. Because the reports detail both the historical problems found during inspections and the reasons for the defects, they include information about the cause-effect relationship of bridge damages [61-64].

Figure-5. Inspection process of bridge structure [62], [65].

Although expensive, bridge inspection is a necessary part of keeping transportation safe. Visual examination is the main approach utilized to inspect the bridges. During a typical bridge inspection, skilled inspectors examine the various bridge components closely to assess their condition and provide an accurate evaluation. The inspection procedure is frequently employed as a tool to determine which bridges need maintenance work. To ensure the safety of the general public, it is necessary to identify bridges with an incorrect likelihood of failure. Damages inspection of bridge components serves the following purposes: determining whether or not a bridge structure is in a safe state; identifying any maintenance, repairing, and strengthening that are necessary; serving as a planning tool for funding any necessary maintenance and strengthening; and providing designers and construction engineers with information on those features that need maintenance. A bridge structure is inspected every two to more years, depending on its state [66], [67], [68], [69], [70], [71].

In general, bridges are built and planned to give the traveling public a wide margin of safety and lengthy service life (75 years). Nevertheless, over time and occasionally prematurely, all structural components degenerate. If they departed without being checked, they will eventually pose a risk to those using the bridge.

Therefore, regular bridge inspections are required to assess the condition of the bridge's construction, to spot structural problems, and to increase the structure's useful life. The bridge inspection symbolizes the low end of technology because it does not make use of easily accessible technologies and because methods and procedures have not evolved much in more than a century. Professional engineers in civil and structural engineering, team leaders, underwater devices, scheduling, coordination, report submission, and report evaluation by the main structures engineer are all part of the operating issue of damage inspection. There are many inspection manuals for bridge structures. Table-1 lists the standard inspection manuals in the USA and Table 2 lists the standard inspection manuals in some countries in the world [72-74], [31].

Table-1. The standards manuals and guides of bridge inspection in the USA [31].

Nation	Publisher	Document
U.S.A	AASHTO	-Commonly Recognized (CoRe) Structural Elements (2001). -Manual for Condition Evaluation of Bridges, 2nd ed. (2000). -Moveable Bridge Inspection, Evaluation, and Maintenance Manual (1998), 608 pp. -Standard Specifications for Structural Supports for Highway Signs, Luminaries, and Traffic Signals, 4th ed. (2001), 272pp.
	FHWA	-Bridge Inspectors Reference Manual, FHWA NHI 03-001(2002), 1762 pp. -Bridge Scour and Stream Instability Countermeasures Experience, Selection, and Design Guidance, 2nd ., NHI-01-003 (2001). -Culvert Inspection Manual, FHWA-IP-86-2 (1986). -Highway and Rail Transit Tunnel Inspection Manual, FHWA-IF-05-002 (2005), 112 pp. -Inspection of Fracture Critical Bridge Members, FHWA-IP-86-26 (1986), 232 pp. -Recording and Coding Guide for the Structural Inventory and Appraisal of the Nation Bridges, FHWA-PD-96-001(1995), 124pp. - Under Inspection of Bridges, FHWA-PD-80-1 (1989).
	USDA	Timber Bridges Design, Construction, Inspection, and Maintenance (1992), Forest Service.

Table-2. The inspections manuals in some countries in the world.

Nation	Document
Denmark	Inspection of Bridges (1994), Danish National Road direction, 175 pp.
Finland	- Guidelines and policy for Bridge MR&R Operation. - Guidelines for Bridge Inspection. - Bridge Inspection Manual. -Bridge Repair Manual (SILKO-Guidelines).
Germany	- Highway Structure Testing and Inspection, DIN 1076 (1999), Deutsche Norm, 10 pp. - Preservation and Maintenance (n. d), Construction and Housing, German Federal Department of Transportation, 23 pp. - Guideline for the Structural Design and Equipment of Bridges for Monitoring, Inspection, and Maintenance (1997), German Federal Department of Transportation, 6 pp. - Recording and Assessment of Damages, Guideline RI-EBW-PRUF, 1998. - ASB Structure Inventory, (coding manual for SIB-Bauwerke) (1998).
Norway	Handbook for Bridge Inspections (2001), Norwegian Public Roads Administration, 339. pp.
United Kingdom	Requirements for Inspection and Management of Bridges, BD 62/94 and BD 63/94.
Canada, Alberta	- BIM Inspection Manual, Version 3 (2005), Alberta Infrastructure and Transportation. - BIM Inspection Manual, Level 2, Version 1 (2004) Alberta Transportation, 153 pp.
Canada, Ontario	Ontario Structure Inspection Manual (2002), Ontario Ministry of Transportation, 380 pp.

