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Assessment of Structural Condition of Baghi-Pul Bridge on Kandahar-Herat Highway Using IBI Technique

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Abstract

It is important to accurately assess the structural condition of bridges for deterioration prevention and maintenance. In recent years, many bridges have reached a critical age in Afghanistan. Thus, preventive maintenance management is required to address this challenging issue. Inspection and bridge prioritization based on their structural condition for regular and effective maintenance, considering economic constraints gained attention. This paper focuses on the assessment of the structural condition of Baghi-Pul bridge to determine its priority level numerically. Hence, initially, field observation was conducted for the bridge, and its conditions are briefly explained. Then, a quantitative assessment of the structural condition of Baghi-Pul bridge on Kandahar-Herat highway was carried out using an integrated bridge index (IBI) technique. The IBI results obtained almost 4.5, which can rate the bridge within a medium priority level for repairs and maintenance. The outcome of this study can help in rationalizing decisions and prioritization by employing the available IBI technique for bridges and using funds available to them. Additionally, this technique can be linked to maintenance optimization as the more important bridges should receive attention first.

Keywords: Bridge Assessment, IBI Technique, Maintenance and Management.

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1. Introduction

Bridges are the largest, most expensive, and complex structures, which makes them a crucial, valuable transportation asset for modern structure [1], [2]. In particular, bridges are an important item of the transportation system; because of their distinct function of joining highways as crucial nodes, they are the most vulnerable element. In addition, bridges are exposed to aggressive environmental conditions and increasing traffic volume and truck loads [3], [4], [5]. Furthermore, bridges are rather costly to design, construct, maintain, and rehabilitate. Thus, preventive maintenance and management have been introduced to address this challenging issue [6], [7], [8]. Structural deterioration and lack of functionality led to important investments in bridge rehabilitation in the last decades. Budgets for keeping or rehabilitating existing bridge infrastructures are always limited, and frequently only a selection of the problems detected can be dealt with by the bridge inventory department. To be aware of existing in services problems and to help in rationalizing maintenance decisions, bridge inspection and prioritization are necessary to be carried out before the commencement of maintenance and management [9],[10][11].

More precisely, transportation agencies face the challenge of balancing limited resources with growing demands of an aging highway system, particularly in addressing the diverse needs of numerous bridges. While deciding what is more optimal for each bridge is crucial, it is important to realize that the ideal choice for one bridge may not match the overall priorities of the entire bridge system, especially when dealing with financial limitations [12]. Acknowledging this complexity, bridge engineers, bridge managers and owners, and public officials understand the necessity for established methods and techniques. These methods or techniques are essential not only to assess the current and future conditions of bridges but also to determine the most effective allocation of funds within a broader system of bridges. In consequence, bridge maintenance and management deal with all activities during a bridge's service life from construction to replacement, aiming to ensure its safety and functionality. It also addresses prioritization of protection needs, planning the maintenance system, and optimization of the bridge life-cycle cost [12], [13], [14].

Several studies have been conducted regarding the problem of maintenance prioritization by developing a scoring system that incorporates factors they deemed important to a bridge's condition in comparison to others in a network. For instance, a bridge prioritization index has been proposed by Valenzuela et al [15]. According to a review of current practices, they recognized the current issues and subsequently generated a list of factors that would better prioritize maintenance. Another group of researchers worked on developing a periodization methodology as part of a long-term bridge performance program that was being conducted by the Virginia Department of Transportation [16]. This group identified three main categories of attributes: maintenance, economic, and political, which formed the basis of their methodology. They compared the economic ranking with the maintenance ranking for a cross-proration plot, which helped them select bridges. In any prioritization methodology, it is important to determine the current physical condition of the bridge.

Similarly, Ni and Wong focused on the use of structural health monitoring (SHM) methods to conduct maintenance and management. The results were used to optimize

maintenance operations. They employed the data provided by the SHM instruments to analyze the structure, prioritize components, and determine required maintenance actions [17]. The other research [18], looked at prioritizing individual bridge components and discussed what previous researchers have performed on a system-wide level. Thus, the analysis of individual bridge components can help for the basis of a multi-criterion structural health index to be included in a prioritization methodology.

