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RESPONSE MEASUREMENT OF A COMPOSITE BRIDGE SUPERSTRUCTURE UNDER STATIC LIVE LOADS

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Abstract

Due to their strategic importance, bridges should be properly maintained so as to allow uninterrupted flow of traffic during their design lives. For prompt maintenance, bridges shall be monitored periodically or continuously so that any flaws or defects can be identified and taken care of with cost-efficient solutions. Ayub Bridge, on Karakorum Highway, carries all types of traffic between Pakistan and China. The reinforced concrete deck of the bridge in the vicinity of the joints has deteriorated significantly over the 25-year life span of the bridge with different repairs applied to the bridge only helping for a short period of time. It was decided by the National Highway Authority of Pakistan to replace only the old, non-composite, reinforced, concrete deck with a new composite one. This paper covers the instrumentation of one span of this bridge with newly-laid composite concrete deck with strain gages and displacement transducers, and the measurement of its response to gradually increasing static live loads in the form of loaded trucks. The response of the bridge system with the new composite concrete deck is compared with that of the bridge system with the old non-composite concrete deck covered in a separate paper by Ali et al[1]. It was concluded from the bridge responses that stiffness of the bridge superstructure is significantly increased and load sharing in the transverse direction is greatly improved by the introduction of composite action between the longitudinal steel girders and the reinforced concrete deck.

INTRODUCTION

Bridges are critical components of a transportation system and play a key role in the development of a nation. Due to their strategic importance, they shall be properly maintained so as to allow uninterrupted flow of traffic during their design lives. For prompt maintenance, bridges shall be monitored periodically or continuously so that any flaws or defects can be identified at a preliminary stage so that they can be taken care of with an easy and cost-efficient manner. Keeping in mind the great costs incurred on the construction and maintenance of bridges, and the limited resources of the national exchequer, bridges enjoy greater importance. Karakorum Highway links Pakistan with China and carries all types of traffic. Ayub bridge, built in the late seventies, is located between a portion of this highway between Havelian and Abbottabad. It is a federal bridge and hence operated and maintained by the

National Highway Authority (NHA) of Pakistan. The reinforced concrete deck of the bridge in the vicinity of the joints has deteriorated significantly over the 25-year life span of the bridge with different repairs applied to bridge joints only helping for a short period of time. It was decided by the National Highway Authority to replace only the old, non-composite, reinforced, concrete deck with a new composite one. One span of the bridge with old reinforced concrete deck was selected, instrumented, and its response was determined for live loads in the form of loaded trucks[1]. The old, non-composite, reinforced, concrete deck of the bridge was replaced with a new composite deck. The composite action between the concrete deck and the steel girder was achieved by welding channel sections on the top of the girders and embedding them in the concrete deck. This paper covers the response of the composite bridge superstructure for static live loads applied to the selected span of the bridge in the form of loaded trucks.

BRIDGE DETAILS

Ayub bridge spans over a length of 272.80 meters and comprises eight simple spans. The two end spans are 17 meters each and consists of concrete deck supported by reinforced concrete T-beams. The intermediate six spans are 39.80 meters each and comprise the composite system of a concrete deck and steel longitudinal girders. It is a two-lane bridge with an overall width of 8.89 meters. The longitudinal girders are not uniform in cross-section with the two exterior girders and are 2,438 millimeters deep, while the remaining three intermediate girders, hereafter called stringers, are 815 millimeters deep. Concrete deck panels are transferring the dead and live loads to the longitudinal elements through one-way structural action. There are six floor beams which transfer the loads from intermediate stingers to the exterior girders. The loads of the exterior girders are transfer red to the substructure through pin and rocker supports.

(a) (b)

Figure 1. Ayub bridge: (a) global view, (b) underside view showing damages at joints

Exterior girders are built-up plate girders while stringers and floor beams are hot-rolled sections. The composite deck is 8 inches thick and overlain by 2 inches of sacrificial wearing course. Cross-sections of different bridge components are shown in Figure 2.