There are several methods of damage inspection for bridge structures. These methods are: [71], [75-82]

3.5.1 Inventory (Initial) inspection

The initial inspection is the first examination performed on a bridge before it is added to the inventory of bridges to give data for all structural evaluations and inventories as well as to identify any structural issues. Before new bridges are put into service and when already-existing bridges are added to the inventory, it is used. Certain components of the inventory inspection will need to be completed on every bridge by the newly established rules. This includes adding baseline stream cross-sections, validating data, coding new fields, undertaking scour evaluations, and conducting surveys.

3.5.2 Routine inspection

The term "routine inspection" refers to an inspection that is regularly scheduled and consists of the observations and measurements required to assess the physical and functional state of the bridge, to look for changes from the initial or previously recorded states, and to make sure the structure still meets current service requirements. At regular intervals, the frequency is at least once every two years. Unique structure types, structures with details with unknown performance histories, structures with possible foundation or scour concerns, non-redundant structures, and bridges with structural issues are among the structures that need more frequent inspections.

3.5.3 Fracture critical inspection

All bridges with one or more fracture-critical members undergo fracture-critical examination. Every two years, or more frequently if necessary, is the frequency. Pins and bottom cords or tension web members on trusses, as well as link or bottom flanges on two-steel girder systems, are common examples of fracture critical members. The fracture critical inspection bridge report (BM-BIR-FC 1) form must be used to report any inspections of fracture-critical members. Within 90 days of opening to traffic, newly renovated fracture-critical bridges must undergo an initial thorough assessment of their bridge members.

3.5.4 Underwater inspection

Bridges with components that cannot be examined by probing or widening at low water or that are not visible from the surface need to undergo underwater inspection. This strategy calls for diving or other suitable methods. At least once every five years is the frequency.

3.5.5 Scour inspection

The purpose of the scour inspection is to assess the streambed's current state and depth, to decide what protective measures can be implemented for the bridge construction, and to ascertain how susceptible the streambed is to scour. Any bridge with piers on soil must undergo inspections at least every two years.

3.5.6 Special feature inspection

All bridges with special design elements that call for specialized knowledge, tools, or inspection techniques should undergo special examinations. Such qualities ought to be noted on the master list and in the database used for the bridge inventory. Depending on how terrible the circumstances are at the bridge, it should be decided how frequently an inspection is needed.

3.5.7 Under Bridge Inspection Truck (UBIT)

The use of an under-bridge inspection vehicle allows the inspector to access bridge components or members that would otherwise be too far away to be properly evaluated. This inspection is often carried out as frequently as required to assess the state of the structure and serves as an additional function within the routine inspection.

3.5.8 In-depth inspection

A close-up examination of one or more members above or below the water line constitutes an in-depth inspection. This type's goal is to find any flaws that are difficult to spot through standard inspection procedures. In some cases, a hands-on inspection may be required.

3.5.9 Damage inspection

Damage inspection is an ad hoc assessment used to evaluate structural damage brought on by external forces or internal ones. When environmental or human causes of bridge deterioration have already happened or are suspected, this strategy is used. Use this technique as often as necessary.

3.5.10 Interim inspection

The purpose of this method is to monitor and assess bridge members that are known to be defective or extremely prone to rapid deterioration. It is a partial inspection. interim inspections should be conducted as often as necessary in the time between regular inspections.

3.5.11 Flood inspection

At bridge locations where there is a chance of flood or scour damage, flood inspection is done during or right after substantial floods. Use this technique as often as necessary.

Figure-6 shows the visual inspection, figure 7 shows the routine inspection, Figure-8 shows the periodic inspection, Figure-9 shows non-destructive testing during the inspection, figure 10 shows the general inspection sections of the concrete bridge, and Figure-11 shows the general inspection sections of the steel bridge [75].

Figure-6. The visual inspection.

Figure-7. The routine inspection [75]

Figure-8. The periodic inspection [75].

Figure-9. Non-destructive testing during inspection [75].