Nowadays, bridge degradation and the risk of failure are a continuing challenge for most of the transportation infrastructure in Afghanistan. The Ministry of Public Works (MoPW) of Afghanistan roughly estimated that 20,849 bridges and culverts existed across the country, of which most of the bridges are degraded and require urgent maintenance and repair [19],[20]. In this paper, initially, a visual inspection of the structural condition of Baghi-Pul bridge was carried out by field measurement. The structural deficiencies, types of deficiencies, including their severity, were discussed for each element of the bridge, and their results are presented. Then, an evaluation of the structural condition of the Baghi-Pul bridge on the Kandahar-Herat highway was carried out using an integrated bridge index (IBI) technique [15]. The IBI results obtained almost 4.5, which can rate the bridge within a medium priority level based on structural conditions.

Finally, this research aims to assess the structural condition of bridges by employing the available IBI technique to determine their priority level for appropriate repairs and maintenance optimization, as the more important bridges should receive attention first.

2. Investigated Bridge

On-site observation was conducted at Baghi-Pul bridge on Kandahar-Herat highways in Afghanistan. Figure 1 shows the monitoring location of the bridge, and figure 2 shows an overview of Baghi-Pul bridge. This is an RCC bridge with 11 spans, a rectangular cross-section, a width of 10 m, and with total length of 154 m; the details of the bridge are given in Table 1. This bridge is precast concrete; as the length of the bridge is 154 m (more than 50 m), it can be classified as a long-span bridge. From a structural point of view, it is a slab-girder bridge, and finally, from an application point of view, it is a river-crossing structure with daily heavy-load vehicles.



Fig. 1. Location of monitoring bridge (Image generated using Google Maps)



Fig. 2. Overview of the candidate bridge

Table 1. Geometric description of investigated bridge and it's coordination

Bridge	Each span (m)	Number of Span	Width (m)	Total length (m)
Baghi-Pul	14	11	10	154
Latitude	31.61517186660172			
Longitude	65.57596836746582			

3. Field Observation of Baghi-Pul Bridge

3.1. Superstructure of Bridge

A comprehensive field observation was carried out for the superstructure of the Baghi-Pul bridge to identify their deficiency for more accurate consideration. A summary was made to explain the structural condition of the superstructure elements of the bridge as follows:

3.1.1 Deck

The deck of this bridge consists of multiple plates with a total width of 10 m; the slab has two traffic lanes. It has been constructed using precast concrete; the slabs were produced initially as prefabricated plates, and then assembled in the field. To collect surface runoff, a drainage system has been installed on the bridge; however, the drainage is damaged and not working well, even some of them are filled with garbage. Additionally, many rutting are observed on the asphalt surface of the bridge, which can significantly degrade the service level.

3.1.2 Girders and Diaphragms

The girders, which connected by the transverse diaphragms and mainly receive loads from bridge slabs and then transfer them to the pillar caps, are satisfactory in general and can be used normally. However, a minor crack was observed only on the cover of the beam, which needs maintenance. Diaphragms that connect the girders in the transverse direction are not in good condition based on their technical viewpoints. A number of diaphragms have cracks, and even the rebar is exposed due to broken concrete. As the rebar exposed

to atmospheric air they may get rusted and will be deteriorated further. Thus, the diaphragms need to be rehabilitated and repaired.

3.2. Substructure of Bridge

An assessment or visual inspection was also carried out for the substructure of the bridge as well as its superstructure. Hence, a summary is made as follows:

3.2.1 Pier caps and Piers

The pier caps of the studied bridge are well, and no deficiencies or damages are observed. The girders are placed on the pier cap in a good manner and function well. However, it should be noted that the surroundings of the girders are filled with debris and waste materials.

The interior piers which receiving load from pier caps have problems to some extent; the concrete has chipped off, although no cracks or other deficiency observed, but most of the piers have no covering on steel bars, which caused rebar exposure. Hence, most of them need to be repaired and maintained technically to strengthen the piers as well.

