Structural Health Monitoring Of Bridges

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This paper mainly aims at the topic of Structural Health monitoring of bridges using Sensor Technology, which can be used to obtain various parameters of the bridge. The paper describes the health monitoring for 5 Spans of Vishakhapatnam Port Trust Bridge. The structure has been monitored to obtain its Deflection, Natural frequency, Lateral and Longitudinal Displacement and measurement to fcracks for its Static as well as Dynamic Loading.

Introduction

Bridges have always been the most pivotal part of the civil infrastructure. Many of our bridges have exceeded their designed life, which means the cost for its repairs and maintenance cost will be quite significant. To ensure and curb the economic investment Structural Health monitoring of bridges is of prime importance. Ithelps us to assess the Structural Integrity of structure accurately, which is not possible through visual inspection. Deflection, Strain, Natural Frequency and Lateral as well as Longitudinal Displacements are the important parameters, which should be monitored in order to assess the structural integrity of the bridge.

Case Study: Vishakhapatnam Port Trust Bridge

This Flyover, located in Vishakhapatnam, connects the port area and Airport to Vishakhapatnam city and NH-5. The length of this flyover is approximately 1.2 km. This flyover bridge is constructed on pile foundation, having Reinforced concrete piers.The super structure consists of RCC girders with composite RCC deck slab. The super structure sare resting on elastomeric bearings. The bridge was constructed about 15 years ago.

There was a little deterioration observed in structural members and bearings. All spans are deviated longitudinally from their original positions and different gaps were found between them. The increasein gap at a few locations is huge and detrimental to both traffic and health of girders. The elastomeric bearings are also found in very deformed and bad shape. Inclined and vertical cracks were also found in the girder.

As the condition of bridge is not good and multiple defects were found, it was decided to perform instrumentation and load tests to quantify the defects and distress precisely. Following tests were performed accordingly and analyses were done.

1. Static Load Test
2. Vibration Analysis
3. Breaking Load Test
4. Crack Width Measurement
5. Measurement Of Movement And Inclination Of Girders

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Visual Observation

The whole bridge was inspected visually. It is found that thecondition of expansion joints is not good. There are huge gaps between expansion joints and the joints have even got opened despite the filler material. This has initiated the hammer ingaction of vehicles which are further worsening the condition of joints. The impact of vehicles while passing the gap canbe easily felt. These gaps are created due to random longitudinal movements of the girders.

***Fig.1:* Vishakhapatnam Port Trust Bridge**

***Fig.2:* Steel Plate Connection between Two Girders**

***Fig.3:* Condition Of Expansion Joint**

The elastomeric bearings are found to be in bad shape and condition. Due to movement of longitudinal girders and severe vehicularimpact, the bearings got severely distorted and dislodged from their original position. The present conditions of all bearings are critical and need replacement.The life of elastomeric bearings is15years and the existing bearings are13 years old. There are cracks in longitudinal girders mainly near joints. These are inclined as well as vertical cracks. As the expansion joint was increased, the bearing got deteriorated and cracks developed ingirders due to development of additional loads. The girders were tied to each other by using steel plates.

Structural Health Monitoring Of Bridge

The Bridge was monitored to find out its Deflection, Natural Frequency, CrackWidth, and Braking Load Test and to find out measurement of movement along with inclination of girders of 5 spans of Vishakhapatnam Port Trust Bridge.

Static load testing and Dynamic load testing were performed to know the behaviour of girders in flexure under live loads. Six loaded trucks of 22 tonnes each were used to perform the loadtest. Axle load distribution and load configuration of loaded test trucks were used for static loading. They were placed behind each other in three lanes at the centre of the deck for each span.

Table1: Vertical Deflection at Mid of Girders for Span 63-64

Sr. No.	Location	Initial Reading	Final Reading	Vertical Deflection In mm
1	G1	18.51	22.75	4.24
2	G2	20.12	23.48	3.36
3	G3	13.56	17.14	3.58
Vertical Deflection for one span				

Deflection Measurement: The Mid Span Deflections were takenby installing the LVDTs at the mid of Girders. Draw wire arrangement were used to connect the displacement sensors to the soffit of the girder.

