Lessons Learned From Inspecting Steel Railway Bridges In Egypt

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Abstract

Railway infrastructures must be maintained safely and reliably not only for both owners and users, but also for generations to come. In Egypt, many of the Egyptian National Railway (ENR) bridges were built in the beginning of the last century. Defects and damage are now apparent and need appropriate rehabilitation planning. The purpose of the inspection is to prolong the structure's life of the bridge. Deterioration signs once identified, appropriate measures are to be promptly taken. Based on the experience gained while inspecting a large number of major steel railway open timber floor bridge type, the present paper summarizes the common defects that arose from this inspection campaign. Many of these defects, if kept without intervention, will lead to structural deficiency or even functionality obsolete. The information derived from this inspection provided guidelines and practices for structural engineers that can be applicable to any particular truss bridge rehabilitation scheme. A proper rehabilitation scheme can extend the service life of any structure. The topics listed below are the hot points arrived at from this campaign carried out on over 75 bridges: Atmospheric corrosion and oxidization of steel elements; Fatigue problems; Bridge approach improvement; Defective connections and member's eccentricity; Scour and abutment movement; and Defects of ancillary bridge elements: water drainage, damp proofing, lighting etc. The purpose of the performed inspection program is to establish a data base of the present status of the in-service bridges and those showing aging signs. Also to improve their durability and serviceability with minimum cost and time. In conclusion, effective inspections at appropriate frequencies are necessary to understand the level of risk and to identify and plan necessary maintenance and even replacement works, whenever needed.

Keywords: Inspection, Corrosion, Riveting, Fatigue, Scour, Steel Bridges.

1- **Introduction**

Railway infrastructure plays a crucial role in the economic, social, and environmental fabric of societies worldwide. In Egypt, many bridges of the Egyptian National Railway (ENR) were constructed in the early 1900s. Signs of defects

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and damage are evident, requiring well-planned rehabilitation. ENR, being a publically funded State Authority, is responsible for the reliability of the infrastructures along the entire network of the country. ENR appointed EHAF in 2014 as a specialized consulting engineering firm, a contract to examine 75 bridges, including a significant portion exceeding hundred years old. Most of these unique structures are crossing the Nile, the main navigation river of the country, some are provided with moveable swing bays to allow for navigation along the river. The oldest of these bridges was constructed late in the nineteenth century, as shown in Fig.(1), while the most recent came into service in the sixteenth of the twentieth century, Fig.(2).

The required in-depth inspection works to perform for these bridges consist to model, test, validate, verify the solidity and integrity of these structures, also assessment of their functional level over the years. The scope of work included a detailed review of information available in the ENR archives along with the in-situ visual inspection of truss members and their connection conditions, sidewalks and painting coats. Also to model mathematically, to perform static and dynamic loading tests, checking the performance of the material to end up with repair recommendations. Obviously, the original nineteenth century structures, still in service today, did not meet the Standard expected today of a modern railway infrastructure.

Fig.(1) Zefta Bridge, Zagazig - Zefta - Tanta Line, 1907

Fig.(2) Raswa Bridge, Benha - Port Said Line, 1987

2-REHABILITATION STRATEGIES

A proper rehabilitation scheme can extend the service life of any structure even for these centennial bridges. The topics listed below are the hot points arrived at from the in-depth inspections campaign carried out on 75 bridges:

- Atmospheric corrosion and oxidization of steel elements.
- Fatigue problems.
- Bridge approach improvement.
- Defective connections and member's eccentricity
- Scour and abutment movement.
- Defects of ancillary bridge elements: water drainage, damp proofing, lighting etc.

