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Assessment of dead load deflection of bailey bridges in Bangladesh

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ABSTRACT: In Bangladesh, collapse of bailey bridges is frequent. In this study, remote observation of dead load deflection of bailey bridges is introduced by Refractor less Total Station. A total of 13 bailey bridges within Rajshahi Division of Northern Bangladesh were studied. The monitored dead load deflection ranges from 12 mm to 93 mm for all studied bridges. The results revealed that bailey bridges deflect more than the safe limit even due to self weight. Addition to vehicular loads makes the bridges more vulnerable to use. These unhealthy bailey bridges are in operation in our road networks and often cause frequent failure.

1 INTRODUCTION

Bridges are very important structures on any highway system. It plays vital role in connecting people, good and transports. Since bridges are important link, it is essential to assess the structural health of bridges in order to ensure safe and durable connectivity. The Bailey bridge system, originally invented for military usages, has been used to meet the emergency or temporary bridge needs. It has also been widely used as a permanent solution for pedestrian and road bridge needs in remote location (Yi et al, 2014).

According Roads and Highways Department (RHD) of Bangladesh, there are 4,507 bridges under the department, of which 996 are Bailey bridges. Of them, 973 have steel decks while the rest have wooden decks (The Daily Star, 2020). Most of these bailey bridges are in unsafe condition; the bridges have already become deteriorated and damaged to great extent. Collapse of highway bridges is seldom while failure of bailey bridge is quite frequent (Figure 1, Fig 2 and Bangladesh Protidin, 2017).

Figure 1. Bailey bridge collapse in Munshiganj (UNB, 2020).

Figure 2. Bailey bridge collapse in Bandarban (The Independent, 2016)

Deflection is an important index for safety evaluation of bridges (Tian, L. & Pan, B., 2016). Bridge deflection measurement can predict the structural health status of bridges and can provide the important reference for structural performance and operational status of bridges (Shan, B. et al., 2016). A high rate of deflection indicates the materials are significantly displaced which may bend, warp or shift in response to the superimposed load. Lower rate of deflection indicates higher structural stiffness. Bridges whose deflections overpass the specified limit of design may increase damage accumulation and even collapse at any time, which pose a serious threat to people's lives and bring about a great loss of property.

Conventional bridge deflection measurement techniques and equipments in Bangladesh are contact-based system, inaccurate and not simple to conduct. To address this challenge; remote and accurate deflection measurement of bridges is introduced in this study using Refractorless Total Station (RTS). Despite the diversity of remote deflection measurement techniques, use of RTS have received increasing attention due to their outstanding advantages such as real-time measurement, easy-to-use setup, low-cost, require less manpower and applicability. This study aims to assess structural health status of bailey bridges by introducing remote or non-contact observation technique.

2 METHOD OF STUDY

Deflection is the degree to which a structural element deforms under loading. For a weightless truss, the imaginary horizontal plane (as line ACB in Figure 3) will be a straight line passes through the supports. Alternately, considering the self-weight of truss, the edge view of the deflected bridge will appear like the dotted line in Figure 4. For a weightless truss bridge having span ‘L’ as in Figure 3, the co-ordinates of point A, B and C will be (0, 0), (L, 0) and (L/2, 0). Assuming, ‘-2’ unit dead load deflection at the mid-span for the truss bridge as in Figure 4, the co-ordinate of ‘D’ will be (L/2, -2). The coordinates of point A, B, C & D are the desired measurements using RTS.