3.2.2 Abutments

The beginning and end abutments of the bridge are in good condition. No deficiencies or structural damage are observed. The only problem was existing a lot of debris and garbage around the main girder. The spacing between girders was almost totally filled with extra materials and debris.

3.2.3 Foundation

The foundations were observed as isolated or single footings. Scouring was seen around some of the foundations during the field inspection. Also, it was found that soil around the footing became empty during the summer season through people illegally for construction purposes, which weakens the foundation and needs to be prevented. Additionally, it was required to provide information to local people to avoid using sand and gravel delivery from the bridge foundation that may cause misery and will cause the collapse of the bridge in the future.

4. Summary of Field Observation

The field observation was carried out for the Baghi-Pul bridge to assess and identify the deficiency or damage of the structural condition of each element of the bridge. The investigation outcome shows, although the bridge can be used for transportation purposes but still there exist many engineering problems which need for technical repair and maintenance.

There observed many rutting and cracks on the top of the asphalt surface of the bridge, and also the slab expansion joints were damaged, and most of them were filled through debris, which needs to be removed and cleaned, the bridge surface can be seen in Figure 3A. The condition of girders and diaphragms is shown in Figure 3 B. According to the figure, some points of the main girder have been chipped off, which need minor maintenance, but generally they are satisfactory. The diaphragms require more attention compared to the main girders, which a complete repair and technical maintenance is need to be done, as it seen from the figure and also found from visual inspection; some of them

are broken, and their rebar is exposed. Hence, when the concrete either crack or broken it will totally lose its functionality, that their strength can be ignored.
Additionally, Figure 3C demonstrates the pier capes of the bridge. According to the figure, the pier caps possess no deficiency and function well. However, it is essential to clean the pier caps of debris and other additional and unnecessary waste. Similarly, the structural condition of the piers was inspected, and there observed many chipping on the pier surface, which can reduce the piers' strength; also, the main rebar and ties were partially exposed. These parts of the piers required urgent and fully technical repair to prevent further strength reduction and deficiencies, as shown in Figure 3D.
Finally, the abutments of the bridge have no structural problems except existing debris and waste as well as pier caps. The existing debris is too much in the Kabul direction compared to the Herat direction; the existing debris can be seen obviously from Figure 3E. Regarding bridge foundations, some scouring appeared around them, which can lead to significant damage if the technical measurements are not fulfilled. Hence, this issue is also an important inspection finding that is essential to be dealt with and repaired.



(A). Bridge surface



(B). Diaphragms condition



(C). Debris on pier caps



(D). Piers condition



(E). Debris on abutments

Fig. 3. Shows the existing condition of both the superstructure and substructure of Baghi-Pul II bridge.

To sum up the discussion, field observations clearly show that the bridge structure requires maintenance for appropriate services and proper functionality of the entire bridge members as a whole. In the next section of this paper, the bridge is evaluated quantitatively using the IBI technique to identify the bridge priority level from maintenance considerations.

5. Assessment of Baghi-Pul Bridge using IBI Technique

There are many bridges, as well as the Baghi-Pul bridge, which were discussed in sections 3 and 4 that need urgent repair and maintenance. However, the budget is limited to manage and repair all of them, so it is important to make an accurate decision for bridge prioritization and then run the bridge maintenance based on their prioritization and the most severe cases. Thus, selecting the most vulnerable bridge requires sufficient data to evaluate the bridge's structural condition, and later on, the decision can be made. In this study, an integrated bridge index is used to evaluate the bridge for maintenance and management. Hence, as it was mentioned, the purpose of this study is the assessment of the structural condition of the bridge quantitatively using the IBI technique, so, in the following section, the IBI technique will be introduced briefly and discussed as follows:

5.1 Integrated Bridge Index (IBI)

The integrated bridge index (IBI) is simply estimated using equation (1). The IBI includes many variables such as bridge condition (BCI), its hydraulic vulnerability (HV), seismic risk (SR), and strategic importance (SI). The index varies within the range of 1 to 10, where 1 is a deficient operating condition, and 10 is the best service condition. Considering the variables, the IBI equation can be written as follows.