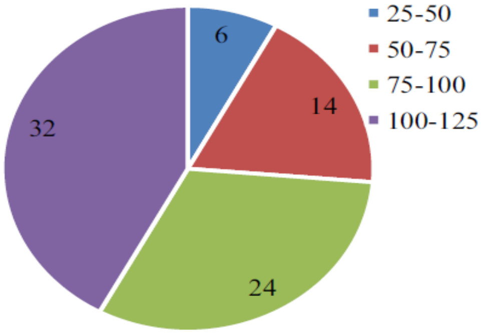

Fig.(3) Distribution by Age of the Studied Bridges [Hassan et al. 2017]

Fig.(3) lists age distribution of bridges considered in the current study. As can be seen, thirty-two of the inspected bridges exceeded 100 years in service. Meanwhile, twenty-four of the inspected bridges fall in the range between 75 to 100 years in service. In addition, seventy bridges exceeded a service life of 50 years. These percentages stress upon the importance of assessing the current performance of metallic bridges in Egypt.

It is to be noted that the structural engineering problems of railway bridge inspection is the fact that staff had to operate in a dangerous working environment due to the narrow working area and the lack of space to store their equipment and machinery. Also, some elements of the structure are difficult to inspect without special access arrangements. For example, the inaccessible top chord of deep trusses and the parts of the sub structure located below ground level or water. The knowledge and the identification of the type of material used in these old constructions, in many cases is not known. For example, steel with high carbon or silicon content and cast-iron Ref. [4], is not easy to weld, also wrought iron is prone to lamellar separation when heated. Therefore, welding and/or heating in such cases should be avoided.

3- **Atmospheric Corrosion And Oxidization Of Steel Elements**

The location and the surrounding of the bridge may be the cause for the development of corrosion. Moisture of an environment in the vicinity of the structure, the salinity in the atmosphere and the chemical effluence from industrial units or any source of heat or fumes near the bridge may cause severe corrosion and loss of protective coating of some elements of the structures. To note also that heavily stressed member in the corrosive environment are most likely to suffer higher decay and disintegration. Proper surface preparation before painting is required and the material used to re-paint bridge construction should be well selected to resist harsh conditions and to last longer

Fig.(4) Corrosion and rusted floor members – Banha Bridge

Fig.(5) Corroded plate due to severe oxidization – Kafr El Zayat Bridge

The severity of corrosion ranged from surface light corrosion to serious corrosion leading to decreasing the sectional area. Generally, the corrosion of steel bridges is much larger than the reinforced concrete bridges.

The two figures (4&5) show the spreading of rusting at the exposed lower surface of the floor beams of the bridge and a totally damaged gusset plate due to severe rust.

4- **Fatigue Problems**

Steel structures might demonstrate the effect of fatigue. The process of initiation and growth of cracks under the action of repetitive force may result in brittle failure for the metal. Visual inspections cannot always highlight potential fatigue problems correctly, especially in terms of identifying cracks. Not only may small cracks be missed or invisible to the naked eye, but also there is the possibility that larger cracks may be identified as dangerous with time, while they are not. In this case wasted resources on repairing these cracks are superfluous as the cracks are not actively growing.

Fig.(6) Fatigue Crack at Stringer-to-Cross Girder Connection, Abo Shosha Bridge

According to the Federal Highway Administration in the USA, only 10% of the fatigue cracks are correctly identified. Corrosion and oxidation of metal is the main reason of hiding out some cracks making them invisible Ref. [1], revealed a new cracking detection technique based on the detection of oxidation process. It is hence recommended to re-examine the critical fatigue suspected areas and members after removing the rust, such as blast cleaning the area and applying dye penetrant, ultrasonic testing or a more thorough visual examination with 10x power magnifier. Some current practices are necessary for extending life of railway bridges and are presented in literature. However, the period and the date of construction can give an idea about the number and magnitude of load cycle the bridge has been subjected to.

In conclusion, visual detection of fatigue cracks in steel bridge component is a very difficult task to perform successfully. Non-destructive techniques for identifying fatigue cracks with a high precision is needed. The prioritization of member replacement by determining the actual capacity of specific individual members within the structure to safely and economically maintain railway bridges in service for longer time. Figure (6) shows a propagated fatigue crack at the web of cross girder. The crack is observed at the lower slotted hole introduced to allow connecting the top and bottom flanges of the stringer beam.