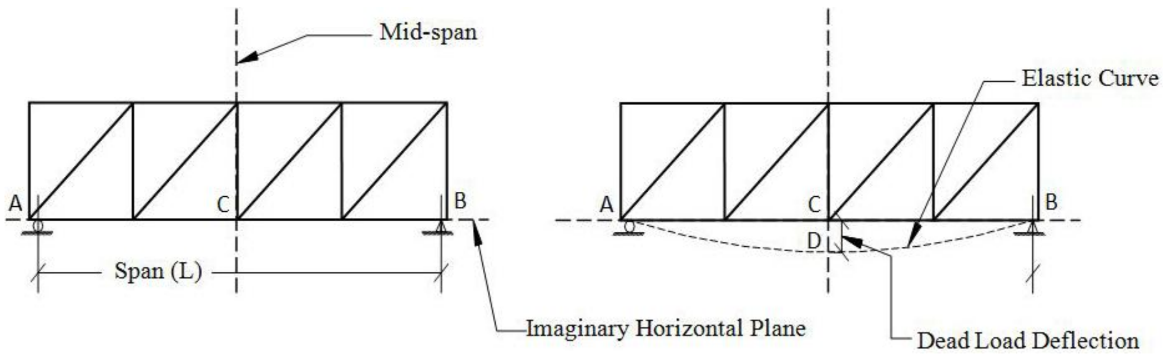

Figure 3. Horizontal plane of a weightless truss.

Figure 4. Elastic curve of the deflected truss.

The edge view of the mid-point of bottom chord of the bailey bridge becomes visible on RTS as ‘point D’ of Figure 4. It is most likely that ‘point D’ appears below ‘point C’. The vertical difference between points C & D (in Figure 4) on the RTS i.e. vertical difference between mid-point of the imaginary horizontal plane within supports and mid-point of the bottom edge of bridge girder is the dead load deflection of studied bridge. Under this concept, mid-span deflection of bailey bridges (for only self-weight) were measured. RTS can also count the vertical difference between point C and D from remote location using “Missing Line Measurement (MLM)” function.

RTS was calibrated before using it at the bridge sites. The least count for the RTS was 3mm. Vertical distance between any two distant points within a testing ground were measured by RTS and steel tape simultaneously to check the accuracy of RTS. Targets were kept at various distant places and measurements were taken. RTS produced same measurements as steel tape up to 122m (400 ft). Thus accuracy of RTS was checked before deploying it in deflection measurement of bailey bridges.

3 STRUCTURAL MODELING OF BAILEY BRIDGES

Before starting the field survey, five bailey bridges were modeled using Structural Analysis Program (SAP 2000). At the beginning, line diagram of the bailey bridges were prepared. Geometric design, members’ connectivity, sectional properties, support conditions, material properties were collected from every bridge sites. Using these data, computer models were developed and analysis was done for self-weight only. Three railway bridges namely: Hardinge Bridge (span 105m), Gorai Bridge (span 57m), Atari Bridge (span 47.5m) were also modeled for the study.

Five bailey bridges in Rajshahi Division were selected for SAP analysis. Those are Mohadebpur Bailey Bridge, Naogaon district (span 41.76m), Pontarjan Bailey Bridge, Bogura district (span 39.63m), Bahuli Bailey Bridge, Sirajgonj district (span 33.53m), Baiguni Bailey Bridge, Bogura district (span 30.48m), Kholishagura Bailey Bridge, Bogura district (span 24.39m). Among the five bridges Mohadebpur Bridge has the largest span and mid-span deflection were found to be 28.25 mm by SAP analysis and the results are presented in Figures 5 & 6. Deflection results of all other bridges by SAP is presented in Table 1.

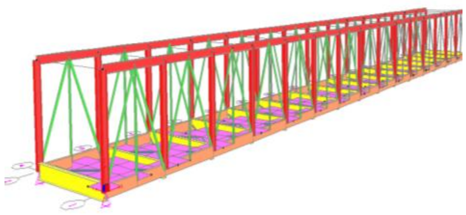

Figure 5. SAP model of Mohadebpur Bailey bridge.

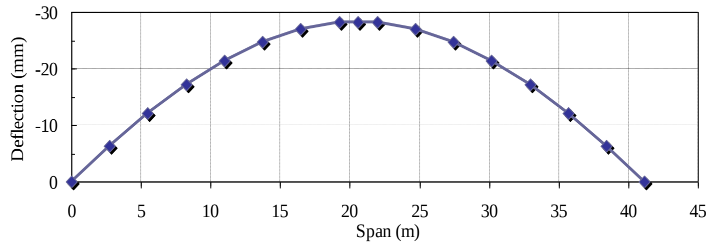

Figure 6. Span vs. deflection curve of Mohadebpur Bailey bridge by SAP.

