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Inspection and Assessment of Highway Bridges in Jordan along the Desert Highway: A Case Study

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Abstract

Bridges, especially highway bridges, are a key factor in nations' development and flourish. Thus, great care should be taken to maintain and inspect their safety and serviceability. An immediate repair will prevent the loss of life and vehicles damage while crossing underpass and overpassing the heavy deteriorated bridges. Reinforced or pre-stressed concrete bridge girders become structurally deficient because of severed reasons including, increasing in the load requirements, corrosion of pre-stressing strands or reinforcement bars and collision of over-height trucks with the bulb of the concrete girders. The purpose of this case study is to evaluate and assess the damages of the highway bridges in Jordan. Since there is no mandatory program in Jordan for inspection of bridges and evaluating their conditions, this paper presents an inspection and assessment of two highway bridges along the desert highway which is the essential nerve connecting Jordan cities, and it also serves as an international road between many middle east countries. These two Bridges have never been investigated or checked since their construction in the late 1980s. The study results showed that the main factor causing the deterioration of these bridges is the collision of the over-height trucks with their elements. Relying on the collected data, solutions and repair methods were introduced to rehabilitate these bridges and assure their structural safety.

Keywords

Bridge Inspection, Reinforced Concrete Beam, Pre-stressed Girder, Concrete, Steel Reinforcement, Case Study

1. Introduction

Highway bridges are very important structures in modern transportation net, so a great concern should be taken regarding bridges safety and serviceability. In

the USA for example, only following the collapse of the silver bridge over Ohio River in 1967 which killed 47 people, comprehensive inspection programs for bridges had been established [1]. Bridges inspection is a very important factor for a rating of bridges. Several researches were conducted to find economical and effective maintenance and rehabilitation programs. Reference [2] developed a new method that has proven particularly suited for strengthening and stiffening reinforced and pre-stressed concrete bridge girders. It makes use of externally bonded carbon fiber reinforced polymer (CFRP) laminates characterized by lightweight, high strength and stiffness, resistance to corrosion, and good fatigue characteristics. Reference [3] developed a repair manual for Concrete Bridges. This study did not constitute a design standard, but suggestions to the decision maker. Reference [4] inspected Jilin highway concrete bridge in China. The results of the investigation showed that some concrete beams suffered from serious damages. Jacketing method, grouting repair method, replacement of expansion joints, and drainage system were the main proposed methods of rehabilitation. Reference [5] performed a detailed evaluation on 12 five-girder T-beam bridges in the southwestern US. They concluded that several factors were causing a failure mechanism, including a limited recognition in the original design standard of cyclic loading, high volume of heavy truck traffic, and transverse moments caused by unbalanced wheel loading. After the investigation, recommendations were made to rehabilitate these Bridges. Reference [6] presented the results of Non-Destructive Techniques (NDT) on the Pentagon Road Bridge, in Chatham, Kent, England. The results were used to identify the portion of the bridge which had undergone the greatest amount of deterioration. Reference [7] studied the influence of neutralisation reaction on 21 bridges in Taiwan. They predicted the performance degradation curve of the Bridges and the appropriate timing for repair. Reference [8] investigated Sorell Causeway Bridge in Tasmania, Australia. The Bridge demolished in 2002 because of the concerns about its safety in the light of the increasing size and frequency of longitudinal cracks in the webs of the beams, progressive failure of the strands in the tendons, and rebar corrosion. Reference [9] assessed the seismic vulnerability of 148 existing RC bridges in Algiers. They presented a simple and efficient inspection method for the preliminary evaluation of the seismic vulnerability of existing bridge structures. The intent of the current case study, which conducted on 27/3/2019, is to provide a comprehensive view of Jordanian highway Bridges which will be valuable for the Ministry of Public Work and Housing in Jordan, the Jordanian Engineers Association, and for Civil Engineering Students and Professors in Jordanian Universities. This case study can lead to building up a comprehensive Database regarding Bridges status in Jordan, in which the Bridges can be classified into categories with respect to their maintenance priority. This proposition will greatly help in avoiding Bridges accidents.

