MONITORING BRIDGE DEFLECTION BY TOTAL STATION

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ABSTRACT
Bridges are an important part of road and transportation systems and deflection is an important index to evaluate the structural health of bridges. In this study, a method of measuring vertical bridge deflection by Refractorless Total Station (RTS) is introduced. A calibrated target board is fixed on the mid-span of the bridge girder and cross hair of the target board was observed remotely by RTS to assess the vertical deflection while passing railway locomotives and coaches. The study was conducted on major Railway Bridges in Bangladesh. It includes Hardinge Bridge, Bhairab Bazar Bridge, Akhaura Bridge, Ghorashal Bridge, Ghatina Bridge and Arani Bridge. The least count of the RTS was 1/8" (3.17mm) and monitored deflection ranges from 1/8" to 7/8" (3.17mm to 22.22mm) for all bridges. The results from the study reveal that the methods to monitor vertical deflection of bridges are quite simple, practical and reliable. It needs less manpower, time and has the potential to access bridge deflection with good accuracy.

Keywords: Total station; vertical deflection; target board

INTRODUCTION
Measurement of deflections of bridges because of dynamic and semi-static loads is essential for their design, function, and structural health (Brownjohn et al. 2010; Bardakis and Fardis 2011), but until recently it was a rather unsolved problem. Moreover, deflection is an important index for safety evaluation of bridges. A high rate of deflection indicates the materials is significantly displaced which may bend, warp or shift in response to the imposed 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. Now a day, monitoring bridge deflections is a challenge to the structural engineers.

There are some studies that report about major difficulty in testing bridges is the measurement of vertical deflections. Dial gauge, accelerometer, tiltmeter etc are traditional tools and methods to measure structural displacement and rotation. These tools must be installed, maintained, and frequently recalibrated to produce reliable results. The collected data from these tools need to be interpreted to obtain direct deflection results which in many cases is very complicated procedure and out of the control of the general structural engineers. The use of instruments such as mechanical dial gauges, linear potentiometers and linear variable differential transducers is usually not feasible. Access under a bridge structure is usually limited, which requires erecting temporary supports to mount the measurement instruments to the ground. Hence, a flexible surveying technique is needed to overcome these obstacles, and make the process of measurements easier and more accurate. These difficulties can be eliminated by using Refractorless Total Station (RTS), which offers the capability to measure the spatial coordinates of discrete points on a bridge without touching the structure.

Systematic measurements of deflections of bridges became possible with the invention of the Global Positioning System (GPS) (Roberts et al. 2004; Meng et al. 2007), on the condition that an unobstructed view of the horizon and of the satellites exists, which is not the case with various railway bridges in which the passing trains deform or even disrupt the satellite signal (Wieser and Brunner 2002). Stiros et. al. (2007) studied about the results of RTS monitoring of the Gorgopotamos Railway bridge in central Greece, a bridge over 100 years old with several openings of ~30m. This bridge was partly destroyed and rebuilt twice, and its dynamic behaviour is practically unknown. Their study focused on the apparent vertical displacements of a reflector set at the mid-span of an opening, where maximum displacement was expected, during the passage of trains. The objective of the present study is to measure the vertical deflection of railway bridges of Bangladesh with the use of RTS which can measure deflection accurate to 1/8" or 3.17mm. This monitoring system is much easier to set up and use, reducing labour and time. The system has almost no site restrictions. This paper discussed the implementation of RTS and contrasts its use to traditional load testing monitoring equipment. In this survey work, RTS is used with target board instead of prism.

METHODOLOGY

Vertical deflection of railway bridges was measured in three different methods. The study accepted deflection results of bridges only when three methods produce same result.

<u>Method 1: Observation of Target Board Only</u>

For measuring mid-span deflection the study used calibrated target board as appeared in Fig 1, 2 and 3.

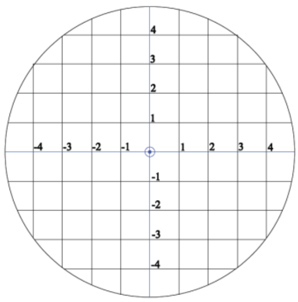

Fig 1: Calibrated Target Board
(Scale: 1 grid = 0.3in)

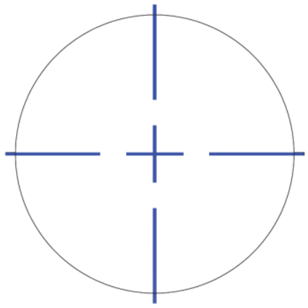

Fig 2: Cross hair of Total Station

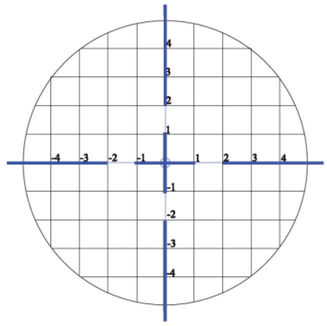

Fig 3: Cross hair of Total Station coincides with origin (0, 0) of Target Board at no Load

Calibrated target board (Fig. 1) was placed at mid-span (Fig. 4) of bridge and the cross hair (Fig. 2) of RTS was kept at origin (0, 0) of target board as like in Fig. 3 with no vehicular load (only dead load).

