DAMAGE MECHANICS OF MEMBERS IN STEEL RAILWAY BRIDGES

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1- ABSTRACT

Old Steel railway bridges were not built for the current trafic intensities and are therefore prone to fatigue damage. Two old truss steel railway bridges have been considered for the assessment of their steel members' mechanics damage. Although the ageing of the bridges, their importance on the railway lines encouraged the challenge to study the cases and find out the solution that ensures the safety of damaged members. The damaged members represent fortunately less than 25% of the bridge elements. Three approaches have been performed for the assessment of the causes and remedies for the phenomena, consisting of complete surveying for the existing bridges, complete structural modelling and stress analysis under real train loads, and field tests through non-destructive tests and static load tests. The stress analysis has been carried out with a simplified FEM model, calibrated with observed strains derived from real scale testing result. The results lead to two mechanics damage for members, the first is related to the fatigue resulted from the increasing service loads, speeds, and cyclic stresses. While the second is related to the tension buckling resulted from the reduction of member thicknesses, owing to flanges sections pack rust, and causing them over time to locally buckle. The paper investigates the two mechanisms, estimation of the bridge remaining lifetime, the cyclic stresses and the tension buckling instability. The practical solutions for the rehabilitation of damaged member have been presented.

2- INTRODUCTION

Several study cases have been considered for the assessment of old railway bridges. The Gerga and Zefta are the two cases presented in this paper concerning the railway bridges mechanics damaged. The two bridges have been erected across the river Nile since 1986 and 1907, respectively. Their importance arises from their services that link between large cities in the Nile Delta **Error! Reference source not found. &Error! Reference source not found.**

Fig. 1. Zefta Bridge Location

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Fig. 2. Gerga Bridge Location

The reporting from the continuous monitoring by the authority showed propagation in the defected bridges members. The normal routine repair techniques did not control such defects, but their initiation and propagation phases make the necessity to carry out thorough studies to find out the causes [0], and consequently the repair methodology. The carried out studies concentrated on those defects which are influencing the mechanical ehavior of bridges [0]. The basic damages that threaten the bridges structures include loss of materials, material degradation, discontinuity resulting in fracture,breaking and cracking deformations and displacements [0]. The surveying for background on the typical structure life cycle including the initial, damage development and any updated renew are considered as the initial state of the study. The paper shall focus as guidelines scenario to distinguish two causes of the main causes for mechanics' damage causes and their repair.

3- APPROACHES FOR THE BRIDGES ASSESSMENT

The versatile method for the mechanic's assessment of the serviceability of steel bridges is obtained based on real stress, strains through the methodology given in **Fig. 3**. The approach results from current practices and technology for the evaluation and rehabilitation of old railway bridges.

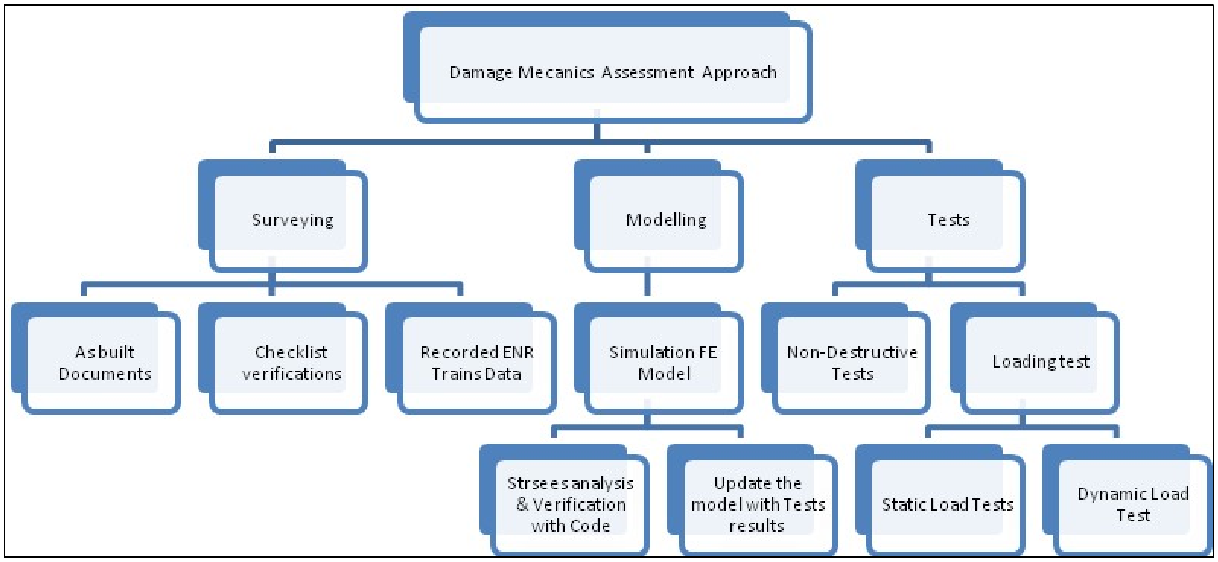
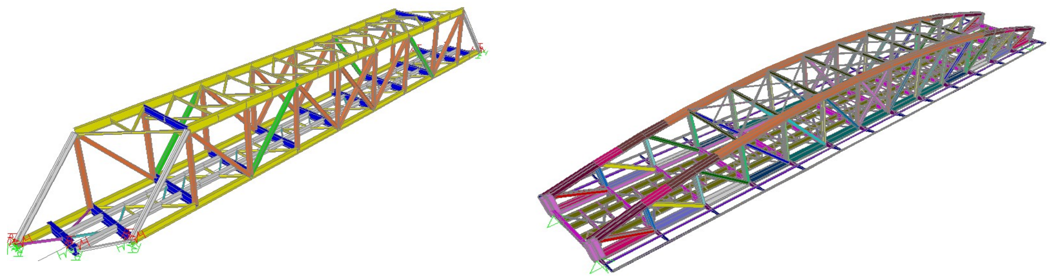