2. Highway Bridges in Jordan

Jordan is a key country in the Middle East connecting the gulf countries with the

northern west countries. The dissert highway in Jordan is the main road crossing the country from Aqaba in the south to Irbid in the north, passing by the capital Amman. Most of the country and Middle East goods are delivered through this highway, specifically 89% of local goods and 32% of Middle East goods are conveyed along it according to the Ministry of Industry and Trade. Nevertheless, there is no official maintenance guide for the highway bridges in Jordan, which are located along the highway. There is even no periodic monitoring or safety check of bridges by officials. In this case study, two highway bridges near Al-Hossainea town southern to Amman will be inspected and assessed. These two highway bridges across the desert highway in Jordan are named as Al-Qadisia and Unayza-Petra bridges. The two bridges are located south of Al-Hossainea with 600 m and 6 km, that is 175 km and 183 km south of Amman, respectively.

2.1. Al-Qadisia Bridge (Pre-Stressed and Reinforced Concrete Bridge)

Constructed in 1985, this bridge is 5 m height and directed east-west, and the traffic under the bridge is from north to south in the direction to Aqaba with two lanes, and from south to north in the direction to Amman with two lanes. The over pass is two lanes, one in each direction. The dimensions and shape of the bridge is presented in Figure 1 and Figure 2.

The superstructure consists of ten pre-stressed I-beam girders (bulb girders) with 1.35 m height and 0.5 m bottom flange, with 1.2 m spacing center to center. Each girder were reinforced with four tendons, each one of them is consisting of six 7-in diameter strands, and 10 φ 25 mm reinforced steel bars at the bottom of each girder. To achieve in depth visual inspection one lane was closed for inspection and the other lane was open to the traffic. To check the strands at 5 m height, a vehicle mountain with ladder four meter height was ready to inspect the strands very closely.

Identification of the Bridge Problems:

- Concrete girders damage caused by over-height vehicle collision.
- Insufficient clearance. The bridge is only 5 m height and according to the highway police directorate, over-high trucks collided with it 117 times since its establishment.
- Inefficient drainage system. For Instance, the highway police patrols locked the traffic over and under the Bridge against hundred vehicles for more than three hours last winter, as a result of pond rainfall around the area of the bridge.

These problems can be seen clearly in Figures 3-9.

2.2. Unayza-Petra Bridge (Reinforced Concrete Bridge)

This bridge was constructed in 1989 and is directed east-west and the traffic under it is from north to south in the direction to Aqaba, and from south to north in the direction to Amman. The traffic under the bridge consists of four lanes two in each direction. The over pass is two lanes, one in each direction. The

Figure 1. Al-Qadisia Bridge (Looking West; 10 Pre-stressed girders setting on three Intermediate Piers with six columns, and two Outside Abutments. Traffic S-N to Amman East Bay, and N-S to Aqaba West Bay).

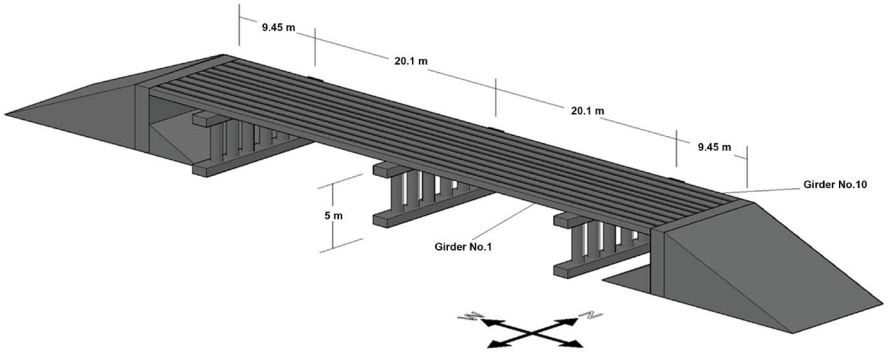

Figure 2. Drawing of AL-Qadesia bridge at AL-Hossaina.

Figure 3. Deterioration at the bottom of web of Girder No.10: sever damage in longitudinal steel reinforcement, cutting of stirrups, full concrete cover spalling, enter removal of pre-stressed duct, and heavy deterioration of strands.

Figure 4. Deterioration at the bottom of web of Girder No. 7: moderate deterioration of Strands and longitudinal main steel, and cutting of stirrups and concrete spalling, also extensive concrete cracks.

Figure 5. Girder No. 6 moderate deterioration: concrete spalling, displacement of main steel and deep cracks.