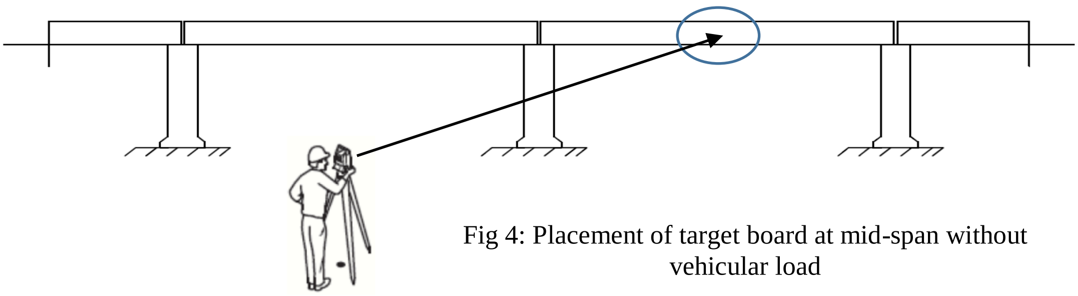

Fig 4: Placement of target board at mid-span without vehicular load

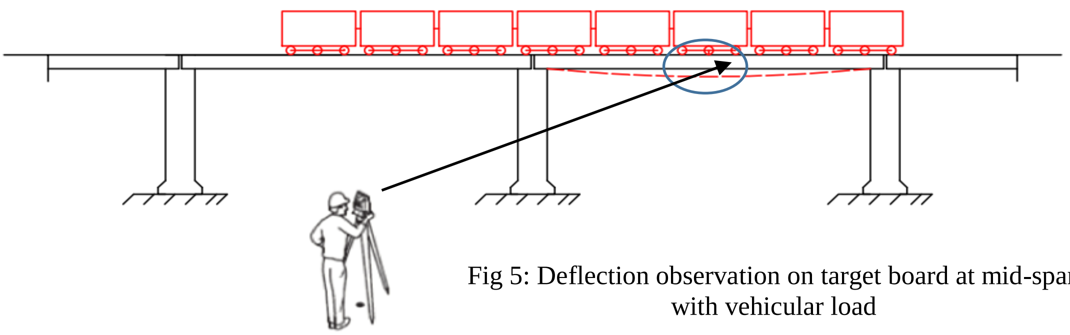

Fig 5: Deflection observation on target board at mid-span with vehicular load

Due to passing of passenger coaches, locomotives and oil tankers, bridges undergo vertical deflections and the target board kept at mid-span moves downward. It was remotely observed by the RTS and the real differences between the cross hair of RTS and target board (as in Fig 5, 6) is observed by operator.

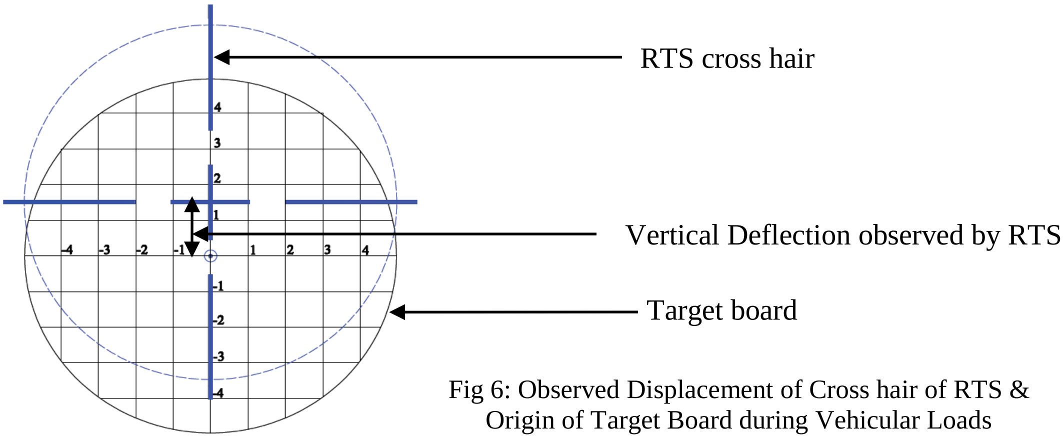

Fig 6: Observed Displacement of Cross hair of RTS & Origin of Target Board during Vehicular Loads

Method 2: Observation of LASER on the Target Board
The calibrated target board was kept on the mid-span of the bridge and LASER was released from RTS to pass through the origin of the target board during no vehicular load. Afterwards, at loaded condition, while train passes, LASER released and the intersecting points observed on the target board as appeared in Fig. 7. The position of LASER from the origin of target board is the deflection as shown in Fig. 7.