$$IBI = -1.411 + 1.299BCI + 0.754HV + 0.458SR - 0.387SI \quad (1)$$

5.1.1 Strategic Importance (SI) Index

The SI presents the importance of the bridge in equation (1), it depends on the presence of alternative routes, traffic level, the type of economic activities performed in the area of the influence of the bridge, the width, length of the bridge, and the load restrictions. To estimate the SI index using equation (2) as follows:

$$SI = 0.261EA + 0.206T + 0.193SEE + 0.093W + 0.133L + 0.114R \quad (2)$$

Where, in the above equation(2); EA is the alternative route index, which can be obtained from Table 2, T represents the average annual daily traffic index, which is obtained using Table 3. SEE means the social and economic environmental index, which can be obtained from Table 4. Similarly, W and L are the width and length of the bridge, respectively; they are obtained from Tables 5 and 6, respectively. Finally, R represents the load restriction index, which can be obtained from Table 7. To calculate the mentioned parameters, the Tables are given below:

Table 2. Alternative routing rating-EA [15]

Type of detour	Rating	Description
Parallel structure	1	There exists a structure nearby the bridge. It permits traffic flow with low disruptions and delays.
Parallel structure or road	2	There exists a structure nearby the bridge. It permits traffic flow with congestion. Three roads exist with a similar standard as an alternative. The travel distance is similar. The travel time and road user costs do not change.

Longer detour	3	Alternative roads increase travel time and road user costs. Minor congestion is observed on the bridge.
Very long detour	4	An alternative road implies rerouting higher than 10 km of length. The standard of the alternative is lower than the main route. High probability of congestion on the bridge.
Without detours	5	There is no alternative route

Table 3. Annual Average Daily Traffic (AADT)-T [15]

Traffic level	Rating
Low (ADDT $<$ 2,000)	1
Medium (1,200 $<$ ADDT $<$ 3,000)	3
High (ADDT $>$ 3,000)	5

Table 4. Bridge Rating by Zone and Economic Activities Supported by the road-SEE [15]

Zone of country	Rating	Economic activities
North	5	Mining
	3	Farming and fishing
	1	other
Central	5	Industrial, winery, and faming
	3	Mining and fisheries
	1	other
South	5	Farming and forestry
	3	Livestock and aquaculture
	1	other

Table 5. Width of the bridge rating-W [15]

Qualification of width	Rating	Description
Unsatisfactory	1	The bridge has one or more lanes with constant problems for vehicle passing: very narrow deck.
Satisfactory	3	Two-lane bridge deck; narrow lanes produce passing restriction for heavy trucks.
Very satisfactory	5	Two or more lanes bridge deck: passing restriction does not exist.

Table 6. Length of the bridge rating-L [15]

Length range	Rating	Type of bridge
≤ 30	1	Very short
$30 < L \leq 50$	2	Short
$50 < L \leq 150$	3	Regular
$150 < L \leq 300$	4	Long
$L > 300$	5	Very long

Table 7. Load restriction bridge rating- R [15]

Type of restriction	Rating	Description
Highly restricted	1	Passing is not allowed for heavy trucks; restricted passing for light vehicles.

Medium restrictions	3	Passing is not allowed for heavy vehicles; passing is allowed for other vehicles.
No restrictions	5	Passing is allowed to any type of vehicle

5.1.2 Hydraulic Vulnerability (HV) Index

The HV is calculated using Table 8, in which hydraulic visual inspection is considered the main input. Normally, this kind of visual inspection can be used to assess the condition of the river bed and bank. Also, flow conditions, including scour level.

Table 8. Hydraulic vulnerability bridge rating- HV [15]

Rating		Description
5	None	There is no probability of failure because of the reviver forces.
4	Low	It is highly unlikely that the bridge and its complementary works fail as a result of floods and/or scour.
3	Medium	It is likely that the bridge and its complementary works fail as a result of floods and/or scour.
2	High	It is very likely that the bridge and its complementary works fail as a result of floods and/or scour.
1	Very high	The bridge and its complementary works are in imminent danger of failure.