Figure 6. Sever deterioration of concrete at Girder No. 1: entire removal of concrete cover, deep cracks on the web reaching the flange, Strands cutting, main steel reinforcements and stirrups cutting.

bridge's superstructure consists of seven reinforced concrete rectangular-beam girders, each girder has a cross section of 1.2 m × 0.5 m with spacing 1.7 m center to center, and each girder is reinforced with 12 φ 20 mm. To achieve in depth visual inspection one lane was closed for inspection and the other lane was

Figure 7. Very heavy deterioration on Girders No. 1 and 2: entire concrete spalling, heavy deterioration and cutting of strands, deep cracks along the web reaching the flange, displacement and cutting of longitudinal reinforced Bars and Stirrups.

(a) (b)

(c) (d)

Figure 8. Close sight on Girder No. 1: (a), (b) Entire removal of concrete, deep cracks, also steel reinforcements, stirrups, and strands cutting. (c), (d) Complete isolation of the bottom flange from the web (Complete Failure).

Figure 9. Deterioration of Girder No. 2: cutting of steel bars, severe removal and cracks of Concrete, and heavy deterioration of Strands.

open for the traffic. The shape and dimensions of the bridge are presented in Figure 10 and Figure 11.

Identification of the Bridge Problems:

- Concrete girders damage caused by over-height vehicle collision as shown in Figure 12 and Figure 13.
- Insufficient clearance.

Figure 10. Unayza-Petra Bridge (Looking west; 7 reinforced concrete rectangular-beam girders setting on three Intermediate Piers with four 0.9 × 0.9 m columns, and two Outside Abutments. Traffic S-N to Amman East Bay, and N-S to Aqaba West Bay).

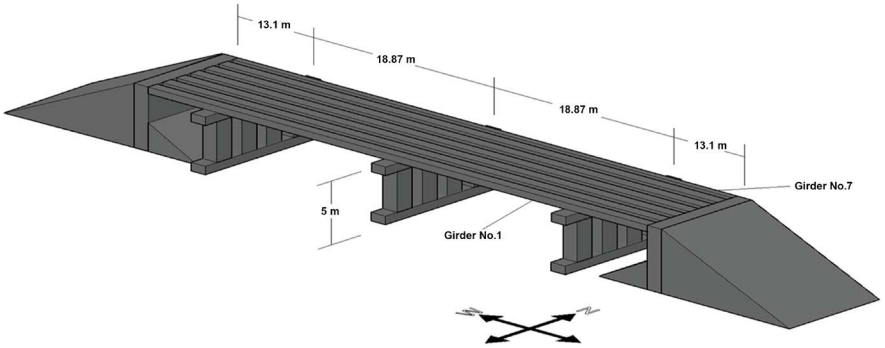

Figure 11. Drawing of Unayza-Petra Bridge at AL-Hossaina.

Figure 12. Deterioration of Girder No. 1: entire spalling of concrete, heavy damage of the girder steel reinforcement, and cutting of stirrups.

Figure 13. The deterioration of Unayza-Petra Bridge girders due to collision with over-height trucks.

3. Inspection Results and Discussion

The case study resulted in a comprehensive view of the two Bridges' conditions and provided recommendations for suitable rehabilitation techniques. All this information is shown in Table 1.

As seen in Table 1. Some girders in both Bridges are totally deficient, these girders can't be rehabilitated due to their intensive failure. The authors advise that these girders must be replaced immediately, any delay will carry over the failure to the next girders and will cause a failure in the Bridges' deck. If such a scenario happens, then loses in lives and costs will be huge.

Regarding the moderately damaged girders, these girders should be rehabilitated immediately to avoid damage propagation. If not, then they will keep deteriorating until they reach the severe damage case. In which, they will have to be replaced, which will increase the cost. The rehabilitation process has to be carried according to [10] [11], and [12]. First, the loss concrete must be removed, and then the concrete surface must be cleaned. After that, epoxy should be used to bond the old concrete surface with the newly casted concrete. This will prevent corrosion of steel reinforcement and section deterioration. As these girders' capacity still not regained due to reinforcement buckling and cutting, FRP composites can be used to strengthen these girders. Concrete or steel jacketing have a larger size and will reduce the Bridges clearance, which will increase the problem since more trucks will collide with them until their failure. FRP laminates are very thin but effective, and their application to the girders is easier.