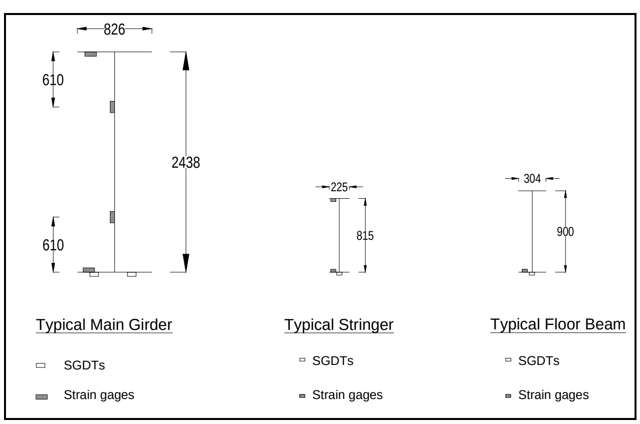


Figure 2. Cross-sectional dimensions of Main Girders, Stingers, and Floor Beams (all dimensions in mm)

TEST METHODOLOGY

As per requirements of the NHA, the selected span of Ayub Bridge was instrumented with strain gages and displacement transducers at the mid-span only and its response was measured for static live loads in the form of loaded trucks each weighing 15 tonnes. The objectives of the tests were to quantitatively measure the response of this bridge with the old, non-composite deck and the new composite deck and report improvements in strength, stiffness, and load distribution of the bridge system in the presence of the new composite deck. The methodology adopted to obtain the afore-mentioned objectives of the load test is given as under:

- Site Preparation
- Instrumentation of Bridge Components
- Test Loads and Loading Sequence
- Performance of Load Tests
- Bridge Response with New Composite Deck
- Comparison of Bridge Responses and Conclusions

The forthcoming paragraphs give detailed information about all phases of this load test program.

SITE PREPARATION

The span of the Ayub Bridge, which was subjected to a load test, previously with the old non-composite deck was subjected to the same loads again, after the new composite deck was in place. The selected span of the bridge was marked with the help of paint spray at mid-span and at regular intervals of 5 meters all along the span. The span was also marked at 1.83 meters from the support to position the trucks for maximum shear at the span.

A rigid space structure of steel pipes was erected beneath the bridge deck to support a horizontal plate form. The plate form was meant to provide a horizontal surface for the movement of testing personnel and to facilitate instrumentation of various components of the bridge system. Once the horizontal plate form was in place, detailed measurements of all bridge components were taken using steel tape. As per requirements of the NHA, only mid-span sections of exterior girders, stringers, floor beams, and all concrete deck panels of the selected span were marked and prepared for instrumentation. Site preparation also involved arrangement for a stable source of electric power supply for data acquisition system and a short-range wireless system for easy communication between the testing staff working below and above the deck.

INSTRUMENTATION OF BRIDGE COMPONENTS

In the load test of Ayub Bridge, strain gages and strain-gage based displacement transducers were used to measure strains and deflections induced at various locations of the bridge system due to the application of static loads. Rust, dust, and grease was removed from the locations of instrumentation with the help of brush and cloths. Sand paper was utilized to expose the actual surfaces of the structural component used to be instrumented. Cyanoacrylate was used as an adhesive to bond strain gages to the selected locations. The strain gage was carefully placed in the desired position and sufficient time was allowed for the curing of the adhesive at field temperature and thump pressure. Strain gage was installed in such a way to eliminate entrapment of air bubbles between the backing material of strain gage and the surface of the bridge.

Four strain gages were installed on each exterior girder to capture the strain gradient across the depth of the girder. Two of them were installed on the underside of the top and bottom flanges while the remaining two were installed on the web at distances of 610 mm from both flanges. Strain gages were also installed on the underside of the top and bottom of all of the flanges, stringers, and floor beams. A strain gage was also installed on the mid-span of the concrete deck panels. Three-element strain gage rosettes were also installed at mid-depths of the exterior girders, stringers, and floor beams to determine strain field at close to end-support. Electrical resistance strain gages of 20-mm grid length and 120-Ω resistance were used to instrument the selected components of the bridge system.