4 DEFLECTION RESULTS

During the field survey, thirteen bailey bridges have been selected for study. Name of bridge, location, span and deflection values by RTS and SAP for those studied bridges are presented in Table 1. All the studied bridges are listed according to span length in descending order.

Table 1. Deflection results of bailey bridges.

No.	Name of Bridges	Location	Span (m)	Deflection by RTS	Deflection by SAP
1.	Katakhali Bridge	Sirajganj	43.29	93 (Max^{m})	---
2.	Buruj Bridge	Rajshahi	42.07	36	
3.	Mohadebpur Bridge	Naogaon	41.15	42	28.25
4.	Pontarjan Bridge	Bogura	39.63	54	22.01
5.	Hasildoho Bridge	Sirajganj	36.59	54	---
6.	Hajibari Bridge	Sirajganj	36.59	84	
7.	Boikunthopur Bridge	Sirajganj	33.54	51	
8.	Bahuli Bridge	Sirajganj	33.53	51	15.75
9.	Baiguni Bridge	Bogura	30.48	78	16.00
10.	Chondidas Bridge	Sirajganj	29.27	60	---
11.	Kurir Chor Bridge	Sirajganj	24.39	81	
12.	Kholishagura Bridge	Bogura	24.39	36	4.57
13.	Sonai Bridge	Sirajganj	18.29	12 (Min^{m})	---

5 ANALYSIS

5.1 *Differences in SAP and RTS Results*

Span of the studied bailey bridges ranges from 18.29m to 43.29m. Dead load deflections were found from 12mm to 93mm in RTS survey and 4.57mm to 28.19mm in SAP analysis (Table 1). In SAP analysis, deflection increases with the increase of span and vice-versa. For example, dead load deflection of Mohadebpur bridge, having typical girder of 41.15m, was 28.25 mm (maximum). Again, dead load deflection of Kholishagura Bridge, having a span of 24.39m, was 4.57mm (minimum). Thus, deflection is likely to be proportional to span of the bridge in SAP analysis.

On the other hand, RTS survey found non-consistent deflection in different span bridges. For example, dead load deflection of Katakhali bridge, having typical girder of 43.29m, was 93mm (maximum). Again, dead load deflection of Kholishagura Bridge, having a span of 18.29m, was 4.57mm (minimum). In addition, dead load deflection of Hajibari Bridge, having a span of 36.59m, was 84mm (2nd maximum). Thus, RTS survey found non-consistent relation between deflection and span length.

As the geometric design, cross sectional area and material properties are similar in long or short span bailey bridges, the theoretical deflection follows a relation between span and deflection in SAP analysis. Same bridges produce more deflection in RTS survey comparing the SAP analysis (Table 1). This is due to aging of the bridges and lack of periodic maintenance and repair. For example, dead load deflection of Buruj bridge, having large span of 42.07m, was 36mm only. Again, dead load deflection of Kurir Chor Bridge, having a small span of 24.39m only, was 81mm (3rd maximum). RTS survey gives an idea that bridges having critical health deflect more and vice versa. Deflection is related to structural health rather than the span. Deflection values from SAP analysis is always less than the deflections measured by RTS. It means that the physical deflection due to dead load has exceeds the theoretical deflection.

5.2 *Deflection vs. Span Ratio*

Deflection to span ratio is an indicator to bridge health. For comparison, three railway bridges are considered here. Those Railway bridges were Hardinge bridge (span 105.18m), Gorai bridge (span 57m), Atari bridge (span 47.56m). The deflection vs. span, (Δ÷L) ratio from SAP analysis is shown in Figure 7 and & Figure 8 represents the same from RTS survey. Deflection of railway bridges due to dead load is less than the bailey bridges. It is evident from the Figure 7 & 8 that (Δ÷L) ratio is lower in case of railway bridges despite railway bridges have longer span. On the other hand, bailey bridges have higher (Δ÷L) ratio despite bailey bridges have shorter span. It comes out from the analysis that bailey bridges are less stiff than the railway bridges.