5.1.3 Seismic Risk (SR) Index

The seismic risk (SR) index is obtained according to the damage level modeled in each structure. The estimation is complex. For estimating the ground acceleration and structural response, a numerical model is needed. For example, it can be used in Fischer's method. The damage level obtained is associated to a semantic scale that explains the numerical rates of SR. The scale is shown in Table 9.

Table 9. Seismic risk of bridge rating-SR [15]

Rating	Damage level (%)	RS level description	
5	0-20	None	There is no likelihood of failure by seismic loads
4	20-40	Low	It is highly unlikely that the bridge fails as a result of an earthquake.
3	40-60	Medium	It is likely that the bridge fails for seismic loads.
2	60-80	High	It is very likely that the bridge fails for seismic loads
1	80-100	Very high	The bridge is in imminent danger of failure due to earthquakes.

5.1.4 Bridge Condition Index (BCI)

The BCI is defined as the weighted sum of each structural element condition(ECI_i), divided by the effect of the materials (m) of each element (i) of the equation (3). In Eq.3, w_i represents the effect of the i-th ECI on the overall condition of the bridge. The condition of structural elements is obtained through the on-site visual segmental inspection of the bridge.

$$BCI = \sum_{i=1}^{n} w_i m_i ECI_i \,/\, \sum_{i=1}^{n} w_i m_i \tag{3}$$

In the above equation, ECI_i is the element condition index of element (i), w_i is the weight of the element (i) with respect to the entire structure, and finally m_i demonstrates the material factor of each element. For calculation of BCI, segmental visual inspection is necessary. Hence, a record with the distresses for each bridge element can be obtained. In addition, the following steps are necessary to calculate the BCI by using Eq. 3[15].

a) The ECI is calculated for each element based on segmental inspection.
b) When a bridge has several elements of the same type, for instance, several piers, the worst of them should be selected as a representative index of that type of element.
c) The BCI is computed by weighting the indexes of each element according to its importance for stability, security, and serviceability. The element weight is defined for typical elements of each type of bridge structure. The weights range within 1 to 5. For example, in a beam bridge, the primary beam and piers have a weight equal to 5, and the road signs a weight equal to 1. The weights are strongly dependent on the type of structure, thus, they should be defined case by case.
d) Each weight is multiplied by the material factor m_i that depends on the element material. The factor reflects the material vulnerability, which ranges between 1(prestressed concrete) and 4 (timber).

6. Results and Discussions

A visual inspection and quantitative assessment of the structural condition of the bridge was carried out using the IBI available technique. Firstly, the visual inspection was conducted for each single element of bridge like; slabs surface, RCC girders, diaphragms, pier caps, piers, abutments including foundation, and some other elements (guardrails, drainage, approach slab, and etc.), among them, diaphragms, piers, foundations, drainages, expansion joints including RCC girders are needed for more accurate and fully repair and maintenance. However, the other elements also need for partial or minor maintenance as well.

The visual inspection shows that the whole bridge requires repair, and maintenance is considering an urgent issue for the studied bridge. In Figures 3A through 3E, the structural condition of some elements was shown as an example to describe the current situation of the existing bridge. According to the figure, the bridge surface has many rutting and cracks on asphalts which can be obviously observed and resulting to low quality services. In Figure 3B, the bridge plate can be seen clearly from beneath that some parts of its concrete have been either minor chipped off or cracked on covering, as the bridge plate (bridge slab) made the most crucial important element of the bridge structure, it requires urgent maintenance and regular inspection in order to keep the bridge safe and secure. Also, the diaphragms and their structural condition can be observed well. As indicated in the figure, most of them have worse condition because their concrete has been removed and their steel bar are exposed. In this bridge, a little vibration and the bridge lateral movement were observed when a heavy vehicle moved across the bridge deck. This movement might be due to inefficient diaphragms to keep the plate independent movement; additionally, the bridge plates (slab) were in touch at expansion joints due to longitudinal plate movement and filling through debris. Thus, the bridge

plates, diaphragms, including some part of the girder, required complete and appropriate maintenance.