Displacement transducers were also used to determine mid-span deflection of exterior girders, stringers, floor beams and all concrete deck panels. To measure a more representative value of the mid-span deflection of the exterior girder, three displacement transducers were installed beneath each girder. All the displacement transducers were of 50 millimeters capacity.

Data acquisition system utilized in this test was Kyowa's UCAM-70A Data Logger with built-in capacity of 30 channels of strain gages or strain-gage based transducers. An extension unit with a capacity of 50 channels was also used because the total number of strain gages and transducers exceeded the capacity of the Data Logger. It can easily be used in a static test as the maximum scanning frequency of this system was 20 channels per second. All the strain gages and displacement transducers were connected to the Data Logger placed on the plate form beneath the bridge deck. Having entered the relevant setting parameters, internal checks of stability and insulation were performed and it was found that all of the devices were performing in a satisfactory manner. For the load test and symmetrical loading of the bridge, a total of 35 channels of Data Logger were utilized comprising 14 channels for displacement transducers and 21 channels for strain gages. For loading causing maximum shear in the system, a total of 20 strain gages were connected to the channels of the Data Logger.

TEST LOADS AND LOADING SEQUENCE

As per requirements of the NHA, the selected span of the bridge shall be loaded with a maximum of 6 trucks each weighing 15 tonnes. Two–axle Bedford trucks, typical of Pakistani roads, were selected for this load test. The distance between front and rear axles of all trucks was measured and found to be 4,420 mm. The distance between wheels of the same axle was determined to be 1,830 mm. Before the test, every truck was loaded with a sufficient amount of locally available gravel to obtain a combined weight of 15 tonnes with a tolerance of ±1%. During the weighing process at computerized weighing station, the gross weight of each truck was recorded along with the weight of individual axles as shown in Table 1. The gross weights and the weight distribution for the selected trucks are approximately equal to those trucks which were used in the load test of the bridge with the old deck.

On the site, all trucks were numbered so that their placement can be facilitated. Prior to the conduction of the test, the positions of the trucks were determined corresponding to gradually increasing and decreasing loadings of the selected span. In doing so, distances of 4,420 mm and 1,219 mm were maintained during the test between two trucks in the same lane and adjacent lanes respectively. The former distance was finalized for reasons of ease of placement of the trucks on the selected span. For precise positioning of the trucks, additional markings were done on the bridge deck.

Table 1. Gross weights and weight distributions for the selected trucks

Truck No.	Gross Weight (Tonnes)	Front Axle Weight (Tonnes)	Rear Axle Weight (Tonnes)
1	15.120	4.070	11.050
2	14.935	5.130	9.805
3	15.040	4.550	10.490
4	15.105	4.430	10.675
5	14.990	3.940	11.050
6	15.140	5.430	9.710

PERFORMING OF LOAD TESTS

Prior to the commencement of the load test, the selected span of the bridge was closed for all vehicles and personnel and the Data Logger was initialized. Throughout the load test, five sets of strain and deflection readings were taken five minutes after every loading or unloading operation of the selected span of the bridge so that any dynamic effects could be eliminated. The loading and unloading of the selected span of the bridge amounted to a total of 12 operations. In the end, five sets of readings were taken five minutes after the removal of the last truck from the selected span. All the readings were measured after turning off the engine of the truck and withdrawing of all personnel from the selected span. Figure 3 shows the six positions of trucks corresponding to the loading of the selected span.

The selected bridge was also loaded in a symmetrical manner with three and six trucks so that the validity of the load test and the response measurement could be established. The selected span was also loaded twice to prove Maxwell's theorem of reciprocal displacements. Data acquisition systems were initialized before the application of these loads.