The minor damaged girders need a concrete cover to protect their reinforcement, so loss concrete must be cleaned and epoxy can be used to bond the new cover to the old section. Since these girders have no concrete spalling or reinforcement failure, then there is no need for strengthening composites.

4. Conclusions and Recommendations

After assessing the two bridges by the authors, who are experts in Bridges inspection with experience from the USA, the following points and recommendations are concluded:

Regarding Al-Qadisia Bridge (Pre-Stressed and Reinforced Concrete Bridge):

Table 1. Summary of the Bridges' conditions and recommended rehabilitation methods.

Bridge Name	Girder No.	Deterioration Condition*	Suitable Method of Rehabilitation
Al-Qadisia Bridge	1	evere damage on the eastern side	Immediate replacement of the deficient part
	2	evere damage on the eastern side	Immediate replacement of the deficient part
	3	Minor damage on the eastern side	Cleaning out the loose concrete and apply epoxy to the rebar. [10] [11]
	4	Moderate damage on the eastern side	Immediate rehabilitation by preparing the surface and applying FRP composites. [10] [11] [12].
	5	Moderate damage on the eastern side	Immediate rehabilitation by preparing the surface and applying FRP composites. [10] [11] [12].
	6	Moderate damage on the western side	Immediate rehabilitation by preparing the surface and applying FRP composites. [10] [11] [12].
	7	Moderate damage on the western side	Immediate rehabilitation by preparing the surface and applying FRP composites. [10] [11] [12].
	8	Minor damage on the western side	Cleaning out the loose concrete and apply epoxy to the rebar. [10] [11]
	9	Minor damage on the western side	Cleaning out the loose concrete and apply epoxy to the rebar. [10] [11]
	10	Severe damage on the western side	Immediate replacement of the deficient part
Unayza-Petra Bridge	1	Severe damage on the western side	Immediate replacement of the deficient part
	2	Moderate damage on the western side	Immediate rehabilitation by preparing the surface and applying FRP composites. [10] [11] [12].
	3	Moderate damage on the western side	Immediate rehabilitation by preparing the surface and applying FRP composites. [10] [11] [12].
	4	Minor damage on the western side	Cleaning out the loose concrete and apply epoxy to the rebar. [10] [11]
	5	Minor damage on the eastern side	Cleaning out the loose concrete and apply epoxy to the rebar. [10] [11]
	6	Minor damage on the eastern side	Cleaning out the loose concrete and apply epoxy to the rebar. [10] [11]
	7	Moderate damage on the eastern side	Immediate rehabilitation by preparing the surface and applying FRP composites. [10] [11] [12].

*Severe damage: entire loss of concrete at the bottom, loss of duct and cutting of strands, intensive deformation of steel reinforcement, cutting of stirrups, and heavy cracks propagation starting at bottom and reaching top. Moderate damage: spalling of concrete cover, exposed tendons and rusting of ducts, deformation and corrosion of steel reinforcement, cutting of stirrups, and cracks propagation. Minor damage: spalling of concrete not more than 3 - 5 cm, appearance of rebar and duct.

1) According to the current inspection, this Bridge needs three box culverts 2 × 2 m for rainfall drainage to avoid ponding at winter season.

2) It is necessary to have clearance of 5.6 m as a minimum height to avoid collision with over-height trucks. This needs a topography surveying to achieve this task.

3) According to the current inspection, Girders No. 1, 2 on the eastern direction and No. 10 on the western direction need immediate replacement because of severe damage (the inspectors concluded that it will be less expensive than repairing and rehabilitating them by 19.6%). However this technique needs highly qualified people and high quality materials with past experience in this field.

4) Girders No. 4, 5, 6, 7 on both western and eastern sides need immediate rehabilitations.

Regarding Unayza-Petra Bridge (Reinforced Concrete Bridge):

1) It is necessary to have clearance of 5.6 m as a minimum height to avoid collision with over-height trucks. This needs a topography surveying to achieve this task.

2) According to the current inspection, Girder No. 1 on the western direction needs immediate replacement because of severe damage (the inspectors concluded that it will be less expensive than repairing and rehabilitating them by 27.1%).

3) Girders 2, 3, and 7 on the eastern direction need immediate repair and rehabilitation.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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