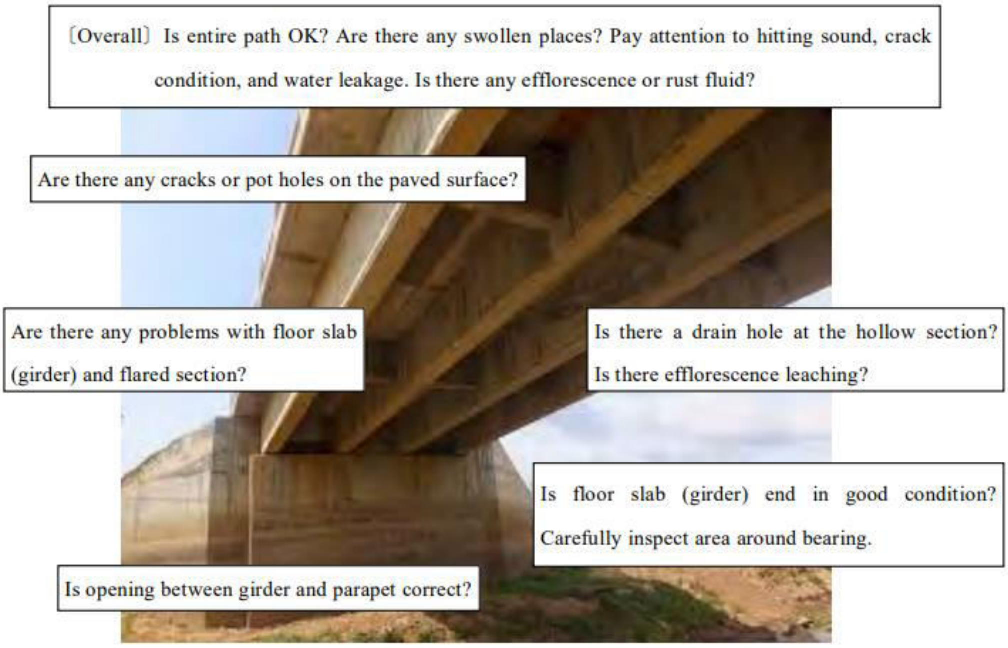

Figure-10. The general inspection sections of the concrete bridge [75].

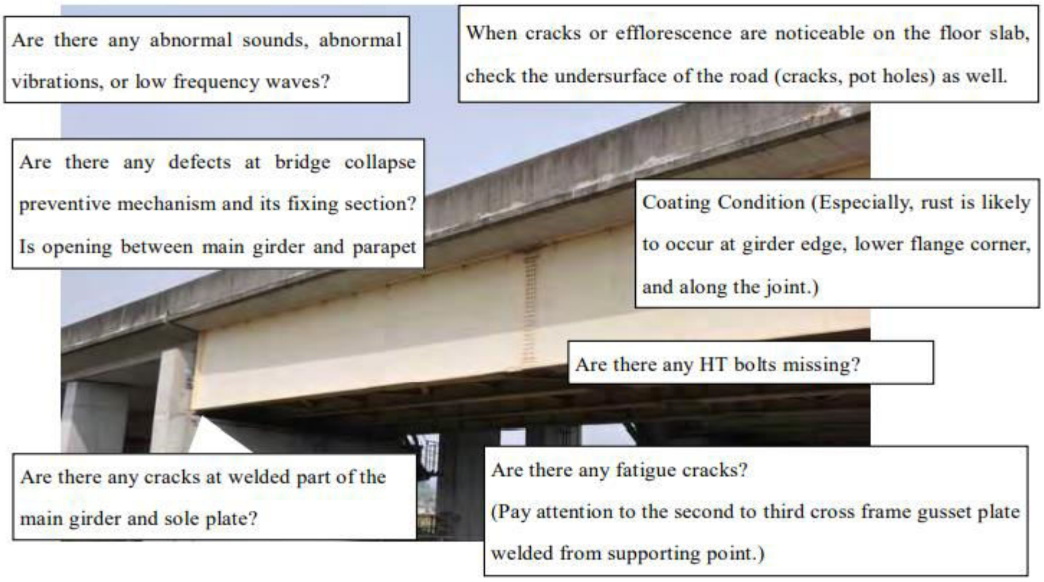

Figure-11. The general inspection sections of steel bridges [75].

