# STEEL RAILWAY BRIDGES IN EGYPT

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## ABSTRACT

Steel bridges generally constitute an important part of the railway transportation network in Egypt. They play a vital role in offering transportation services for a wide range of users. Most of the railway steel bridges in the country have been in service for over 50 years. During their service life, bridges may undergo abnormal events such as accidents, fire, earthquakes, deterioration, increased axle loads, and terrorist attacks. Performance of bridges during such events affects highly the human and economic causalities in developing countries. Steel bridges may be subjected to forces which were not considered during the original design. In addition, the performance of steel bridges under normal or extreme events is expected to change with time due to aging and deterioration of material. Improving the resilience of steel bridges involves many technical, environmental, and economic aspects. Periodic maintenance and major repair activities are mandatory to sustain a satisfactory performance that preserves public safety and extends the service life. In this study, assessment procedures for a group of railway steel bridges in Egypt are reviewed and explored. Observations during the study are highlighted and discussed. Resilience of the studied bridges is judged from previous observations and accidents throughout the service life of the considered bridges. The study is part of the efforts made to enhance the transportation sector in Egypt.

## INTRODUCTION

One of the oldest railway networks across the world exists in Egypt. Steel bridges with different structural systems, spans, and detailing constitute part of this network. Hence, the age of a large number of these steel bridges exceed 50 years. In addition, a considerable number of the old steel bridges have been functioning for over 100 years. During their service life, steel bridges are exposed to environmental changes, increased loads, corrosion, and poor maintenance applications which results in overall deterioration and inability to achieve satisfactory performance. Resilience of the railway steel bridges against aging or disasters is crucial as they represent an important part of the transportation railway network which serves a wide range of passengers in Egypt. During certain periods of the year, increased demands are imposed on the railway network. Disasters including accidents and terroristic bombing in such cases would result in high economic losses. Generally, resilient infrastructure is characterized by low probability of failure, less severe negative consequences when failures occur, and faster recovery from failures. There are no records quantifying the resilience of the steel railway bridges in Egypt. Hence, during the last years, several campaigns were initiated in order to assess the condition of these critical structures. The assessment procedure followed the same outlines and guidelines reported by previous researchers (1-10). Different researchers have tried to quantify the resilience of infrastructure in disasters. Most of the work focuses on determining the behavior of the different components when subjected to extreme conditions. Some studies focus on a local level considering the infrastructure itself while others might extend the scope including the influence on the neighboring structures or even on the business across the country or worldwide. Usually, such studies would yield contingency plans that recommend the best course of action during and after disasters. The aim of the current paper is to

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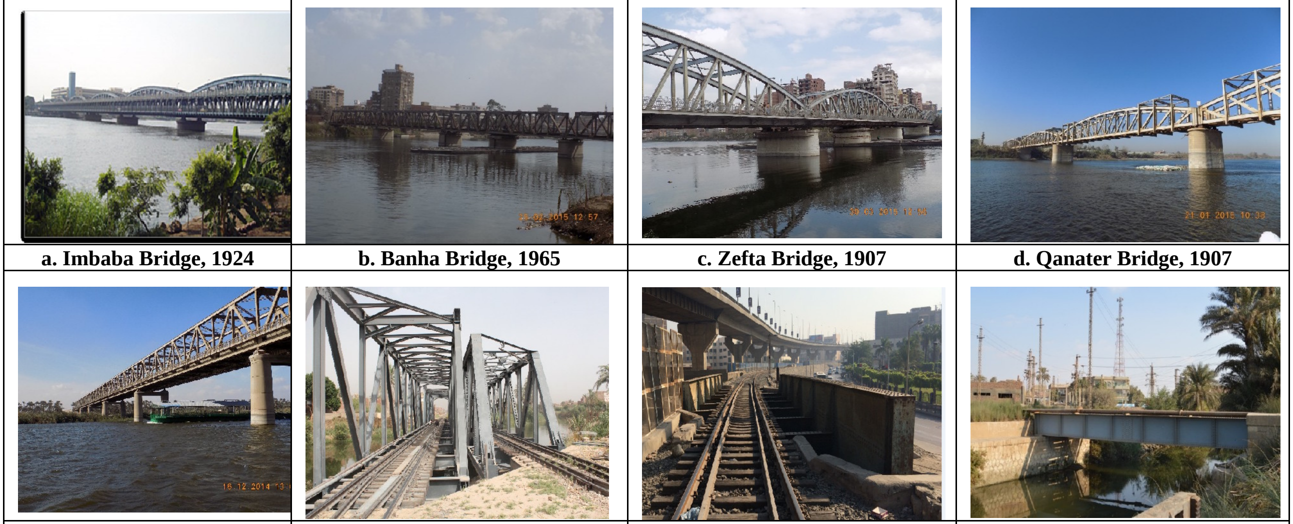
shed light on the current condition of the old steel railway bridges in Egypt, examine their behavior after being in service for a long time, and study their performance when subjected to extreme conditions.