In the end, the selected span of the bridge was loaded with three and six trucks placed close to the end support so that the strain fields in exterior girders, stringers, floor beams and exterior girder bearing stiffeners could be obtained corresponding to the maximum shear.

BRIDGE RESPONSE WITH NEW COMPOSITE DECK

After the completion of the load test, the measured responses of the bridge components were processed and graphs were developed to better understand the behaviour of the bridge system. The response of the bridge system as a whole and of each individual component is discussed in the forthcoming paragraphs.

During the test, the distance from the face of the curb to the centerline of the truck wheels was maintained at 610 mm while the distance between the trucks in adjacent lanes was kept at 1,219 mm. The loads on the selected span were closer in the transverse direction to the east side of the bridge. This proximity was also reflected in the measured response of the exterior girders and shown in Figure 5. The increase in mid-span deflection was not proportional to the corresponding increase in loads, because as the total loads in the selected span were increased, they were placed away from the center of the span. This trend is also shown in the measured responses of three stringers shown in Figure 6. Greater portion of the loads taken by the east stringer resulted in larger deflection.

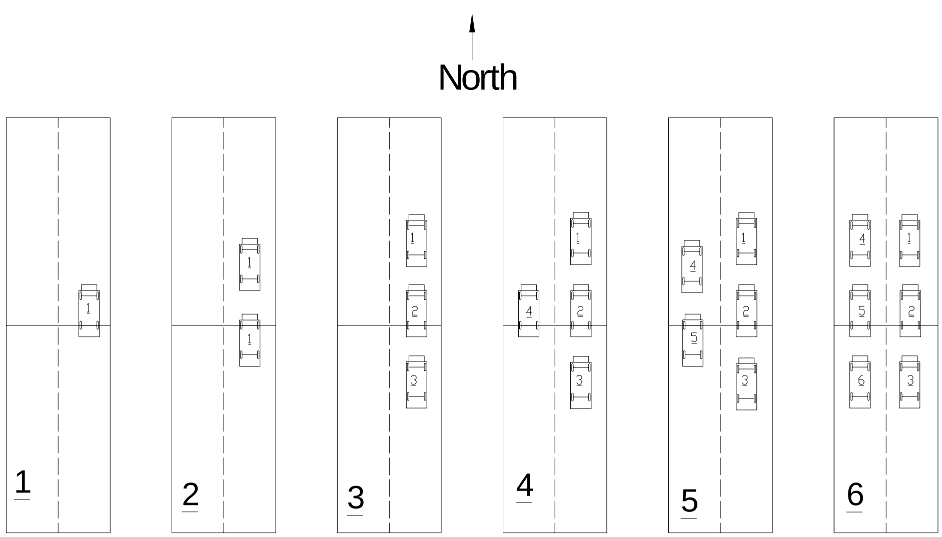


Figure 3. Sequence of loading and unloading followed during the load test

Figure 4. Loadings of the selected span for (1 and 2) Validation of Maxwell's Reciprocal Theorem, (3) Symmetrical loading, and (4) Maximum shear at end-span

