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Dynamic Response of RC Bridges due to Heavy Vehicles

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Abstract: As a South Asian country, Sri Lanka is having a promising development in infrastructures in the country. Amidst of them, concrete bridges that are constructed in highways and expressways have substantial effect on developing transportation sector. The performance evaluation of bridges starts with the inspection of the bridge to determine the present condition. Currently, Structural Health Monitoring (SHM) in most of the developed countries is characterized by traditional visual inspection along with referencing of old inspection reports to maintain an accurate account of the bridges condition. This paper presents evaluating method for current condition of reinforced concrete bridges by evaluating dynamic characteristics of the bridge. Accelerations of the bridge were measured by imposed in moving vehicles. For the measurements, tri-axial accelerometer was used. Analysing of the acceleration is complex due very large number of readings and acceleration values required to filter from other disturbances. Matlab program was developed to filter and analyse the acceleration readings. In addition, displacements were calculated from the acceleration waveforms to evaluate bridge stiffness for different moving loads. The effect of the loads generated by moving vehicles on the displacement of the bridge is varying with the speed of the vehicle. To simulate that in model of the structure, an appropriate method was applied. By considering both result taken from actual acceleration measurements and the model, current condition state of the bridge was evaluated.

Keywords: Structural Health Monitoring, acceleration, displacement, bridge rating

1. Introduction

Bridges become lifelines of world transportation system during last two century. During the last seventy years a number of reinforced concrete (RC) bridges and pre-stressed concrete (PC) bridges were build all over the country. Maintenance of bridge structures in a transport network is essential in order to ensure safety, in addition to providing cost-effective maintenance operation of the network to save replacement cost by maximum utilization of service period.

Structure health monitoring (SHM) of bridges is essential for reliable structural conditions. Also SHM systems of bridges should be upgrade rather than it's depending on visual inspection and Non-Destructive Testing (NDT) and static load test can be increase the accuracy of test.

Deterioration and overloading become major factors that can happen to reach end of the lifespan of structure. Figure 1 shows collapse of a steel bridge in to Daduru Oya in Meeliyadda, Kurunegala due to deterioration and overloading (News Lanka) [4].

Figure 1: Meeliyadda Bridge collapse, 2015

When a vehicle passes over a bridge movement may generate in bridge girder base on its stiffness. With the Deterioration, stiffness of bridge get lower value and ultimately movement can be increase (Takács, (2002)) [7]. Uneven moment than designer allowed can happen to collapse of bridge. Here, Acceleration sensors can be used to track deck vibrations as well those results can be used to optimize typical visual inspection results or non-destructive test results.

2. Methodology

2.1 Bridge Selection

For the analysis and validations, three numbers of RC bridges in Ginthota, Magalle and Mahamodara were selected (Ref. Figure 2).

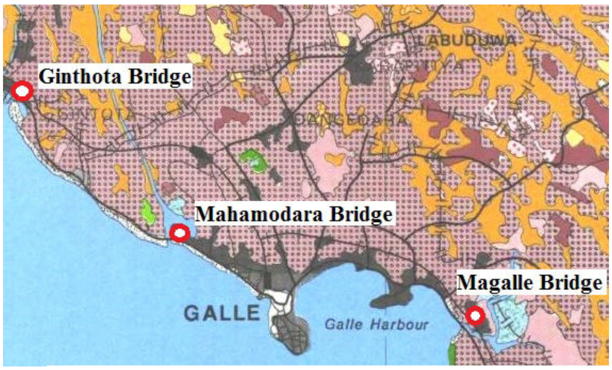

Figure 2: Selected bridges

A newly constructed Magalle bridge was used to validate the final outcome of the results. Also Ginthota Bridge which shown in Figure 3 is one of moderately deteriorated bridge which constructed in 1964 and another bridge at Mahamodara is slightly deteriorated Bridge (Pradeep, et. al, (2013)) [5].

Figure 3: Ginthota Bridge

Those three bridges are existing along the coastal line on Colombo-Galle (A2) main road. Coastal exposure condition can happen to accelerate deteriorate processes severely and effective lifespan of selected three bridges will be shorten than bridges that exposed to normal environmental conditions.

2.2 Instrumentation

Tri-axial accelerometer is used as main instrument to grasp vibration response vs. moving vehicle. Tri dimensional Acceleration of bridge deck was measured at the middle span and end of the bridge deck as well on top of the support. The accelerometer had tightened to the bridge deck via grouted steel plate that can transfer deck vibration to sensor as it is.

