Structural Health Monitoring of Superstructure of Composite Bridge Model using Wired Sensors

Irshad M. Nadaf*, **Dr. Chandrakant B. Pol****

* M.Tech Student, Department of Applied Mechanics, Walchand College of Engineering, Sangli,
** Professor, Department of Applied Mechanics, Walchand College of Engineering, Sangli.

Abstract- Composite Bridges combines the advantages of both Concrete Bridges and Steel Bridges. Composite bridges are most suitable for construction of Medium Span Bridges. Major types of Highway Bridges are Medium Span Bridges. Structural assessment of these bridges can be done using SHM sensors. Structural Health Monitoring (SHM) is a new emerging technique used for structural condition assessment of various structures using attached or embedded sensors. In this paper, a Composite Bridge Model is constructed and the Structural Health Monitoring of this bridge model is done using the wired sensors. The response of these sensors is compared and validated using Simulation Model Analysis Results of same bridge prepared on Finite Element Method based software MIDAS Civil.

Index Terms- Composite Bridge, Deflectometer, Structural Health Monitoring (SHM), Simulation Model

I. INTRODUCTION

Many structures like cable stayed bridges and composite bridges are being constructed for development of country. In composite bridges, different types of materials are combined together to act as one like steel and concrete. Various advantages of concrete bridges are combined in composite bridges. So they are becoming more popular nowadays. The erection of steel girder is easy as compared to in-situ construction of concrete girder. Using steel girder in place of concrete girder gives lighter structure, which exert less self-weight on foundation and piers, which indirectly provide economy.

In composite bridges, concrete deck is fixed to steel girders with studs, due to this they act like one member. This increases the strength and reduces the deflection. The concrete deck in place of steel deck gives ease in construction and reduces vibrations. Composite bridges may have some disadvantages like binding problem, difficult execution and less durability. Composite bridges can be effectively adopted small and medium span bridges in place of concrete bridges and steel bridges.

The collapse of these bridges results in human as well as economical losses. For example, due to improper maintenance the foot over bridge in Mumbai is collapsed in March 2019, six people died and at least 30 are injured in that accident. Therefore, a proper maintenance of bridges is very important. Different methods are used for maintenance and monitoring of bridges. In last few years, the SHM technique has emerging rapidly in civil engineering field.

SHM is non-destructive method for structural evaluation, which uses various types of sensors embedded or attached to a structure. The sensors monitor the response of structure and analyze the characteristics of structure for estimating the seriousness of deterioration and finding consequences in terms of service life and collapse. SHM gives different management applications like durability improvement and extending service life by retrofitting. In a SHM System, data collected by various sensors is analyzed to capture response of structure or track down issues.

SHM system consists of Various Sensors, Data Acquisition, Structural Assessment and Decision Making. The data collected by sensors in mostly in form of electrical output. This output is digitalized and further processing in done by computer system which interprets the data and store it for potential diagnosis of a bridges condition. Final decision-making is done using the interpreted data and the standards available for responses. The SHM system gives accurate and fast results which can be useful in early detection of damage and the proper retrofitting technique can be effectively applied for strengthening the structure.

II. EXPERIMENTAL SETUP

a) Composite Bridge Model:

A two-lane composite bridge model is designed and constructed having 3 simply supported spans of 2-meter length and 1.2-meter width. Mild steel and RCC sections are used for the construction of the bridge. The components of the bridge are deck, longitudinal girders, cross girders, pier and pier base.

Fig.1: Composite Bridge Model

The deck is made up of steel sheet of 2mm thickness. For longitudinal girder, ISMB 200 section is used. Cross girders, pier and pier base are constructed as RCC sections with M20 concrete. Loading on bridge is given by using iron trolley whose weight varied from 1kN to 5kN.