5- Bridge Approach Improvement

Bridge approaches incorporate transition slab, expansion joints, and rail expansion adjusters. Bridge approach slab is the transition component between bridge and pavement. The bridge end is supported on the abutment while pavement lays on the natural embankment. The quality of railway bridge approaches directly impacts the bridge overall structural performance. The rise of impact loads caused by bridge approaches damages the structural integrity of both approaches and bridge elements. The sudden change of stiffness between the portion of track immediately outside the bridge and the track within the two end abutments has to follow a transition path. This change is much higher for open timber floor deck than for ballasted decks. Deficient bridge approaches cause considerable maintenance problems resulting from the settlement of the pavement adjacent directly to the abutment.

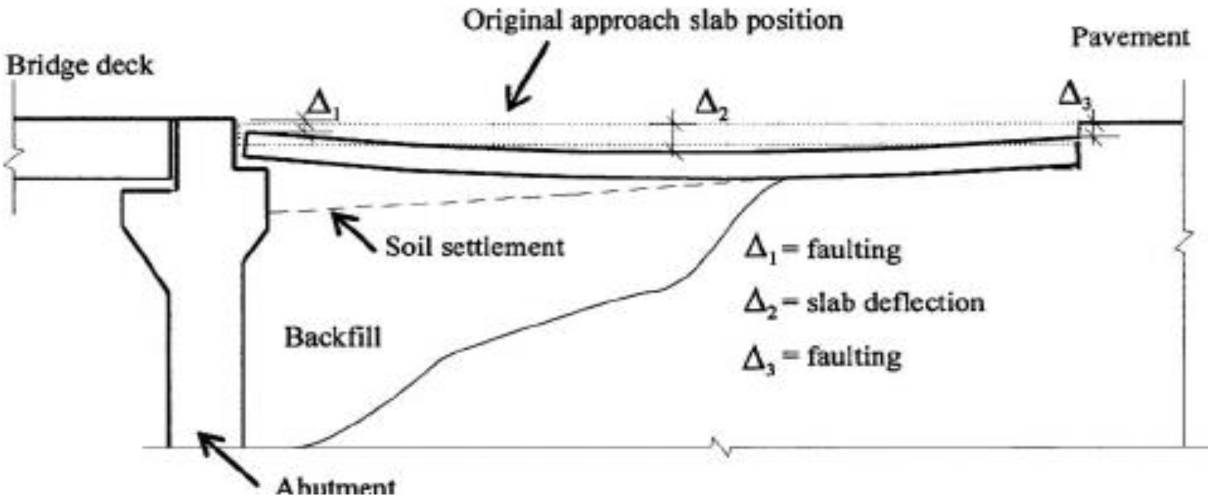

Fig. (7) Approach Slab showing uneven joint on bridge deck [Arema]

Figure (7) shows settlement of an approach slab that may be attributed to compression of embankment fill or poor drainage systems. Faulting adjacent to the abutment and to the pavement will contribute largely to amplify the impact and the dynamic response in bridge decks

Fig. (8) Creep of Asphalt over the Expansion Joint, Marazek Bridge

Fig. (9) Settlement of Approach Slab at Entrance of Roadway Lane, Marazek Bridge

Deck expansion joints are also critical bridge components. In our case of these old bridges, almost coming to the end of their design life, expansion joints are susceptible to endanger the whole traffic unless regularly inspected.

Fig. (10) Poor Condition of Expansion Joint, Sanae Bridge

Also, rail expansion adjusters are to be installed on the abutments at each end of the bridge to accommodate any displacement of long welded rails and the bridge structure that may be caused by loads and/or temperature variation.

6- **Defective Connections And Member's Eccentricity**

Lost or loose rivets in an existing connection will need replacement by new fasteners. Nowadays, the use of bolts or high strength friction bolts is only available, as riveting technology is almost abandoned and not any more used. The replacement of lost rivets in these old bridges can be done using bolting techniques. The structural function of mechanical fasteners differs from one connection type to the other. Figures (11 to 18) denote the main defects observed during our assigned job of examining the bridges. These defects are missing rivets, combining rivet with high strength bolts in one connection and eccentric connections.