Fig. 3. Approaches for the bridges assessment

The site surveying represents an important role in the assessment approach. The obtained input data from the surveying will serve as real output resulted from the studies. The data were collected from the As-Built documents and verified through checklists for bridge dimensioning, structural elements sizes and conditions, bearings and railway status.

The bridges dimensions are then sized in 3-D odeling for the bridges **Fig. 4** which represent advanced technique toward the original available 2-D analysis. In addition to the study of the recent bridge cases due to the changes in train speed, and the number of passing cars of locomotives, passengers and goods are obtained from recoded data.



(a)Gerga Bridge (b) Zefta Bridge

Fig. 4. 3-D finite element model of (a) Gerga & (b) Zifta Bridge

The model is further updated in accordance with tests carried out on site for materials and loading tests **Fig. 5** seeking for the real stresses in members. The non-destructive tests include ultrasonic tests, hardness, welding and paint thicknesses

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Fig. 5. Gerga & Zefta Loading Test (Locomotive Wagon)

4- DAMAGE MECHANICS FHENOMENA

4-1- Fatigue Mechanism

The application of cyclic load to a structural member inducing fatigue cracking of materials and structural components due to cyclic (or fluctuating) stress [0]. While applied stresses may be tensile, compressive or torsional, crack initiation and propagation are due only to the tensile component. The causes for fatigue damage of steel can be summarized in the presence of defects on the welds, adoption of details with poor fatigue ehavior, secondary deformations and stresses, and excessive vibrations. The assessment methods in accordance to BS5400 – Part 10 [0] concerned with the structural components of bridges that are subjected to dynamic loading (varying stresses). The method is considered by either without or without damage calculation. The first calculation considered the simplified method, which determines the limiting value of the maximum range of stress for the specified design life [0]. While the second method is more accurate and it involves a calculation of Miner's rule and it can be used for any detail for which the S-N curve depending on their geometry. The outputs of studies identified that Gerga railway bridge' cracks as an example of such nature of cracks **Fig. 6**. The excessive railroad traffic were additional reasons found for crack propagation and final fracture stress due to fatigue. Fatigue crack growth $\frac{da}{dN}$ can be calculated using the Paris–Erdogan Law0to define the straight-line region of crack growth, relating the number of cycles to the stress intensity, as follows:

$$\frac{da}{dN} = C(\Delta K)^m \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(1)$$

$$\Delta K = Y(\sigma_{max} - \sigma_{min})\sqrt{\pi a}$$

Where a= Crack Size in mm; N =number of cycles; C=intercept constant characteristic parameters of the material obtained experimentally; Y=Crack geometry; m = material constant equals 3.0 for carbon steel.

The cross girder section is checked against fatigue as per specification listed in the Egyptian code (ECP 205-2001), and the number of cycles imposed by trains according to the records obtained from ENR data.