The specifications of all components are given below-

1) Total Length of Bridge = 6 meters
2) Total Width of Bridge = 1.2 meters
3) Thickness of Deck = 2 mm
4) Length of I-Girders = 2 meters
5) Length of Crossbeams = 1.2 meters
6) Height of Circular Pier = 850 mm
7) Height of Pier Base = 200 mm

8) Vehicle Dimensions = 300 x 600 mm

Table 1: Specifications of Components of Bridge

Sr. No.	Component	Section (mm)	Material
1	Deck	1200×2000	Fe250
2	Steel I Girder	ISMB 200	Fe250
3	Cross Girder	100×150	M20
4	Circular Pier	Dia = 150	M20
5	Square Pier Base	300×300	M20

Fig.2: Components of Bridge

b)   Condition Assessment of bridge

Rebound Hammer Test and Ultrasonic Pulse Velocity Test are done for condition assessment of bridge using the guidelines given in IS 13311 Part 1 and Part 2. Ultrasonic Pulse Velocity test is used to check the quality of concrete members.

Fig.3: Ultrasonic Pulse Velocity Test

The results from the UPV Test shows that the concrete quality is good and there are no cracks or deterioration of concrete. The results are given in following table:

Table 2: Concrete Quality by Ultrasonic Pulse Velocity Test

Sr. No.	Components of Bridge	Ultrasonic Pulse Velocity (km/sec)	Concrete Quality
1	Cross-Girder	3.9	Good
2	Circular Pier	4.05	Good
3	Rectangular Pier Base	4.61	Excellent

Rebound Hammer Test is also performed to check the compressive strength of concrete members. Digital rebound hammer is used for testing which gives directly the value of compressive strength. The results show that the compressive strength of concrete is approx. same as the design strength and the results are given in table 3.

Fig.4: Rebound Hammer Test

Table 3: Compressive Strength by Rebound Hammer Test

Sr. No.	Components of Bridge	Compressive Strength (MPa)
1	Cross-Girder	20.25
2	Circular Pier	20.85
3	Rectangular Pier Base	25.43

c)   Deflectometer:

Deflectometer is a sensor used for measuring deflection of structural member. It is a wired sensor which can be attached externally to the structural member. At the bottom of sensor there is a magnet which is used for attachment. A metal node is there on the sensor which is placed at the point where deflection is to be found out.

Fig.5: Deflectometer Connected to Longitudinal Girder

d)   Connections

Maximum deflection occurs at the center of longitudinal girder so Deflectometer node is placed at the center of longitudinal girder. As longitudinal girder deflects under load the node on deflectometer also deflects. This node is connected with wire which gives electrical output to data interpreting elements and these elements are connected with computer. The software installed in computer directly gives the deflection values in microns ($\times 10^{-3}$ mm).

Fig.6: Data Interpreting Elements

e)   Loading on Bridge

Moving load is applied on the bridge using a metal trolley which is operated manually. The load is applied from 100 kg (1kN) to 500 kg (5kN) in successive increment of 100KG (1kN). The weight of trolley is 100 kg and other increments of 100 kg are done using 12 concrete cubes. The average weight of single concrete cube is 8.5 kg approximately.

Fig.7: Loading on Bridge

f)   Deflectometer Results

The deflection values are taken for all 5 loadings. The maximum deflection is recorded which occurred when the trolley came at center of longitudinal girder. The deflections for various loadings are as follows:

Table 4: Deflectometer Readings for Maximum Deflection

Moving Load (kN)	1	2	3	4	5
Max. Deflection (mm)	0.099	0.169	0.246	0.320	0.394

III.   FEM BASED MODELLING

All the dimensions of the above bridge model are measured and using that dimensions FEM based model is prepared on a finite element method (FEM) based software MIDAS Civil. MIDAS Civil software is specially used for the analysis and design of various bridges. The bridge model is prepared by using plate element for deck and beam element for other all components.
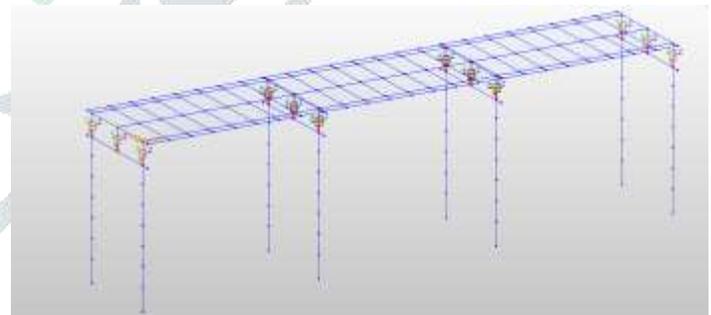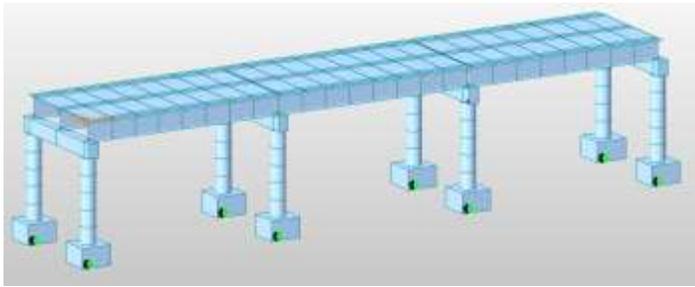

Fig.8: FEM based 1D Element (Beam) Bridge Model

Fig.9: FEM based Bridge Model with Sectional Properties

Comparison of Deflection

In MIDAS Civil special command is there to apply moving load. In that first lanes are defined, then the vehicle is defined manually as per the specifications of trolley. The moving load is applied in 5 vehicle cases i.e. 1kN, 2kN, 3kN, 4kN and 5kN. Then the analysis of bridge is done and it gives the deflection diagram shown in figure below.
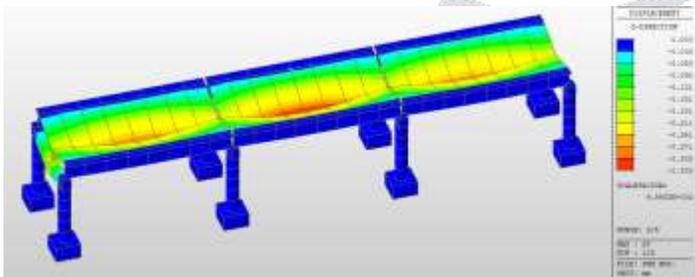

Fig.10: Deflection Diagram under Load of 5kN

As shown in above figure, the maximum deflection value of bridge is at the center of longitudinal girder. This value is noted down for all vehicle load cases are as follows:

Table 5: Simulation Model Results for Maximum Deflection

Moving Load (kN)	1	2	3	4	5
Max. Deflection (mm)	0.064	0.128	0.192	0.265	0.332

IV. COMPARISON OF RESULTS

The deflection results from deflectometer and software model are compared for various loads. It is seen that the deflectometer results are slightly greater than the FEM based model results. The comparison between two deflections with respect to load is given below.

Table 6: Deflection Comparison of Longitudinal Girder Bridge

Moving Load (Kg)	Midas Model Results (mm)	Deflectometer Readings (mm)
100	0.064	0.099
200	0.128	0.169
300	0.192	0.246
400	0.265	0.320
500	0.332	0.394

Graph 1: Comparison of Deflection Results

V. CONCLUSION AND FURURE SCOPE

a) Conclusions:

From the results obtained from the deflectometer and simulation model, the relation between the sensor and simulation model is determined. The conclusions made from the dissertation work are as follows:

1. From condition assessment of bridge model, it is found that the quality and strength of concrete member is good and as per design.
2. The maximum deflection occurs at the centre of central longitudinal girder & the maximum bending moments also act on the same part.
3. The simulation model deflection values and the deflectometer deflection values are approximately same.
4. The deflectometer results are slightly greater than the simulation model results due to the environmental effects on the bridge component.
5. The retrofitting is not required for any component as the condition of members are good and the deflection is within the permissible limit.
6. The SHM system can be effectively implemented on the actual bridge to get more accurate and realistic results.

b) Future Scope

SHM is a very accurate and beneficial method of Structural Evaluation. SHM Sensors results can be obtained instantaneously and/or after specific intervals. The SHM system can be implemented on the actual bridge and the continuous monitoring and maintenance of bridge can be done. The continuous monitoring of structural responses of bridge is possible which provide desired data for scheduling structural audits, scheduling and selection of retrofitting technique. SHM system can give early warnings before collapse or structural damage so accidents causing human and economic losses can be avoided.