**DESCRIPTION OF THE ASSESSMENT CAMPAIGN**

An extensive assessment practice for a group of steel railway bridges (74 bridges) constituting part of the railway network in Egypt was initiated in 2014. The inspected bridges included major Nile bridges spanning 60-90 m in addition to local bridges spanning 3-30 m. Figures 1.a. through 1.h show a sample of the inspected bridges. As can be seen, systems include simple and continuous trusses with variable or constant depth in addition to plate girders. Upon examining the records of each bridge, it was found that in many cases complete calculations and detailed structural drawings were available even for bridges with service life exceeding 100 years. The records were carefully examined and compared to the available structure to pinpoint any changes along its service life. Consequently, the assessment procedure was initiated and performed in several steps including visually inspecting the different components while focusing on recording the extent and location of the defects. Afterwards, material and load tests, structural analysis, fatigue assessment, and finally repair recommendations were employed to rate the condition of the studied bridges. Details of the observed defects are listed in (11 and 12).



a. Imbaba Bridge, 1924; b. Banha Bridge, 1965; c. Zefta Bridge, 1907; d. Qanater Bridge, 1907; e. Marazek Bridge, 1959; f. Gerga Bridge, 1930-1986; g. El-Waziz Bridge, 1908; h. Ibrahimia Bridge, 1906

**Figure 1. Sample of the Inspected Bridges during Assessment Campaign**

## Visual Inspection

Visual inspection phase constitutes a very important part of the assessment study. The different elements of the inspected bridge were extensively investigated to pinpoint defects for further investigation. Focus is given to condition of steel sections and connections, concrete slabs, piers, abutments, drainage system, lighting, and handrail guards. Inspection forms are employed in order to ensure scanning all of the components. The main observed defects for the 74 inspected bridges were surface to severe corrosion, permanent deformations in members, missing rivets, cracks, improper repair applications, loss of connecting rivets, spalling, cracks, scaling, reinforcement corrosion, material deterioration, poor condition of concrete, in addition to inadequate lighting or drainage facilities. Figures 2 through 9 show the main defects observed during the visual inspection phase. Observations from the visual inspection phase were recorded and used to determine the suitable repair procedures. Consequently, FE models were developed based on the as-built drawings and the visual inspection observations. Static and dynamic tests were performed to validate the built models. Hence, models are used to analyze the bridge performance under the increased axle loads. In addition, fatigue assessment study was performed considering the records provided by Egyptian National Railways (ENR).

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| **Figure 2. Severe Corrosion of Gusset Plate, Kafr El Zayat Bridge** | **Fig, 3. Loose Bolts at Lower Bracing Member Connection, Qanater Bridge** | **Fig, 4. Improper Maintenance Works for Roller Bearing, Marazek Bridge** | **Figure 5. Loss of Restraining Blocks, New Gerga Bridge** |
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| **Figure 6. Permanent Deformat-ions in the Main Beam, Masraf Tta Bridge** | **Figure 7. Loss of Concrete Cover and Corrosion of Reinforcement, Mansoura Bridge** | **Figure 8. Spalling of Concrete Cover, Edfina Bridge** | **Figure 9. Crushing of Concrete and Appearance of Reinforce-ment, Masraf Tta Bridge** |

## Material Tests

Tests were performed to determine the material properties of the different elements of the inspected bridges. Material tests included: Hardness tests, Chemical composition test, Schmidt hammer tests, and core testing. Test results help in building the finite element models and checking the safety of the different members. In addition, the tests give an indication of how the deterioration might have happened.

## Loading Tests

Static and dynamic load tests were carried out during the assessment campaign to determine the response of the studied bridges. Test locomotives were positioned such that the resulting straining actions do not exceed 85% of the ultimate load. Deflections and strains were measured at key locations and compared to the results extracted from finite element models. In addition, modes and frequencies were deduced from test results and used to verify the analytical models. Test results were used to validate the finite element models. In addition, results were compared to the previous load test results performed throughout the bridge service life to pinpoint any deterioration in performance. Figures (10 and 11) show sample of performed tests.

## Analysis of FE Models

The SAP 2000 (14) program was employed to build 3-D models for the studied bridges. Figure 12 shows a sample of one of the analyzed bridges. Models were built considering the sectional properties extracted from the as-built drawings or measured during the visual inspection phase. Frame elements were used to simulate the different bridge components. Rigid and pinned joints were used to simulate the connection at the truss and floor beam levels as per the observed details. It is worth mentioning that many of the inspected bridges were designed to support loads lower than the ones imposed by the current standards (11); however, most of the members and connections were found safe under the current loads. This may be attributed to the fact that the original design was made while considering a large factor of safety. Meanwhile, the fatigue stresses for the floor beams were usually found not meeting the allowable fatigue stress ranges. In addition, in many cases, the lower bracing elements and their connections were found insufficient to sustain the applied loads.