Natural Frequency Measurement

Fig.5: Linear Potentiometer

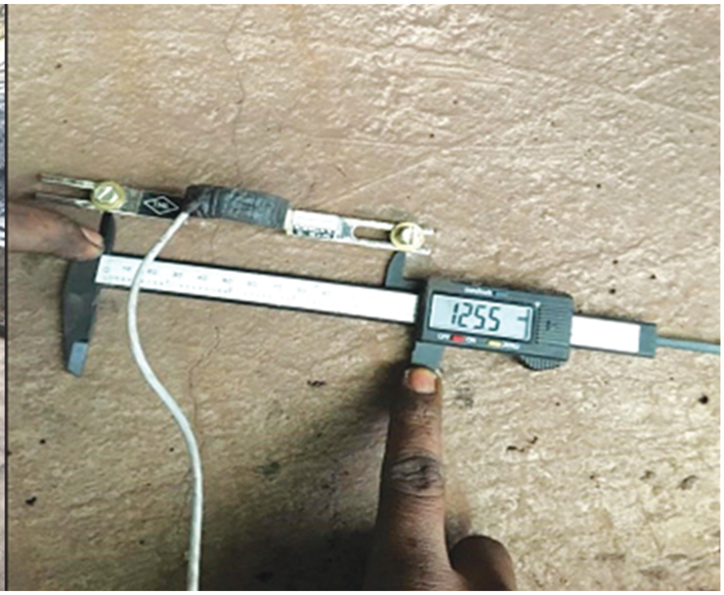

Fig.6: Omega Sensor and Vernier Calliper

Natural frequencies of the RCC girders and deck were measured by installing accelero meter on the deck. The accelerometer was installed at the bottom of the girders.pecific sensitivity and the frequency range of the accelero meter used at site are 9.863 and 0.3 Hz to18k Hz respectively.The deck was excited by getting a vehicle passed over the deck.The response under free vibration was measured in time domain. The natural frequencies of girders are in the range of 4.411Hz to 4.612 Hz.

Table 2 : Natural Frequency Measurements

SpanNo.	62-63	63-64	69-70	70-71	71-71
Natural frequency in Hz	4.602	4.587	4.411	4.596	4.612

Crack Width Measurement

In this test, the increase in width the existing cracks were measured.The activeness of the cracks was established measuring the increment of width by performing load tests. All cracks were found active. Anomega type displacement transducer (crack width sensor) was mounted across the crack. It is a strain-gauge-based-transducers, which can measure minute displacements. Studs for each transducer were fixed at predefined locations. These transducers were wired in a full bridge configuration. Initial readings were taken before loading of the bridge. Final readings were noted after two hours of loading to determine the increase in crack width under load.The increase in width is in the range of 0.6 mm to 0.9 mm as measured during static load tests.

Table 3 : Crack Width Measurement in Static Load Test

Spans No.	Girder	Crack Width Reading		Increase in Crack Width in mm
		Before Loading	After Loading	
63-64	G2	85.8	86.7	0.9
70-71	G2	125.5	126.1	0.6

Fig.7: Placing of Inclinometer

Measurement of Girder Inclination

Adigital magnetic in clino meter with an accuracy of 0.05 degrees was used to study the inclination of girders before and after the Static Load Test. Inclino meters were mounted on a metal surface, which was bonded to the girder with aproper adhesive andsealing compound. Final readings were noted after two hours of loading to find out if there was any inclination of the girder. Maximum inclination observed was 0.6 Deg.

Braking Load Test

During inspection it was found that all girders are displaced longitudinally from their original position creating gaps in expansion joints. Some gaps are so huge that it can be easily noticed from to pas the gaps are opened with filler material.

Table 4 : Inclination of Girders in Static Load Test

Spans	Girder No.	Reading of Inclinometer		Inclination of Girders in Degree
		BeforeLoading	AfterLoading	
63-64	G1	87.7	87.75	0.05
	G4	1.05	1.35	0.3
70-71	G1	1.3	1.8	0.5
	G4	0.6	1.2	0.6

Table 5 : Girder Displacement Resting of Spans Restingon Pier 70 WhenBrake Applied on Span 69-70.

Sr. No.	Location	Initial Reading	Reading at Maximum Displacement	Maximum Displacement	Reading After Completion of Test	Net Displacement in mm
1	L1	10.3	11.26	0.96	10.74	0.44
2	L2	27.93	29.05	1.12	28.17	0.24
3	L3	32.23	33.26	1.03	32.53	0.31
4	L4	10.77	11.98	1.21	11.16	0.39
5	L5	9.38	10.03	0.65	9.96	0.07
6	L6	27.39	28.23	0.84	27.10	0.58
7	L7	25.29	26.42	1.13	25.51	0.22
8	L8	10.47	9.96	0.51	10.13	0.34

Observations

1. It was found by visual inspection that the condition of expansion joints is not good.Huge gaps between expansion joints and the joints have got opened despite the filler material.
2. This has in itiated the hammer ingaction of vehicles, which are further worsening the condition of joints.The impact of vehicles while passing the gap can easily be felt at the bridge site. These gaps are created due to random longitudinal movements of girders.
3. The maximum longitudinal and trans verse displacement measure dis 0.58 mm and 0.44 mm respectively. This indicates that dueto longitudinal braking forces of test vehicles, the girders got displaced slightly even after removal of loads.
4. The maximum deflection of 6 mm has been recorded at mid-span of the girder at the centre of span 69-70 where Linear Potentiometers were placed
5. The natural frequencies of the girders are in the range of 4.411 Hz to 4.612 Hz. There is very minor variation in natural frequencies, which indicate that the flexural stiffness of girders is almost similar.
6. The maximum in clination has been recorded as 0.6 degrees for girder G4 of span 70-71.
7. These opening are of considerable magnitude and are in the range of 0.6 mm to 0.9 mm.This indicates that these are active structural cracks and required to be repaired on priority.
8. Expansion joints were improper and got damaged, which need to be repaired as and where required.