4. STRUCTURAL DAMAGES OF BRIDGE STRUCTURE

Infrastructure system structural deterioration is a critical problem since it could shorten the systems' useful lives and reduce their dependability. Additionally, by accounting for their life cycle, the design of infrastructure systems can be made more effective by using structural deterioration prediction. Models to forecast the life-cycle performance of infrastructure systems are particularly necessary in light of the development of performance-based engineering methodologies. [83]

Visible indicators of damage are frequently present when a bridge structure is damaged. A thorough assessment reveals details regarding the damages. The quantity and type of deterioration, as well as the significance of the structure, should be taken into consideration while choosing testing methods and tools. In addition to assessing the impact of damage on the bridge structure's load-bearing capability and long-term service life, this evaluation aims to identify the root causes of any flaws. There are four different types of bridge structure damage. The first kind of damage, which consists of surface nicks and scrapes, can be left alone. The second sort of damage requires repair since it consists of a few small cracks, nicks, and spalls. The third type of damage is moderate damage, which includes large spalls and concrete cracks that expose the reinforcing steel and prestressing strand. This kind may shorten the life of the structure. The fourth form of damage is severe damage, which involves the loss of significant cross sections, exposed and damaged prestressing tendons, and damaged reinforcing steel. This kind needs strengthening and repair. Pre-stressed concrete bridge damages typically include cracks between the beam and slab, Additional settlement of the bridge slab, increased vibration from passing loads, corroded steel reinforcement, corroded pre-stressing tendons, lost expansion joints, stains, and spalling concrete are just a few of the problems that might occur. [31], [84], [85], [86]

Damage is typically understood to be the alteration of a material's characteristics and sectional geometry, including alterations to the boundary condition and system connectivity. During their useful lives, civil engineering buildings like bridges are vulnerable to damage. The major reasons why concrete structures don't perform well are shoddy construction and a lack of understanding of the mechanisms of destruction, which leads to inadequate planning and inaccurate assessments of the consequences on the environment. It is crucial to understand that materials' and structures' durability depends on both the environmental factors at the exposed surfaces of the structures and the material’s resistance to the action of harmful substances. A variety of factors can determine how long a bridge will last. Therefore, aging processes, poor design, and construction, lack of maintenance, accidents involving large ships and vehicles, fire, tiredness, and egregious conceptual or computational errors can all lead to damage to bridge structures that are already in use. The type of member, the method of attachment, the structural systems, and the climatic conditions all affect how the damage appears and how severe it is [87-89].

4.1 General Classification of Damages in Bridge Structure

4.1.1 Classification of damages according to the level of affected

The bridge damage can be categorized and color-coded based on the findings of prior research and inspection experiences. Damages fall into four categories. Affected damages, minor damages, significant damages, and destroyed damages are these.

4.1.2 Classification of damages according to the nature of deterioration

The deterioration of concrete bridge structures can be divided into several categories based on their type:

a) Alkali reaction, electrolytic attacks, fungoid growths, the chemical character of cement that causes it to degrade, the physical nature of concrete that causes it to deteriorate, and other factors are examples of chemical degradation.

b) Mechanical deterioration comprises shock waves, abrasion, fatigue, differential heat and moisture strains, internal stresses, freezing and thawing, and setting shrinkage failure.

4.1.3 Classification of damages according to the place of deterioration in the bridge

The concrete damage is categorized according to the area of the bridge structure where the deterioration is occurring:

a) When a bridge is subjected to unanticipated displacements, the foundation may deteriorate, which will also affect the majority of the bridge's components.

b) Cracks, exposed horizontal surfaces to circulation, corrosion of steel, infiltration, carbonation, porous and permeable concrete, abrasion of the deck surface, increased deformations, vibrations, accidental damage, and chemical deterioration are some of the damages to the superstructure of bridges.

4.1.4 Classification of damages according to the load type

The kind of loading that results in concrete bridge constructions being damaged by:

a) Overload and load concentration under the category of static load.

b) Dynamic load, which encompasses seismic loading, forced vibration-resonance, dynamic variables, and fatigue.

In general, different kinds of fractures, scaling, spalling, and corrosion of steel reinforcement are the principal damages that occur in reinforced concrete bridges. Figure-12 shows the damage to the structure of the bridge [90-92].

Figure-12. Damages of bridge structure [93].

5. PAST RELATED STUDIES FOR STRUCTURAL PERFORMANCE ASSESSMENT OF BRIDGES STRUCTURE

Numerous studies and investigations provide approaches and processes for damage inspection, structural performance assessment, strengthening, and bridge structure restoration.