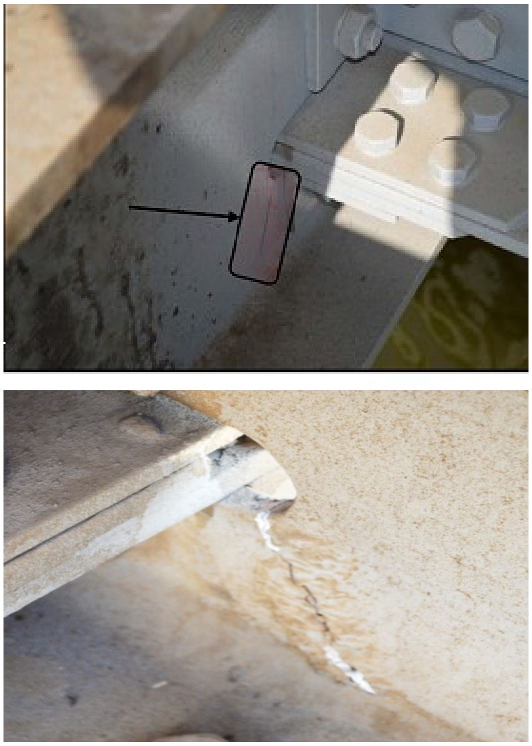

Fig. 6. Gerga railway bridge' Fatigue cracks

4-2- Tension Buckling mechanism

The tension bucking mechanism is considered as loss of stability that occurs under in-plane tension loads in thin plates due to pack rust. Thin rectangular plates with a cut-out for rivet hole results in crack**Error! Reference source not found.**. The crack may lead to locally buckle in the surrounding of the cut-out. In consequent, the sheet is stretched due to transverse compressive membrane forces being activated where the free edges, formed by the hole. The cracks are predominantly oriented perpendicularly to the loading direction. The cracking process leads to continued stress redistribution in the system, and after saturation further stretching of the plate, the member will fail to sustain the acting load. In the present paper, the damage mechanics phenomena in thin plate dealing with buckling under tensile loads, are presented.

One of the main causes of the sections reduction in their thicknesses is when the metal starts to corrode and rusts packs overtime in between the plane of the flanges' assembled surface. Reaching a significant pack rust, the plates shall be overstressed and it may buckle locally between rivets connecting the sections of the bridge member.

The buckling stress for isotropic material can now be estimated [0] by the following equation:

$$\sigma_{Cri} = 3.55E\frac{t^2}{R^2} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots(2)$$

Where E = Young's modulus; t = plate thickness; and R = hole radius

The damage mechanics problem in Zefta bridge due to tension buckling or wrinkling in the thin plate due to pack rust were observed at the tension diagonal member of truss main girder section **Fig. 7**. The tension members were firstly rusted, became thinner at their edges with increasing the width to depth ratio, thus resulting in local buckling appeared between wider spaced rivets. However, the structure analysis showed that the tension diagonal member section satisfies the stress requirement for Egyptian code.

Fig. 7. Zefta railway bridge' Tension Buckling effect

5- PRACTICAL SOLUTIONS FFOR REHABILITATION

The selection of the practical solutions for the rehabilitation of bridges depends on several items concerning its simplicity, effectiveness, cost, repetition along with the structure and the contractors capability [0]. Fortunately, the cracks in Gerga bridge and tension buckling in Zefta bridge did not exceed 25% of bridges' elements. In addition, the existence of alternative load paths after the occurring of cracks or tension buckling lead to the decision of structural elements' repair versus their removals and replacements. The retrofit of element is intended to upgrade the fatigue resistance and prevent the future occurrence of fatigue cracking.

The stitching method is suggested to be used to repair the cracked web for the stringers, cross girder and main truss of Gerga bridge. The stitching process **Fig. 8 (a-f)** involves drilling few holes on the material around the crack These holes are in line across the crack and also perpendicular to the crack, opened holes on the material by jig-drilling tool, shaped keys made of high nickel steel put into the holes. When the stitching across the crack is done, threading process starts for stud screws. These stud screws overlap on each other and fill the crack. Attention should be taken to watertight the holes.