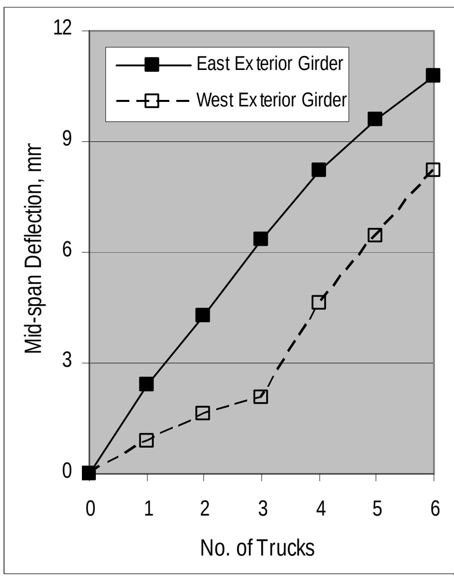


Figure 5. Response of exterior girders

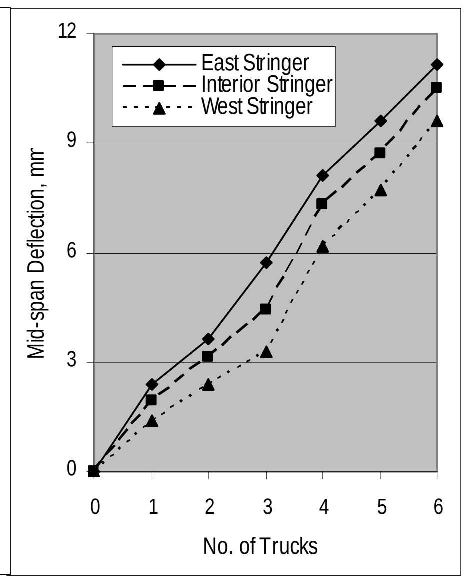
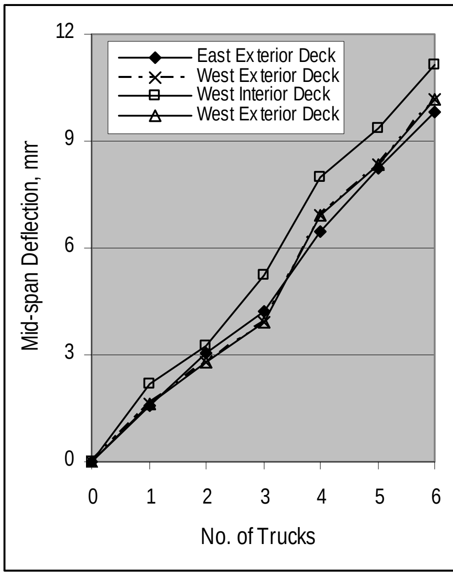


Figure 6. Response of stringers

The downward deflections in all deck panels have increased in a relatively uniform manner for the whole range of truck loads as shown in Figure 7. The deflection in the floor beam increased sharply for loading of the second lane as these loads were close to the mid-span of the floor beam.



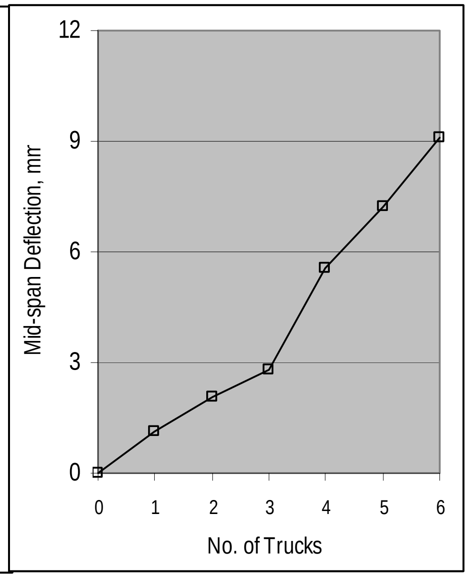


Figure 7. Response of concrete decks

Figure 8. Response of floor beam

The deflection profile of the centerline of the bridge system in the transverse direction was shown in Figure 9. The east side of the bridge was deflected more due to the proximity of the loads.