Figure 4: Instrument used for test

Figure 4 consequently shows the Tri-axial accelerometer, data reader and data logger which used to measure accelerometer on the middle span of Ginthota Bridge. A high resolution data recorder that can record up to 50,000 data per second was used to capture deck vibrations. Accuracy of data will be critical when final deformation keep it in micro meter range.

2.3 Data Acquisition

Accelerations in the bridge deck were recorded for varies types of vehicles. Although for the further analysis definite load class was selected. Therefore dynamic loads from regularly loaded busses were selected due to its availability. Also own vehicle which having known load can used for receive deck vibrations and it may increase cost of test. With the change of vehicle speeds, there were different in accelerations. Similar accelerations results were selected around 40 kmh^{-1} to ensure the corrected result.

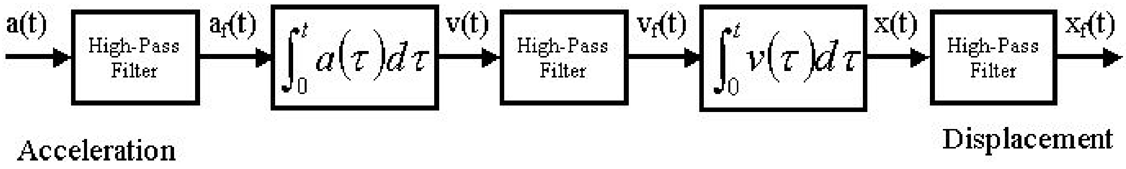

Figure 5: Double Integration with High pass filtering

Using dynamic test results that can be monitor some deviation with results of accelerations as well as deflections in to tri-axial direction. The relationship of deflection vs. stiffness acts as major reasons for deviation of results in to tri directions. Usual bridge deck has relatively low stiffness along the direction of gravity due to its shape and major gravitational load apply along the low stiffness direction.

Considering those criteria movement of bridge deck along either traveling direction or crossing direction can be neglect. The possibility to fail bride along gravitation direction is too high with normal load condition rather than loading due to natural disaster or motor-vehicle accidents.

The variation of deflection along the bridge deck can predict by acquiring multiple measurement in several locations along the deck. Consider about resultant deflection along the deck vs. moving load, maximum deflection come off at mid span as well deflection on support reaches to neutral region.

2.4 Acceleration Data Analysis

The recorded accelerations were converted into displacements by double integration method (Slifka, (2004)) [6]. Noises that generate with data recording session was led to make some different in deflection results.

High pass filters were used to remove that generated noise signals. All the process was done using a coded matlab script. Compiling procedure inside matlab environment is shown in Figure 5.

Acceleration of mid span of Ginthota Bridge according to moving load is shown in Figure 6.

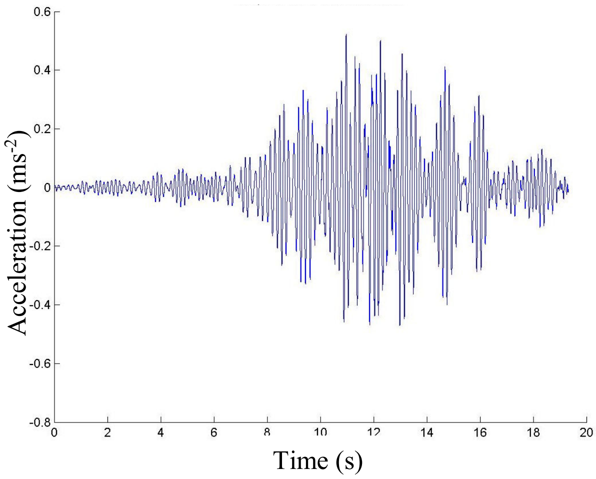

Figure 6: Acceleration graph vs. Time.