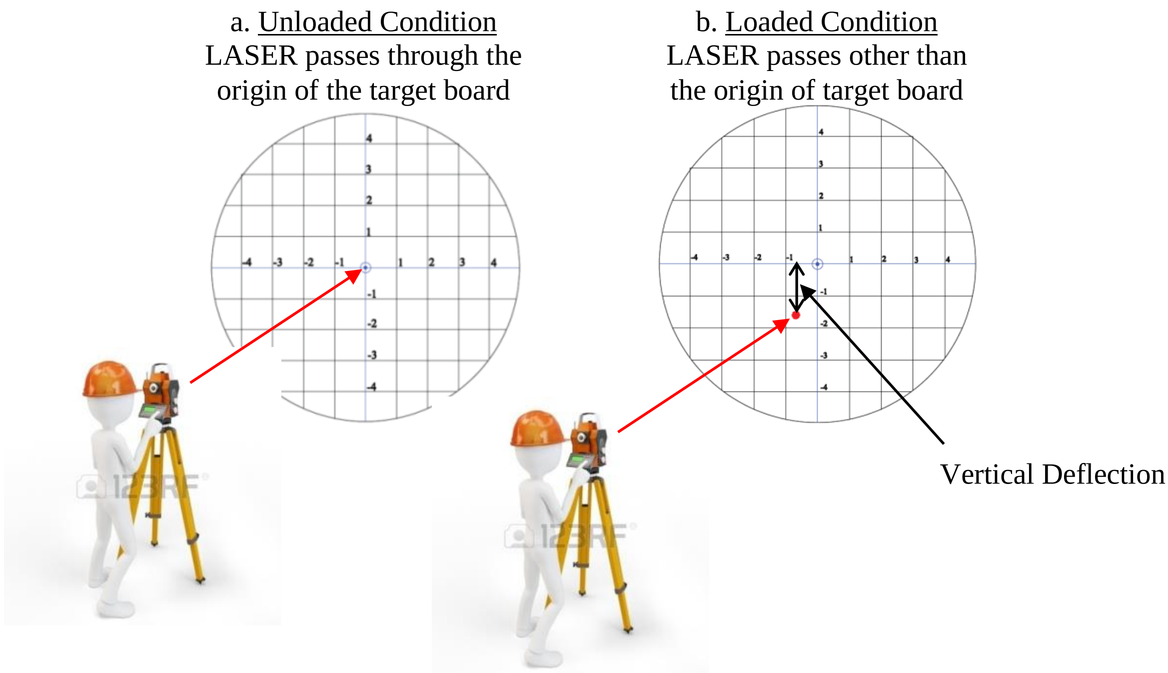

Fig 7: Observation of LASER Rays on the Target Board at Loaded & Unloaded Condition

Method 3: Missing Line Measurement (MLM) by Total Station
MLM means missing line measurement which is used in RTS to measure horizontal distance (HD), vertical distance (VD) and slope distance (SD). At the beginning of this measurement, the origin of target board and the centre of cross hair of RTS were kept at same line of sight at unloaded condition. Then, at loaded condition, while the origin of target board moves downward, the centre of cross hair of RTS again sighted to the origin (0, 0) of target board. This readjustment of line of sight of RTS gives the value of HD, VD and SD. The VD usually gives the vertical deflection of the studied bridge.

RESULTS AND DISCUSSIONS

In this study, six railway bridges were studied and the deflection results are presented in Table. 1.

Table 1: RTS Observed Deflection of Major Railway Bridges of Bangladesh

No.	Bridge Name	Span (ft)	Condition	Vertical Deflection (in)
1.	Hardinge Bridge	345' (105.18m)	For Locomotive	5/8" (15.88mm)
			For Passenger Coach	3/8" (9.53mm)
			For Oil Tanker	7/8" (22.22mm)
2.	Bairab bridge	335' (102.13m)	For Passenger Coach	3/4" (19.05mm)
3.	Ghatina bridge	206' (62.80m)	For Passenger Coach	3/8" (9.53mm)
4.	Arani bridge	54' (16.46m)	For Passenger Coach	1/8" (3.17mm)
5.	Akhaura bridge	105' (32.01m)	For Passenger Coach	5/8" (15.88mm)
6.	Ghorashal bridge	104' (31.70m)	For Passenger Coach	1/2" (12.7mm)

The results of field survey lead to the following conclusions:

1. AASHTO Standard Specifications for Bridges (2002) states that, for simple or continuous spans, deflection due to service live loads shall not exceed 1/800 of the span for Railway Bridge. Vertical deflection of bridges varies with respect to span length. According to AASHTO specification, deflections of all studied bridges are within allowable limit.
2. In case of Hardinge bridge, deflection is comparatively less with respect to span length.
3. In case of Akhaura bridge, deflection is comparatively high with respect to span length.
4. Using target board with RTS gives good accuracy for the measurement of vertical deflection.

CONCLUSIONS

Use of RTS to monitor vertical deflection of major railway bridges is the concern of this paper. RTS has the potential to produce accurate results compared to the traditional deformation monitoring systems. Deflection estimation of major railway bridges in Bangladesh by three different measurement methods produce same vertical deflection results ranging from 3.17mm to 22.22mm. Thus, RTS measurements showed promising results and can be regarded as a powerful tool for monitoring bridge deflection.

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