Fig.(11) Replacement of rivets with bolt – Dessouk bridge

Fig.(12) Missing rivet – Edfina bridge

The connection mode in most of the ENR bridges is predominantly riveting in shear, thus resisted by the cross section of the rivet's cylindrical shaft. Unlike a riveted joint, the high friction grip bolt fastener consists of squeezing the attached plates so that the transverse load across the joint is resisted solely by friction rather than the rivet shank's strength. This indicates that replacing a lost rivet by a high friction bolt does not by anyway improve the capacity of the joint. It is thus preferable to replace any lost rivet by a normal ordinary bolt as in both systems the load is transferred only by shear. In all cases however, holes of lost or corroded rivets and bolts should be first identified then filled properly to avoid eccentric connections and or corrosion spread. The eccentricity is commonly found in deficient connections and or damaged members. In many cases, deficient basically concentric members or connections are strengthened by the addition of material or fasteners.

Fig.(13) rivet and bolt in one connection – Edfina bridge

Fig.(14) Replacement of rivets with bolt – Kanater bridge

This addition gives rise to eccentricity, if the center of gravity of the strengthened section does not coincide with the original. In case, adding plates over a riveted member, it is required to remove any rivet head that would interfere with the splice plate.

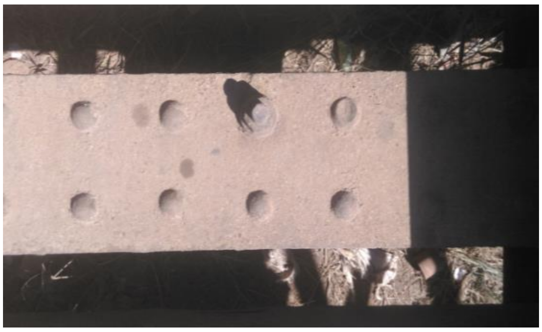

Fig.(15) rivet and bolt in one connection – Abo Sheashae bridge

7- Scour And Abutments Movement

Scour and aggradation around piers and abutments are the two factors that impact the river bed and the flow of water Fig.(16). The scour of railway bridge foundations is an important topic of research and development. Scour refers to undermining of bridge pier foundations capacity caused by a change in the soil conditions, generally caused by a strong streams and currents under flooding events. Aggradation denotes the increase in land elevation at bridge supports due to the deposition of sediment.

Fig.(16) Local Scour at Navigation Pier due to Horizontal Vortex, Imbaba Bridge

Fig.(17) Distortion of Roller Bearing due to Abutment Movement

Figure (17) shows the mechanical roller bearing distortion created by a horizontal thrust of the abutment. While Fig.(18) shows the longitudinal displacement of the bridge due to the lateral earth pressure of the soil behind the abutment.

Bridge piled abutments founded mainly on soft ground are liable to move laterally due to backfill excessive loading Fig.(18). The effect of this movement on the overall performance of the bridges is a source of troubles. The increase of the rigidity of the foundation structure with increasing the number of pile's row might be effective, Ref. [6]. The investigation should focus not only on the lateral movement of the abutments, but also on the slope stabilizing effect of the foundation. The abutment movement is harmful on the Barings as this movement cannot be accommodated resulting in misalignments, sheared bolts and loss of restraining blocks.