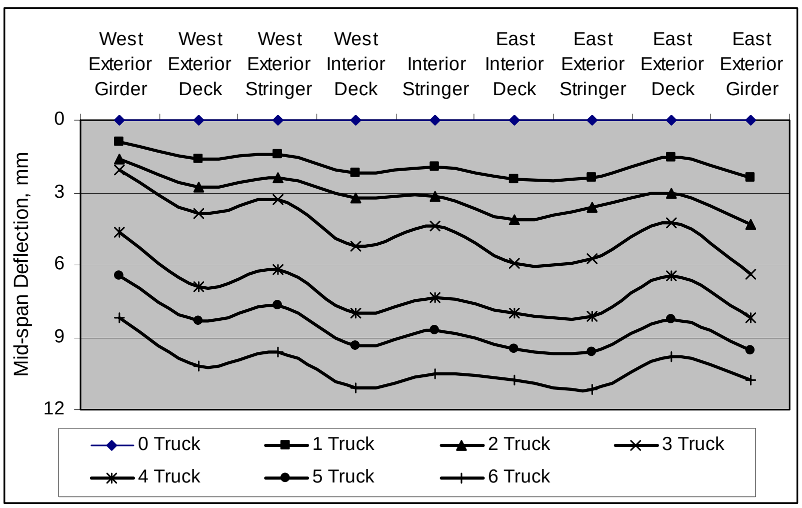


Figure 9. Transverse profile of deflected bridge system

Strain profile of the east girder was developed using the strain data obtained from four strain gages attached to the exterior girders and shown in Figure 10. Neutral axis of the section shifted for the whole range of the loads to the top flange, clearly demonstrating the presence of composite action between steel girder and concrete deck.

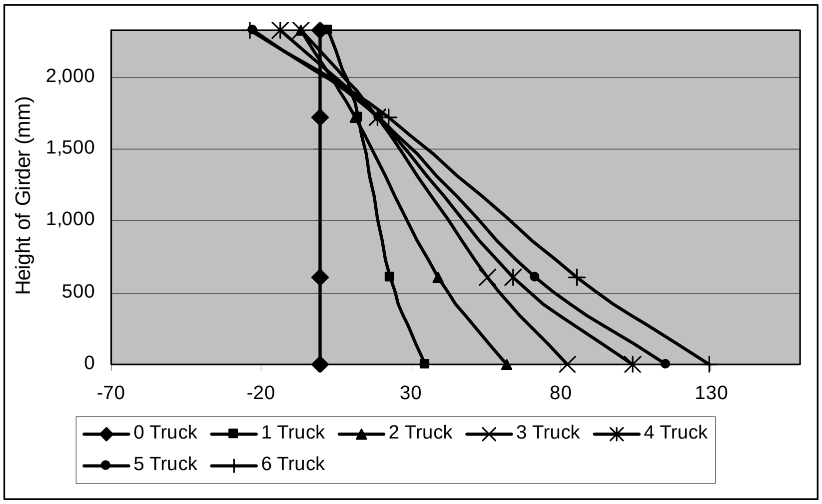


Figure 10. Strain gradient in east exterior girder

To validate the accuracy and reliability of the test set-up and data measurement, all of the trucks were placed symmetrical about the mid-span of the instrumented span and the responses of the bridge components were obtained. Figure 11 clearly prove the accuracy and reliability of the test set-up and the data measurement.

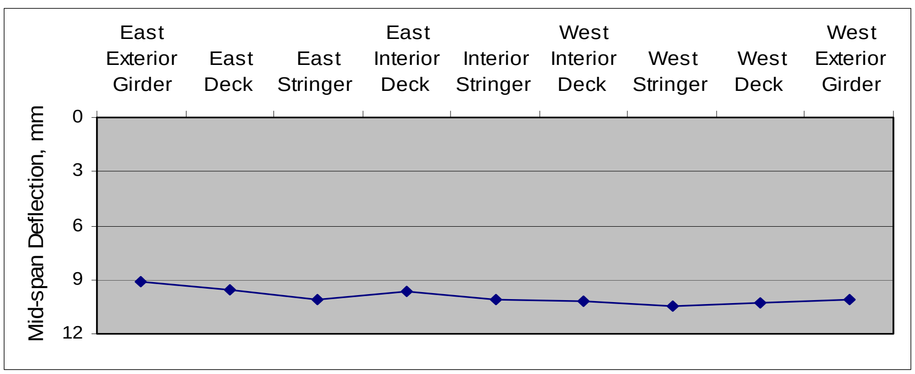


Figure 11. Response of bridge components for symmetrical loading

Using Maxwell's law of reciprocal displacements, additional tests were also done to validate and calibrate the test set-up and data measurement. In doing so, trucks 1, 2, and 3 were first placed on the east side and then on the west side of the bridge and the response of the bridge components were obtained for both loads and shown in Figure 12.