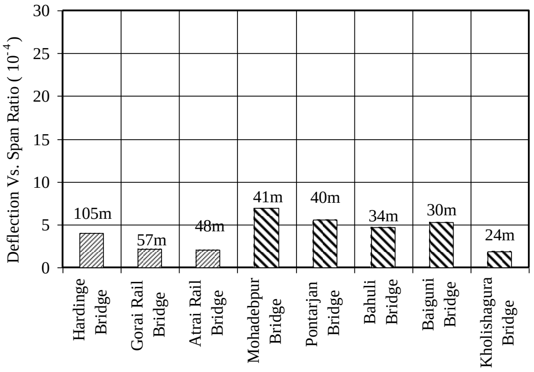

Figure 7. Comparison of deflection vs. span ratio for railway and bailey bridges by SAP results.

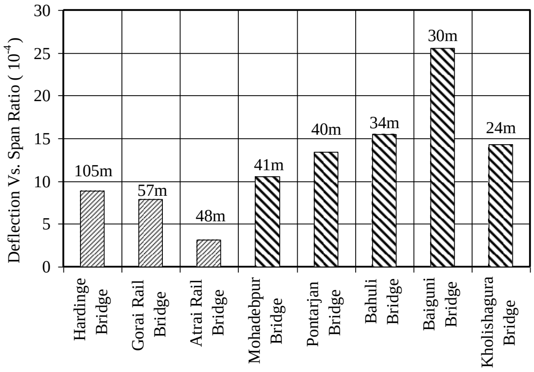

Figure 8. Comparison of deflection vs. span ratio for railway and bailey bridges by RTS results.

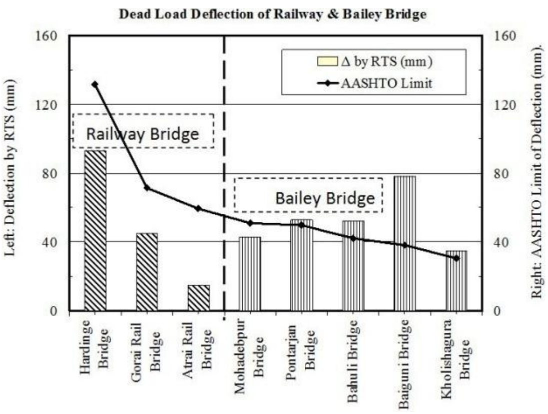

Figure 9. Observed deflection by RTS and AASHTO limit of deflection for railway and bailey bridges.

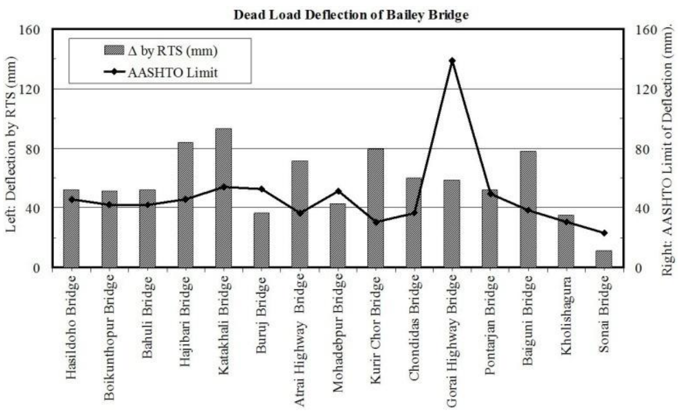

Figure 10. Observed deflection by RTS and AASHTO limit of deflection for bailey bridges

5.3 *Safe Deflection Limit*

The maximum 1/800 of the span length for general vehicular bridges and 1/1000 of the span length for vehicular bridges with pedestrian traffic are universally accepted criteria for the live load deflection limit. The RTS measurement of bridge deflection due to dead load showed the deflection of railway bridges are within the allowable deflection limit (Figure 9).