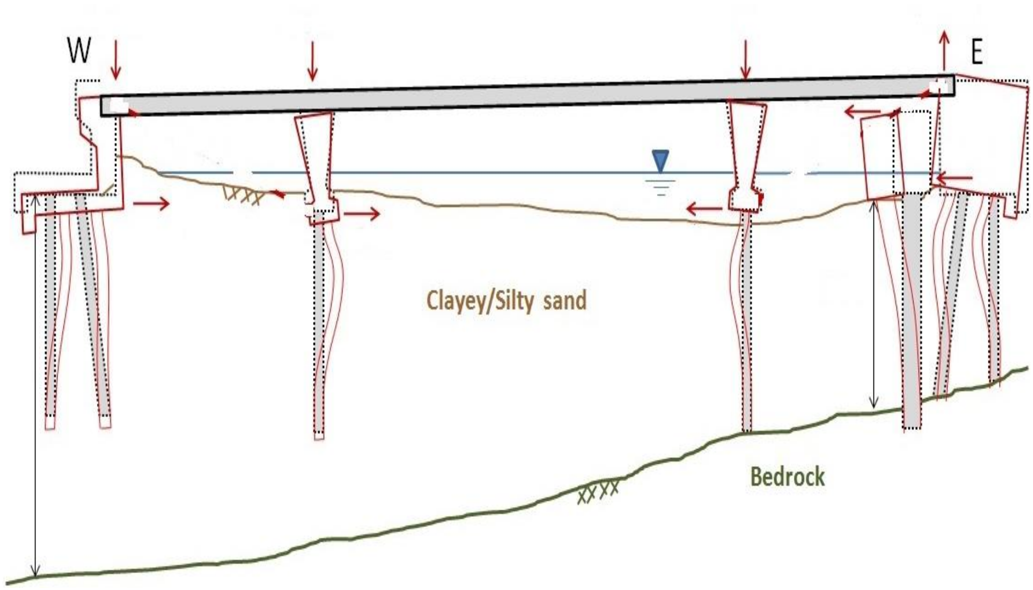

Fig.(18) Side Movement of a Bridge due to lateral ground loading [Tasiopoulou et al. 2012]

8- Defects Of Ancillary Bridge Elements: Water Drainage, Damp Proofing, Lighting Etc.

Ancillary bridge elements include all non-structural elements which affects the performance and serviceability of inspected bridge. These include water drainage systems, lighting, sleepers and rails, approach embankment and slab, utilities…etc. For the considered bridges, ancillary bridge elements were inspected and defects were determined and categorized. For RC slabs used at bridge approaches, defects included settlement of the approach slab which was attributed for the inadequacy of soil layers' compaction below the slab Fig.(19&20). In many bridges, pedestrian walkways were used by motorcycles and light traffic instead of pedestrians only. Hence, increased vertical loads are imposed on RC slabs in addition to impact and braking forces resulting from moving vehicles. Accordingly, defects at such as cracks and loss of parts of slab were observed at many walkway slabs

Fig.(19) Cracking of Concrete, Imbaba Bridge

Fig.(20) Settlement of Wearing Surface, Marazek Bridge

Rails and sleepers directly impacts serviceability of passing trains. For the inspected bridges, cracked sleepers and loose rails were detected Fig.(21).

Fig.(21) Condition of Sleepers, Banha Bridge
Rail and slipper defssionses

Fig.(22) Improper Drainage System, Marazek Bridge

Such defects lead to increasing the dynamic effect on the supporting steel structure under the applied loads. Hence, corrective actions and periodic maintenance need to be applied in order to sustain accepted level of performance. Bridges need to possess a clear drainage system as specified by different specifications in order to discharge allocated water away from concrete or steel structural elements. For the inspected bridges, it was observed that there was not a clear drainage system Fig.(22). Only separate pipes discharging in the crossed waterways were available. In addition to drainage, introduced lighting systems at different inspected bridges. It was found that most of the inspected bridges lack sufficient lighting service or power supply items Fig.(23).

Fig.(23) Poor Lighting System, Marazek Bridge

9- CONCLUSIONS

Bridge inspection aimed at improving the efficiency of ENR railway network and the anticipated growth of the traffic. Bridge engineers are facing a number of problems when planning inspection of railway steel bridges and when analyzing the large amount of data collected during their inspection campaign and the results yielded by these studies. There is a crucial need in making available tools to assist inspectors and consultants to inspect properly the bridges. Because funds are limited, appropriate and cost-effective maintenance management and repair strategy have to be adopted.

At last, we strongly recommend that once repair schemes have been taken and approved by the concerned Authority, these must be earnestly implemented without delays and within predefined targeted timelines. Also, Continuous monitoring of these centennial bridges is crucial.

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