Reference 94 examined and assessed almost 250 different kinds of bridges, both modern and old. These bridges are subject to inspection procedures that include looking for random surface cracks, transverse cracks, and corrosion of steel reinforcement brought on by exposure to cracks or spalling of the deck's riding surface. The damage inspection process' findings revealed that spalling mostly occurs in traffic lanes, that some sections of a single deck may be severely spalled while the others are in good condition, that there are numerous random cracks caused by concrete spalling, and that some bridges did not exhibit random or transverse cracks but did exhibit spalling. They discovered that there were numerous antique, well-maintained bridges. Static, dynamic, and thermal analysis is all included in bridge analysis. The analysis's findings demonstrated that dynamic stresses, deflections below the permitted limit values in AASHO requirements, and compressive and tensile stresses were not the main causes of cracking. As the depth of the girders of the bridge construction increased, the tensile stresses brought on by temperature change increased [94].

Reference 95 discussed the load testing and inspection of a Texas bridge made of prestressed concrete that had been damaged. The bridge under test has four spans. The findings of the damage investigation revealed that the affected beams were nos. 1, 2, and 4. The center of Beam No. 1 was close to the pre-stressing steel hold-down point and had severe damage. The remaining strands were entirely exposed along a 16-foot length, with four completely severed threads. The crucial portion of the beam No. 1 web was destroyed. Two interior spans were subjected to a static load test, one of which was unharmed while the other was. A total load test of 53460Ibs (237.81kN) was applied to the vehicle, with 22% going to the front axle and 78% going to the rear tandem. The results of the static load test revealed that the damaged span's maximum deflection was 0.22inches (5.588mm), while the undamaged span's maximum deflection was 0.16 inches (4.064 mm), both of which were less than the allowed limit value deflection for damaged spans, which was L/5000, demonstrating the excellent performance even in the presence of severe damage. The static load test findings suggested that the bridge structure needed to be repaired [95].

When analyzing the Arta Bridge under plane stress circumstances, Reference 96 developed a finite element methodology for the static and dynamic analysis of bridge structures. The theory of continuum damage was used to simulate the behavior of inelastic materials. The analysis's findings indicated that the bridge's structure was impacted by potential ground settlements at one or more pier supports and seismic excitation stress, which appeared as damages in key locations. On the other hand, the bridge's response to its weight was entirely elastic and the location was undamaged. The inelastic material modeling was crucial for a realistic assessment of the bridge reaction and the key, and hence sensitive, sections of the structure to the various loading situations, as can be seen from this study [96].

The testing of bridges in situ that have been conducted in the Czech and Slovak Republics since 1968 was described in Reference 97 as static, dynamic, and long-term. The requirements for elastic and permissible deformations, the dynamic impact factors, and natural frequencies were added to the standard techniques. The monitoring of stresses under typical traffic loads yields crucial information for the fatigue of bridges, the estimation of their remaining life, and the determination of inspection intervals. Bridges' distinguishing characteristics are ascertained from their reaction through modal analysis and identification. Damage to bridges may be indicated by changes to their inherent vibrational frequencies or modes [97].

Reference 98 documented the Luiz 1 Bridge's field dynamic load test and theoretical dynamic studies when it was subjected to the movement loads of Porto, Portugal's new light metro. They built the approach and computational tools with an eye toward the comfort of pedestrian and train passes, and they presented some of the most significant findings from numerical simulations carried out using an experimentally calibrated finite element model [98].

Before it was opened to traffic loads, Taiwan's longest cable-stayed bridge, the Kao-Ping-Hsi Bridge, underwent field static load testing in Reference 99. To evaluate the behavior of the bridge, a total of 40 loading scenarios, comprising unit and distributed bending and torsion loads, were performed. The main girder deflections, the prestressed concrete box girder's flexural strains, and the variations in cable forces are the reactions to the static load test. A three-dimensional finite element model was created for their analysis. The analysis' findings demonstrated that the bridge had linear superposition characteristics under the planned load test conditions, and the analytical model demonstrated extremely excellent agreement with the bridge responses [99].

Reference 100 examined the deterioration of many bridges in north Mississippi that had concrete bridge decks. According to the inspection's findings, corrosion, efflorescence, scaling, and pop-outs are the key factors contributing to deterioration. The initial study was done to assess the bond integrity of concrete and a variety of resin- and cement-based products that were most frequently utilized by maintenance staff. [100].