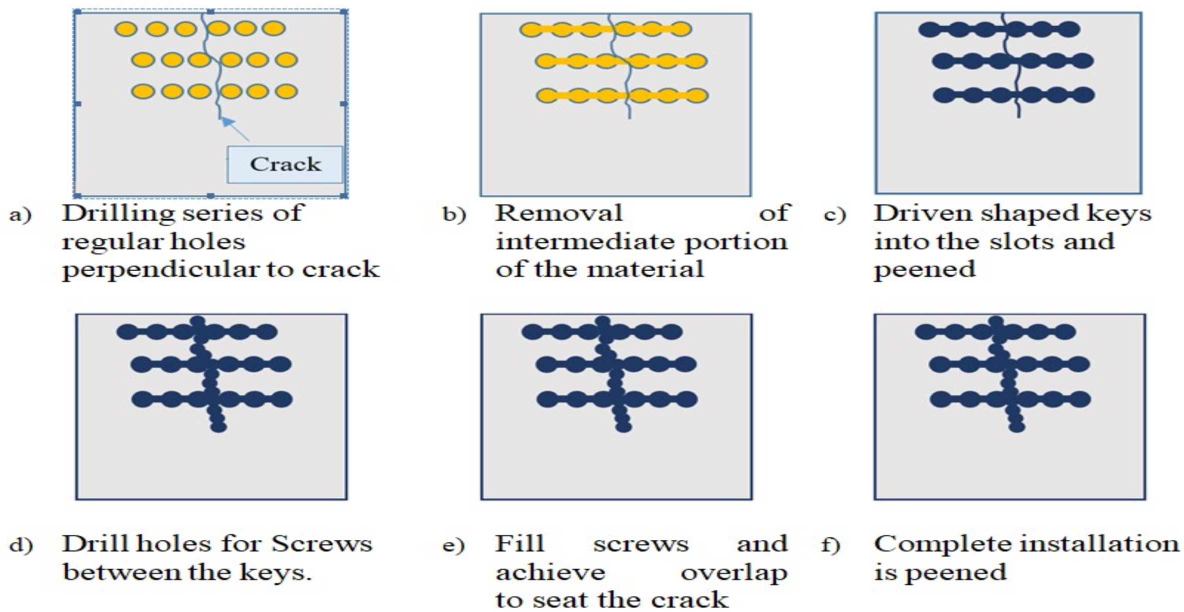

Fig. 8. Fatigue Repair

The repair solution for the tension diagonal members of truss of Zefta bridge is proposed by rust cleaning and refilling of swelled parts and introducing additional bolts at the space between old bolts for the positions of buckled parts, as in **Fig. 9**

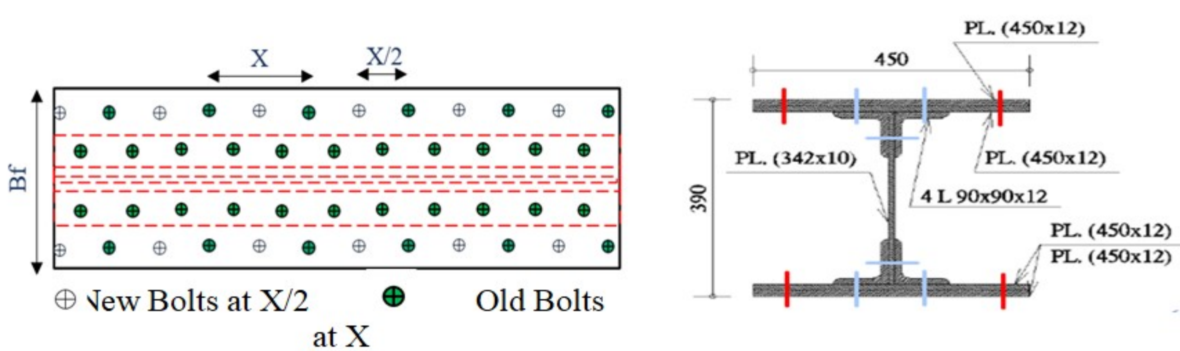

Fig. 9. Tension Buckling Repair

6- CONCLUSIONS

According to the several cases of study for old railway bridges mechanics damages, and the two presented cases, we can conclude the followings:-

1- Periodically schedule system for monitoring of railway bridges is versatile tool to early detection of damage mechanics' defects, and consequently the repairing cost.

2- The study of damage mechanics due to fatigue for ancient bridges needs to be carried for members subjected to cyclic fluctuation loads to determine their remaining lifetimes.

3- Proper design and welding process against the damage mechanics phenomena for the member's connections shall increase their capabilities to sustain cyclic loads without cracking.

4- Bridges need to be designed as redundant and can develop alternative load paths under a loss of member continuity to avoid fracture critical member.

5- Practical repair solutions should be selected for railway lines to avoid great turbulence in the flow of excessive railroad traffic.

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