Similarly, many debris, unnecessary materials filled out pier caps, furthermore, the joints between slabs have been filled through extra materials, which should be cleaned and require regular inspection. According to Figure 3D, the piers need full maintenance because the covering concrete has cracked and event has been removed; the main longitudinal steel bars, including spiral (ties), are totally exposed. Chipping concrete not only reduces the pier strength but also causes the steel bars rusting and finally can be resulting pier collapsing. Hence, this element of the bridge also needs more accurate and efficient repairs. Finally, the bridge abutments also has been filled with debris and unnecessary materials, which need to be removed, as well as pier caps. To summarize the field observation, a segmental visual inspection for each element of the bridge was carried out to describe the structural condition of the bridge for details and provide a comprehensive overview of the whole bridge structure.

Secondly, a quantitative assessment of the structural condition of Baghi-Pul bridge was conducted using the IBI technique. The main objective of this evaluation was to describe the bridge condition numerically for bridge prioritization. This is very important because most of bridge required for the maintenance simultaneously, and budgets are always limited. So, just visual inspection is insufficient to identify and categorize the most deficient bridge for repair. Hence, the assessment of the bridge was conducted based on the IBI technique using mathematical equations explained in Section 5 of this paper. In addition, a number of related tables are used to determine the required parameters considering the bridge situation. The green shaded color shows the selected parameters in the tables based on the actual situation of the bridge. In this study, by employing equations (1) through (3) with considering their related tables, the IBI obtained almost 4.5, which shows the medium priority level for the bridge. As it was explained, the IBI index ranged from 1 to 10, where 1 is a deficient operating condition, and 10 is the best service condition. For easier understanding, the IBI can also be subdivided to describe different priority levels, such as: (when IBI≥ 8, it shows a very low priority level, $6 \leq IBI < 8$ shows a low priority level, $4 \leq IBI < 6$ shows medium priority level, $2 \leq IBI < 4$ shows high priority level, and $IBI < 2$ shows a very high priority level). In this research, as the IBI of the Baghi-Pul bridge obtained almost 4.5, it falls within the medium priority level and identifies the bridge structural condition numerically, which gives a clear index for repair and maintenance.

Finally, this study aimed to assess the structural condition of the Baghi-Pul bridge using the IBI technique. The investigation outcome shows that visual inspection gives an overview of the structural condition of the bridge; however, evaluation of the bridge using the IBI technique provides a more accurate index numerically and information that enables us to identify the bridge priority level as well. Thus, the investigation more precisely shows that Baghi-Pul bridge is located at a medium priority level for maintenance and management.

7. Conclusions

An integrated bridge index (IBI) is the simplest available technique and can be applied easily to assess the bridge structural condition. In this paper, a visual inspection for every single element of the Baghi-Pull bridge was carried out using field observation, and their deficiencies were identified. The investigation results clearly show that some member/element of the bridge partially has been deteriorated and required for fully an appropriate maintenance; otherwise, will no further service can be done. Also, it was found that the diaphragms are the most deficient and have been damaged compared to other elements of the bridge. As the diaphragms connect the bridge plates (deck) laterally and has key role on prevention of single independent movement of the girders and beams, are need to be repaired and secure the whole bridge structure.

Additionally, a quantitative assessment of the bridge was conducted using the IBI technique. As most of bridge reached at the age of aging in the country, to do maintenance a huge number of bridges simultaneously with considering budget limitations is a tough issue, and only visual inspection is insufficient and cannot describe the bridge's structural condition well. In this study, the use of the IBI technique for bridge assessment was carried out as well, and it was seen that IBI has the potential for more easily evaluating bridge condition. Thus, the investigation was conducted for the same bridge by employing of IBI technique; the IBI index obtained was almost 4.5, which shows the medium priority level for maintenance. The determination of bridge priority level through the IBI index has a significant role and gained attention to rating the bridge deficient numerically and can help for rationalizing decisions regarding bridge maintenance and management.

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