Reference 101 investigated the dynamic behavior of a bridge made of reinforced concrete that was being loaded by moving cars. This study used a four-degree-of-freedom system with linear suspensions and flexible tires to model the car as a moving mass. A continuous Euler-Bernoulli beam with simple end supports was used to model the bridge. A reinforced concrete beam with a T-section was put through a field dynamic load test while being loaded by automobiles to assess how well the bridge structure's crack models performed. The simulation study took into account the effects of additional factors like the vehicle's speed and the roughness of the road surface. The dynamic deflection, relative frequency change (RFC), absolute frequency change (AFC), and phase plot of the responses were all examined for any potential correlations with damage represented by an open crack or breathing crack. The analysis's findings indicated that when the bridge structure was destroyed, the deflection significantly increased, and the deflection can be a sensitive indicator of damage to bridge structures, the frequency ratio between the vehicle and bridge has some influence on the RFC and AFC, and the road surface roughness has little influence on the deflection and the phase plane plots of the responses when the vehicle is moving on the bridge. The RFC and AFC vary when the vehicle is moving on the bridge, and they were sensitive to the weight of the moving vehicle. [101]

A continuous two-span box girder bridge subject to changing loads was the focus of a three-dimensional dynamic analysis in Reference 102 using folded flat shell elements to examine the dynamic behaviors at various places. They created finite element computer software with six degrees of freedom per node for the box girder bridge taking moving load effects into account for the theoretical dynamic analysis. They performed dynamic load tests for actual structures to validate the theoretical dynamic analysis, and the findings revealed that the field test results and those computed using the theoretical dynamic methods were in good agreement. Various parameters, particularly at various places at the box girder cross-section, were taken into consideration to study the dynamic characteristics of a two-span box girder bridge subjected to moving loads. The intricate dynamic effects for long-span box girder bridges could not be correctly predicted by the current standard standards for highway bridges. Because of the dynamic behavior of bridges subjected to moving loads, which depends on the placements of box girder section, vehicle weight, moving load speeds, and bridge type. There was a need for more thorough criteria that took these numerous issues into account. They concluded that moving loads largely governed the behavior of box girder constructions due to the dynamic impacts for various places on the cross-section of the structure. They shouldn't be disregarded, so for a more accurate analysis of these structures, three-dimensional models incorporating folded flat shell elements should be utilized [102].

A nondestructive testing technique was proposed in Reference 103 as an alternative to the long-practiced visual inspection for assessing the condition of bridges. Their research showed a strong association between visual assessment and strength as measured by rebound hammer results. The compressive strength of the concrete used in the bridge's structure was determined using the rebound hammer test. Potentially, the rebound hammer might serve as an initial assessment of the state of the bridge. According to the results of the rebound hammer test, the overall concrete strength of the abutment was equal to 19 N/mm^2, indicating that it was in very poor condition. The concrete strength for the deck was equal to 55 N/mm^2, while that for the pier was equal to 35 N/mm^2, indicating that it was in sound and moderate condition, respectively [103].

The theoretical analysis of the composite continuous box girder bridge with corrugated steel webs in Reference 104 uses a finite element model. Software from Ansys was used for this investigation. The Juancheng Yellow River Highway Bridge in China has its structural performance during its service life evaluated using static and dynamic load tests. Results from the theory and experiment were contrasted. They concluded that while the model CBCW offers a simple and very effective tool for bridge engineers, there was no specific simulation model for bridge structure in the Ansys program. The analysis's findings demonstrated how well the theoretical and experimental results matched up, indicating that the CBCW model could be trusted to replicate these types of bridges [104].

The shear stiffness of segmental joints was evaluated in reference 105. Cantilever-casting concrete bridges need special consideration while designing and building the joints between the segments. These joints cause a break in the bridge's structure and reduce the connection's strength and stiffness, which could cause the bridge to stretch excessively downward. Monolithic non-joints, roughened joints, and joints roughened with shear-key were among the criteria examined. It was discovered that the shear stiffness of jointed sections is significantly lower than that of non-jointed sections, but the shear key may significantly increase the shear strength and, in particular, the shear stiffness of the joint section. Measures are suggested for shear-key design, which could offer a sound foundation for the design of concrete cantilever bridges [105].