***Fig.8:* Placing of Linear Potentiometer**

Case Study

TAXI Way at Mumbai International Airport Limited Dgc Engineering Pvt. Ltd. was awarded the contract by Larsen & Toubro Ltd. To carry out Instrumentation of N 1 taxi way inside Mumbai International Airport, which leads to take off Runway 09/27 and lies to North of Runway. Various departing air crafts use this Taxiway.

Mithi River crosses the Taxiway. Hence bridge across Mithi River has been constructed by A A Iinyear 2007.Certain Cracks had developed in the girders beneath the Taxiway, sodeflection and Straingauge tests were performed to find out the Deflection and strain on the object. Deflection was calculated by movement of linear potentio meters and strain was calculated by applying strain gauges to the object by a suitable adhesive, such as cyanoacrylate. As the object is deformed, the foil is deformed, causing its electrical resistance to change. This resistance change, usually measured using a Wheat stone bridge, is related to the strain by the quantity known as the gauge factor.

Fig 9: TaxiWay of MIAL

Structural Health Monitoring was carried out in the steps mentioned below :

A) Erection of scaf folding and Drilling of holes

Initially induction & assembly of scaffolding materials was provided for access to site to drill holes and to investigate as octagonal holes were drilled according to drawing provided for detail investigation and crack mapping of the box girders

Fig.10 : Erection of Scaffolding

Fig.11 : Drilling of Holes

B) Visual Inspection and Crack Mappin

- Extensive Visual Inspection was carried out and Crack mapping was performed to measure width and depth of the cracks using feel ergaugeand Crack width measurement card.
- Lots of cracks were observed inside the box girder and adetailed investigation was carried out.

Fig. 12: Crack Width Measurement Card

Fig.13: Feeler Gauge

Fig.14: Inspection of Box Girder

Fig. 15: Placing of Sensors

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C) Placement of Sensors and Arrangement of Data Acquisition System

- Linear potentiometers and strain gauges were mounted at various locations as provided in the drawing to carry out the deflection and straintest.
- CCTV cameras were mounted at a distance to record the flight Movement and its position of the Nose wheel.
- 27 Deflection and 27 strain sensors were mounted and all of them were connected by wire assembly, which were brought to a single point where National instrument sequipment were placed. The wires were plugged in the NIDAQ to acquire the desired reading of deflection and strain at various points.
- Over night Testing was performed to record deflections of heavy flights. Readings were recorded and later processed, and the signals were filtered to obtain the Actual deflection and strain at that point.

Fig. 16 : Sensor Inside the Box Girder

Fig. 17 : Linear Potentiometer

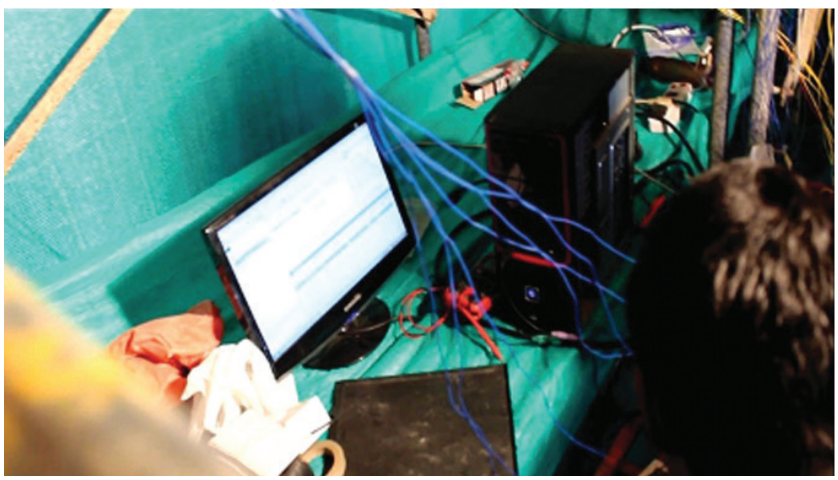

Fig. 18: NIDAQ

Conclusion

1. It was observed that the deflection and strain was more at the canti lever portion where the front wheel and rear wheels of aircraft passes through.
2. At some points very less deflection was observed.
3. At some points where deflection was more the graphrises and where no movement was observed the graphre mains still.
4. The Exercise was successfully completed under the super vision of L&T Engineers and TCPL engineers. Enough data as required by the third party appointed by MIAL has been collected and sent for further analysis.

Structural health monitoring of bridges gives the interpretation of current health of bridge. It gives pattern of bridge health degradation and through this we can also find the exactreas on for deterioration. So, we can rectify the health of bridge for only that and that much deterioration and can suggest best suitable Repair/Retro fitting solution. It leads to economical and reliable rehabilitation.

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