VI. REFERENCES

1. Casas J. and Paulo J. S. Cruz (2003), "Fiber Optic Sensors for Bridge Monitoring", Journal of Bridge Engineering/ASCE, Vol. 8

2. Alampalli, S. and Mohammed Ettouney (2006), "Structural health monitoring as a bridge management tool", Structures Congress/ ASCE

3. Bisby, L.A. (2006), "ISIS Canada Educational Module No. 5: An Introduction to Structural Health Monitoring", ISIS Canada, www.isiscanada.com

4. Thurgood, T., Marvin W. Halling and Paul J. Barr (2006), "Structural health monitoring of the cherry hill bridge", Structures Congress /ASCE

5. Ansari, F. (2010), "Simple cost-effective scour sensor", Research Report ICT-10-070, Illinois Center for Transportation

6. Yongtao Dong, Ruiqiang Song (2010), "Bridges Structural Health Monitoring and Deterioration Detection- Synthesis of Knowledge and Technology", Prepared for Alaska University Transportation Centre

7. Zhu Dapeng, Xiaohua Yi, Yang Wang, Jiajie Guo and Kok-Meng Lee (2010), "Mobile Sensor Networks: A New Approach for Structural Health Monitoring", 19th Analysis & Computation Specialty Conference/ASCE

8. Xue, W., Linbing Wang, Dong Wang and Christian Druta (2014), "Pavement Health Monitoring System Based on an Embedded Sensing Network", Journal of Materials in Civil Engineering/ASCE, ISSN 0899-1561

9. Agdas, Jennifer A. Rice, Justin R. and Ivan R. (2015), "Comparison of Visual Inspection and Structural-Health Monitoring As Bridge Condition Assessment Methods", Journal of Performance of Constructed Facilities/ASCE

10. Sardar Kashif Ur Rehman (2015), "Non-destructive testing method of concrete bridges", Construction and Building Materials

11. Seo, J., Jong Wan Hu and Jaeha Lee (2015), "Summary Review of Structural Health Monitoring Applications for Highway Bridges", Journal of Performance of Constructed Facilities/ASCE, ISSN 0887-3828

12. Asadollahi, P., and Jian Li (2017), "Statistical analysis of modal properties of a cable stayed bridge through long term wireless structural health monitoring", Journal of Bridge Engineering/ASCE

13. Gunawardena, Y., Farhad Aslani, Jun Li and Hong Hao (2018), "In Situ Data Analysis for Condition Assessment of an Existing Prestressed Concrete Bridge", Journal of Aerospace Engineering/ASCE, ISSN 0893-1321

14. Whitlow, R., Richard Haskins, Sarah L. McComam, C. Kennan Crane, P.E., Isaac L. Howard, and Mihan H. McKenna (2019), "Remote Bridge Monitoring using Infrasound", Journal of Bridge Engineering/ASCE

15. Aguilar, S., Zhenyu Zhang, Zhaoshuo Jiang and Richard Christenson (2019), "Infrasound based noncontact sensing for bridge SHM", Journal of Bridge Engineering/ASCE

16. IRC 5 IRC 5: 2015 – General Features of Design, Standard Specifications and Code of Practice for Road Bridges

17. Limin Sun, Zhiqiang Shang, Ye Xia, Sutanu Bhowmick and Satish Nagarajaiah (2020), "Review of Bridge Structural Health Monitoring Aided by Big Data and Artificial Intelligence: From Condition Assessment to Damage Detection", Journal of Structural Engineering/ASCE

18. IRC 6: 2016 – Loads and Stresses, Standard Specifications and Code of Practice for Road Bridges

19. IRC 22: 2008 – Composite Construction, Standard Specifications and Code of Practice for Road Bridges

20. IRC 112: 2011 – Code of Practice for Concrete Road Bridges

21. IS 13311 (Part 1): 1992 – Ultrasonic Pulse Velocity Test, Non-Destructive Testing of Concrete – Methods of Test

22. IS 13311 (Part 2): 1992 – Rebound Hammer Test, Non-Destructive Testing of Concrete – Methods of Test