Most of the bailey bridges exceed the maximum permissible deflection limit for dead load only. Addition of live load will put extra stress and make bridges more vulnerable. Observed maximum deflection for Katakhali Bridge (span 43.29m) was 93mm where as the AASHTO maximum deflection is of 54.12 mm only. Out of 13 bailey bridges, 10 bridges exceeds safe deflection limit and are unsafe for vehicular use (Figure 10).

5.4 *Unsafe Bridges*

Table 2 provides a list of studied bailey bridges according to 'deflection to span ratio' in descending order. Short span bridges have higher 'deflection to span ratio' and more vulnerable. Based on the AASHTO limit of maximum deflection, Table 2 also provides a list of safe and unsafe bridges considering dead load only. Addition of live load will make all the bridges more susceptible to fail. Only three bridges, out of thirteen bailey bridges are found to be within the permissible deflection limit and it might not be safe if live loads are added.

Table 2. Safe and unsafe bridges according to deflection results by RTS (Due to dead load only).

No.	Bridge Name	Span, L (m)	Deflection Δ_{DL}, (mm)	AASHTO Limit (mm)	$\Delta \div L$	Remarks
1.	Kurir Chor Bridge	24.39	81	30.49	0.0033	Unsafe
2.	Baiguni Bridge	30.48	78	38.11	0.0026	Unsafe
3.	Hajibari Bridge	36.59	84	45.73	0.0023	Unsafe
4.	Katakhali Bridge	43.29	93	54.12	0.0021	Unsafe
5.	Chondidas Bridge	29.27	60	36.59	0.0020	Unsafe
6.	Bahuli Bridge	33.53	51	41.92	0.0016	Unsafe
7.	Boikunthopur Bridge	33.54	51	41.92	0.0015	Unsafe
8.	Kholishagura Bridge	24.39	36	30.49	0.0014	Unsafe
9.	Hasildoho Bridge	36.59	54	45.73	0.0014	Unsafe
10.	Pontarjan Bridge	39.63	54	49.54	0.0013	Unsafe
11.	Mohadebpur Bridge	41.15	42	51.07	0.0011	Safe
12.	Buruj Bridge	42.07	36	52.59	0.0009	Safe
13.	Sonai Bridge	18.29	12	22.87	0.0006	Safe

6 CONCLUSIONS

In this study, dead load was used to understand self-weight only. Live load analysis was skipped during the study as the bridges already become unsafe in dead load. The application of RTS and method used in this study is simple enough to conduct field survey for deflection study. RTS was used effectively to measure bridge deflection. RTS results for bridge deflection can be attained accurately, quickly and easily. It is useful for structural health monitoring of bridges, predict bridge health, reduce bridge failure and eventually lower the loss of lives and assets.

Results obtained from RTS and SAP analysis conversed and indicates that most of the studied bridges exceeds the permissible deflection limit and hence unsafe to use. The maximum dead load deflection was 93mm for a span of 43.29m for Katakhali bridge. It forms the 'deflection to span' ratio as 0.0021. So, the 'deflection to span' ratio becomes 0.0021. Thus the bailey bridges have more than four times 'deflection to span' ratio than the other type bridges. Deflections are more related to bridge health rather than other parameters like span length. Aged and faulty bridges have more deflections even with short span and healthy bridges have less deflection even with long span.

Failure of bailey bridges in Bangladesh is quite frequent. Overloading is the main reason for collapse of bailey bridges. Apart from the case of overloading, one unseen reason is uncovered in this paper. Due to lack of repair, maintenance and supervision, most of the bailey bridges suffer from high rate of deflection. A bridge failure causes huge loss of life, assets and interrupts mobility. Inspection of bridges and regular data observations are essential for safe, durable and smooth bridge operation.

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