To determine the causes of the longitudinal fractures in the web and bottom of the box girder, Reference 106 studied and evaluated the temperature and shrinkage stresses of the mid-span cross-section of a 20-meter-long box girder. The web and bottom slab of box girders has numerous longitudinal cracks, particularly in the web of the edger beam, where the crack is quite obvious, according to the results of the damage examination. To calculate the temperature stresses brought on by the temperature difference between the inside and outside of the box and the shrinkage stresses based on moisture diffusion, a two-dimensional finite element model of a typical cross-section of a real bridge is analyzed using the Ansys ver.10 software. The analysis's findings indicate that the fabricated box girder's bottom slab and outer surface will both experience tensile stress when there is a negative temperature difference. Tensile stress does not generate creaks in the cross-section of concrete after a certain age. The moisture gradient in the box section affects the shrinkage stress. In 15 days, it will reach its peak, after which it will start to decline as people get older. Because the tensile strength of young concrete is poor, shrinkage stress may result in surface cracking [106].

Reference 107 conducted a two-method analysis of four bridges in China. The zero-bending moment approach, which can significantly lessen structural distortion, was the first way. The classic design theory method was the second. The formula for determining the effective pre-stress of each section was developed using these two techniques by the idea of the dead load's zero bending moment. The analysis's findings with the zero bending moments approach revealed that the structure had a significant safety reserve and that the stress and deflection differences between each segment were reduced. It demonstrated that the design principle of zero bending moments of the dead load was effective in reducing deflection [107].

Using Midas software, Reference 108 assessed the structural performance of a prestressed concrete bridge that was only partially supported. On the bridge, static and dynamic load testing were conducted. When the deflection was measured under static load and the structural frequency was measured under dynamic load, the calibration was acquired, and these values were compared with the findings of the finite element analysis. They demonstrated that the demands were met through strain calibration and deflection calibration. The T-beam bridge has a higher safety reserve since the maximum deflection complied with the Chinese Code for Design of Highway Reinforced Concrete and Prestressed Concrete Bridges and Culverts. The benefit of the theoretical study, however, was outweighed by the measured natural frequency of the field testing. This indicates that the bridge's overall stiffness increased and that resonance can easily result as a result. 108]

By using a static stress test and theoretical analysis, Reference 109 assessed the condition of the Qing Shang Bridge in Heilongjiang Province, China. The inspection process included examining and assessing the damage to the box girder and T-section concrete beam. Utilizing Dr. Bridge software V.3.0, finite element analysis was utilized to examine the behavior of the bridge structure theoretically. The structural performance is in good shape, but the bridge No. 10 needs to be strengthened, according to the load test results. The box girder demonstrated that it was in good condition and had no obvious damaging effects. [109]

Reference 110 examined the Jiamusi highway prestressed concrete bridge's appearance, described all bridge structural component damages, and assessed the bridge's structural performance under dead and live loads. The depth of concrete carbonation test, concrete compressive strength test, steel reinforcement corrosion test, and static load test are the field tests used in this study. According to a visual assessment of the bridge construction, there are no significant damages and the general condition of the bridge is satisfactory, although there are diagonal and longitudinal fractures in the inside web of the box girders in blocks No. 8 and 9. Expansion joints are severely damaged by things like cracking, dislocating, shedding, and rubber deformation. The results of the field tests demonstrate that there is no carbonation in the concrete of the bridge structure, that the concrete is strong, and that the steel reinforcement is not corroding. The values of the load test for vertical deflection, strain, and stress are also less than the theoretical values, and the findings of the cracks observation demonstrate that the length of diagonal cracks in the web of the box girder does not change when the load test is applied. This shows that the bridge structure is in good condition and is in good operational order [110].

To illustrate how to apply strengthening and repair techniques to improve the performance of the bridge structural parts, Reference 111 identified the damaged members of the Jilin highway concrete bridge structure. The majority of the bridge's components are in good condition, except the arch waves, spandrel arch, deck pavement of the new arch bridge, and corbel of the old simply supported beam bridge, according to the findings of a comprehensive inquiry into the bridge's look. In their investigation, the damaged members of the Jilin highway concrete bridge were strengthened and repaired using the jacketing method, grouting repair method, patching method, replacement of the expansion joint, and drainage system Arch waves, spandrel arches, and deck pavement are in good condition after the strengthening and repair processes are complete, but it is necessary to assess the performance of the strengthened and repaired structural members by using static and dynamic load tests and keeping an eye on the appearance of cracks [111].