**Figure 10. Static Load Test, Imbaba Bridge**


**Figure 11. Static Load Test, Zefta Bridge**

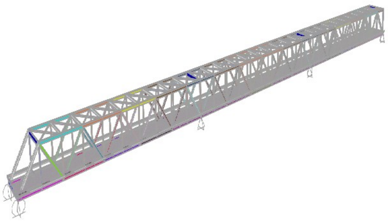
**Figure 12. Marazek Bridge FE Model**

## OBSERVED REPAIR AND REHABILITATION WORKS

The different inspected bridges showed signs of previous repair works during their service lives. This would include periodic repair works in addition to major rehabilitation of the bridge following structural assessment or accidents. It was observed that in many cases, the original lower plate bracing system was replaced with steel angles (Figure 13). In addition, stringer and cross girder bracing were added to the original structural system (Figure 14). Most of these modifications were implemented upon assessing the bridge condition 70 years after its construction upon considering the increased axle loads during checking of the different members. In Qanater Bridge, increased vibrations were observed along with train passages which lead to unsatisfactory behavior and discomfort to users. Hence, a study was performed in 2004 and recommendations included increasing the lateral stiffness of the bridge by adding rigid frames (Figure 1.d).


**Figure 13. Replacement of Lower Bracing Members, Mansoura Bridge**


**Figure 14. Addition of Stringer Bracing, Banha Bridge**

### Fatigue Life Assessment

The assessment study included determining the remaining fatigue life for the fatigue-critical members based on records of trains since construction of the bridges. The traditional S-N method (13) was used to estimate the remaining fatigue life for the different members. The method depends on estimating the damage accumulation due to the applied cycles. The members is considered to reach its fatigue life if the accumulated damage ratio reaches 1. The axle loads and dimensions are defined for the different considered train types including: passenger train, special type train, air-conditioned train, and cargo train. Hence, the stress levels for the fatigue-critical members were determined. For the different considered bridges, it was generally observed that the stress levels in different truss members due to the considered live loads were low and the remaining fatigue life was very large. Meanwhile, for the secondary beams of the floor system, the stress levels were in the range of 50-60% of sectional capacity. In addition, larger number of cycles due to train passages compared to main truss members was considered. Hence, the secondary beams were found to have reached their fatigue life. Recommendations generally include full replacement of members, strengthening using steel plates, or strengthening using Carbon Fiber Reinforced Polymers (CFRP) sheets. However, in considering the different possible repair method-logies, the estimated repair costs will be very high in addition to hindering the traffic during repair.

## RESILIENCE OF STUDIED BRIDGES

Upon examining the performance of the different considered bridges across their service life, it was concluded that they behaved in a satisfactory manner even under the extreme cases. In 2002, a train derailment caused immediate loss of several main truss members of Marazek Bridge. However, due to the redundancy of the bridge, the bridge did not suffer from sudden or successive failure. Figure 15 shows the replaced truss vertical member and cross girder. Such accidents stress the importance of providing bridge designs that can safely provide alternate load paths to prevent or minimize large human losses.

**Figure 15. Replacement of Vertical Truss member after Train Derailment Accident, Marazek Bridge**

One of the bridges that was determined to perform below the accepted levels was the Qanater Bridge. Upon visual inspection, the Qanater Bridge was found to have suffered from deterioration and heavy rust for the different members and connections. The total length of the bridge is 490 m (seven equal bays) and it serves a single track railway line. The main bridge system is two riveted truss bridges with variable depth (3.5 m at edges and 7.8 m in the middle). Floor beams consist of longitudinal secondary beams (stringers) supported on transverse secondary beams (cross girders) spaced at 5.3 m supporting the open timber floor system. In addition, lower and upper bracing systems are employed; however, it was observed that the upper bracing system is only present at the middle part of the bridge (Figure 16). The bridge was built in 1907 and has gone through major rehabilitation procedures along its service life. Repair works included: adding stringer bracing, changing the lower bracing sections with larger angles, adding cross girder bracing, adding cross frames at the end bays (Figure 1.d), strengthening of cross beams, removing and replacing of rusted parts from the main truss members, and lubricating of bearings. However, the bridge performance was found unsatisfactory after several phases of repair and it was recommended to replace the existing bridge with a new one.


**Figure 16. Qanater Bridge Condition before Strengthening Applications**

## RESULTS DISCUSSION AND CONCLUSIONS

The current study generally highlighted the different steps followed during the assessment campaign initiated in 2014 and covering 74 railway bridges in Egypt. Assessment procedure included examining the available bridge records, visual inspection of the different components, material tests, load tests, fatigue assessment, structural analysis, and finally recommendations for repair and rehabilitation of the studied bridges. The current study focused on discussing the performance of the studied bridges when subjected to irregular load situations. It was generally found that:

* The different inspected old bridges can sustain the increased axle loads imposed by new codes and standards with minor strengthening to the floor beam system.

* Repair and rehabilitation procedures have been applied throughout the service life of the different bridges including changing of the lower bracing members, introduction of stringer and braking force bracing, strengthening of members, and replacement of rivets with high strength bolts.

* For the reported accidents including derailment, bridges have performed well with suitable reserve capacity for the undamaged members to sustain the increased loads.

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