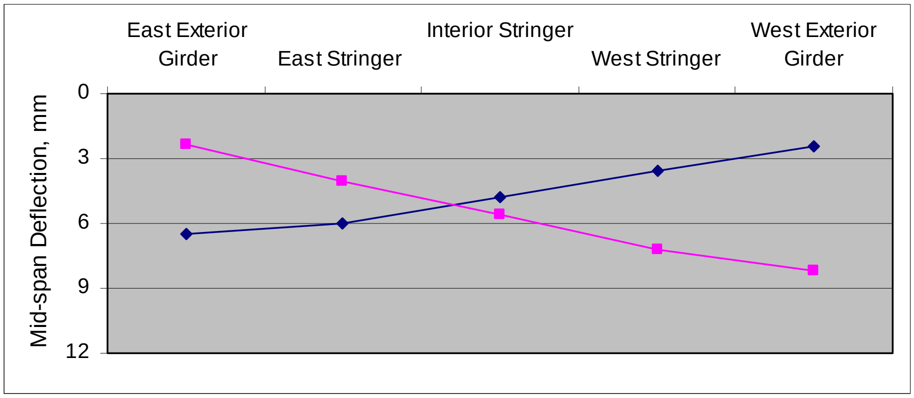


Figure 12. Response of bridge components for calibration of test set-up by using Maxwell's law

COMPARISON OF BRIDGE RESPONSES AND CONCLUSIONS

The measured response of the bridge with the new deck was analyzed and compared with the response of the bridge with the old deck and the following conclusions were drawn:

- The bridge response was found to be more rationale with the new concrete deck than with the old one. With the new deck, the east side of the bridge deflected more than the west side because loading was closer to the east side. With the old deck, the west side of the bridge deflected more than the east side although the loading was closer to the east side.
- The maximum deflection of the longitudinal girders and stringers for the six loaded trucks was 11.145 mm with new deck and 17.204 mm with the old deck. Likewise, the minimum deflection of the longitudinal girders and stringers for six loaded trucks was 8.396 mm with the new deck and 11.263 mm with the old deck[1].
- The girders and stringers deflected in a more uniform manner with the new deck than with the old deck, showing greatly improved load sharing between the girders and stringers in the transverse direction.
- The maximum deflection of the floor beam at the mid-span of the bridge for the six loaded trucks was 9.110 mm with the new deck and 15.520 mm with the old deck[1].
- The maximum deflection of the deck panels at the mid-span of the bridge for six loaded trucks is 11.118 mm with new deck and 16.149 mm with the old deck. Likewise, the minimum deflection of the deck panels at the mid-span of the bridge for the six loaded trucks was 9.801 mm with the new deck and 13.007 mm with the old deck[1].
- The deck panels at the mid-span of the bridge deflected in a more uniform manner with the new deck than with the old deck, showing improvement in the load sharing between the deck panels in the transverse direction.
- These improvements in behavior might be attributed to the following::
  - New concrete deck
  - Presence of composite action between girder and deck, ensured through mechanical shear connectors (channel sections) welded to the top of the girder flanges
  - Presence of one segment deck i.e., the new deck for one span was cast in a single segment while the old deck was fabricated in four segments.

REFRENCES

1. Ali, S.M., Khan, A.N., Razzaq, Z., Hussain, Z., and Naseer, A. Response Evaluation of Prototype Noncomposite I-beam Bridge under Static Live Load Test, Paper submitted to The 3rd International Conference on Structural Health Monitoring of Intelligent Infrastructure, Vancouver, Canada, November 14-16, 2007.