Reference 111 examined and categorized the damages to the Longtan truss-arch concrete bridge structural members to assess the structural performance of the bridge members, as well as the compressive strength of the concrete, corrosion of the steel reinforcement, and deck leveling. The internal forces were analyzed using the Ansys ver. 10 software. The field tests used in this study are (a) the test for concrete's compressive strength, (b) the test for steel corrosion, and (c) the test for static loads. These tests are used to assess the structural health of a bridge. The bridge structure is in good condition, but the piers and arch rings have fractures, corrosion of the reinforcement steel, and spalling of the concrete, according to the results of the appearance examination and field testing. The results of the static load test demonstrate that under test loads, the deflection, strain, and crack development meet the specifications. Therefore, their research suggested strengthening and repairing the Longtan truss-arch concrete bridge's damaged parts [112].

Reference 102 provided a simplified method for assessing the structural response in the early phases of design, and they compared the results on real bridge cases. The analysis method, which offers the solution in terms of deformation and stress pasts over time, is predicated on closed-form equations and only necessitates the remedy of simple elastic agreements. This technique is suitable for the preliminary design phase, attempting to avoid staged construction assessments that can be implemented in finite element modeling software for the successive conclusive design phase [113].

Reference 114 used Finite elements and experimental analysis and assessment of static and dynamic for prestressed concrete box Girder Bridges. His research aimed to determine the damage in the bridge and evaluate the structural performance under the influence of dead and surrounding loads. Where he used the SAP200 Ver14.2.0 program in the structural analysis and also relied on the dynamic load test for the structural evaluation of the bridge. A dynamic load test analysis results indicate that the assessed frequency of just able (4.40) Hz. was lower than the normal frequency which was 4.963 hertz. The worth of the variable load test coefficient was 0.88. As a result, the resonance frequency evaluated under the frequency of vehicles passing on the bridge was equivalent to 5Hz [114].

Using experimental work, Reference 115 assessed the fatigue resistance of welded connections in steel truss bridges. They employed CFP and discovered that, when CFP and UIL were applied, respectively, weariness rose by 24% and 36%. The fatigue failure mechanisms of the welded joints were changed by the use of CFP and/or UIT. On the flange plate edges of welded connections without CFP and on the flange surface of welded joints with CFP, fatigue crack initiation forms. At the weld root or weld of joints related to construction, as well as at the weldment of non-UIT-welded joints, fatigue cracks develop. The fatigue resistance of welded joints was increased by 24 percentage points and 36 percentage points, respectively, by using CFP and UIT combining CFP. Combining CFP and UIT led to a 6% increase in fatigue rigidity. For instance, UIT proved more effective at boosting wear resistance than CFP [115].

To evaluate finite element models for concrete bridges, Reference 116 used load testing. They enhanced the processes that are applied when static load tests are applied. In this study, the De Beek bridge was examined, and it was discovered that this structure did not meet the conditions for the bending moment. How the model was applied model of nonlinear finite elements. Proof load testing can be a useful strategy for evaluating existing bridges when the ability unknowns are likewise too big to employ analytical assessment techniques. Traffic is currently restricted in the specific case of the De Beek viaduct since it was determined critically that none of the bending moment standards in the code were met across its four lengths. The bridge in question only has one lane. A crucial interval has the largest Unity Inspection with spans 2 and 3. These divisions cross the highway directly. It was not an option to open the highway during the proof load testing of these spans [116].

Based on ambient vibration tests, operations and maintenance modal analysis, and finite element model updating of an ultra-high-performance concrete bridge, reference 117 conducted this research. They reached the research to the appropriate conditions for torsion, as well as to the bending of natural frequencies ranging from three to seventeen hertz, which leads to the development of the model. He also mentioned that it is possible to update the model by modifying the uncertainty or inaccuracy in the input information based on the results of a formal determination of the outputs only. Modal variables such as structural stiffness and free vibration can be used to evaluate current structural bridge conditions, to changes in precipitation frequency denoting destruction or degradation and being found to correlate with adjustments in structural stiffness [117].

6. CONCLUSIONS

This paper deals with reviewing of damage inspection and structural performance evaluation of bridges structure. Some theoretical and experimental research was presented in this study using real constructed bridges structure. Several studies found that many structural damages appeared within bridges structure such as cracks and vertical deflection. They applied some field tests during the damage inspection process. These tests included concrete compressive strength, leveling of the bridge deck, carbonation, and steel corrosion. Static and dynamic load tests are also applied with theoretical analysis by using engineering software such as SAP2000, Ansys, and Staad Pro. Most researchers concluded that the bridge's structures suffered from much damage and they suggested some strengthening and repairing methods to improve the stiffness of the bridge's structure.

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