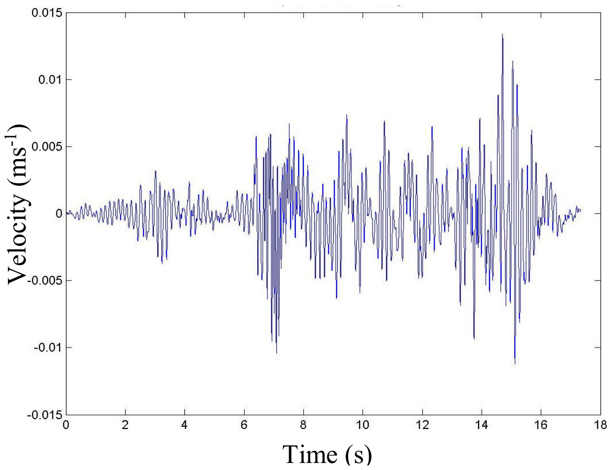

Figure 7: Velocity graph vs. Time

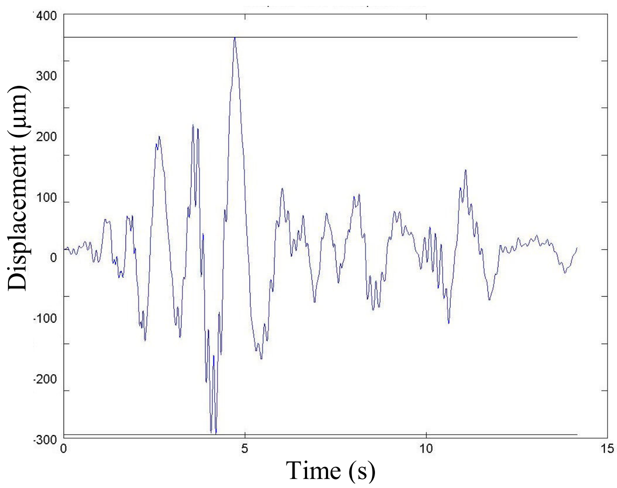

Figure 8: Displacement graph vs. time

Corresponding velocity as shown in Figure 7 can be generated by single integration process of filtered acceleration data and deflection as shown in Figure 8 predicted by re-integration of velocity results.

Mechanical condition of vehicle, road surface condition and driving path along the girder can generate slightly different results in repeated tests. That error can repeat off by taking the mean average value of arrived results. Table 1 shows calculated deflection results of Ginthota Bridge at mid span and top of the pier for number of vehicle at same load conditions.

Table 1: Calculated deflections of Ginthota Bridge

Displacement at mid span (µm)	Displacement at the pier (µm)
352.6	52.8
368.2	41.3
333.1	42.6
322.3	46.1
368.2	51.8

The average deflection of Ginthota Bridge is about 348µm in mid span and 46 µm in top of the pier.

2.5 Bridge Model

From referring each structural drawings bridge models were designed based on finite element method (FEM). For each bridge were drawn in the ANSYS work bench as Transient structure. Material properties, reinforcement location and pre-stressed or post stressed load applied on FEM model to fell initial condition of bridge. The load equal to measure the actual deflection (18000 N) was applied as transient load and speed as actual speed of data recording. The characteristic data of model constructed for Ginthota Bridge and FEM model are shown in Table 2 and Figure 9, consequently.

Table 2: model properties of Ginthota Bridge

Dimensions (m)	Material by volume
Length = 25. 162	Concrete = 92.3%
Depth = 04.155	Steel = 3.7 %
Width = 15.25	

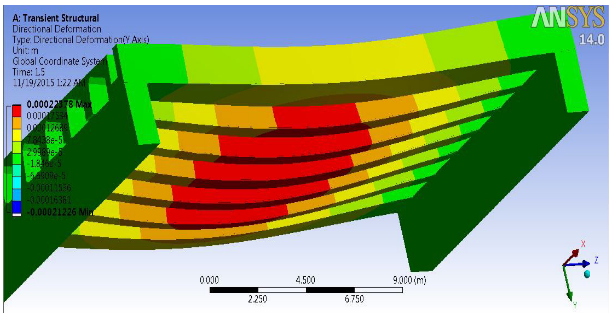

Figure 9: Model of the Ginthota Bridge

Assign material properties for original bridge conditions are shown in Table 3.

Table 3: Material properties assign for Ginthota FEM model

Property	Concrete	Steel
Density (Kg/m^3)	2300	7850
Ultimate Compressive Strength (MPa)	41	450
Ultimate Tensile Strength (MPa)	5	450
Young's Modulus (Pa)	3.e+010	2.e+011
Poisson's Ratio	0.18	0.3

To simulate the deterioration of concrete in the model, compressive strength and young's modulus of the concrete were reduced as a percentage. Change of young modulus that affect to deformation of girder vs. concrete compressive strength is shown in Figure 10 [1] (Carmichael, (2009)). Further, to simulate corrosion of steel, steel volume of the structure change as a percentage.

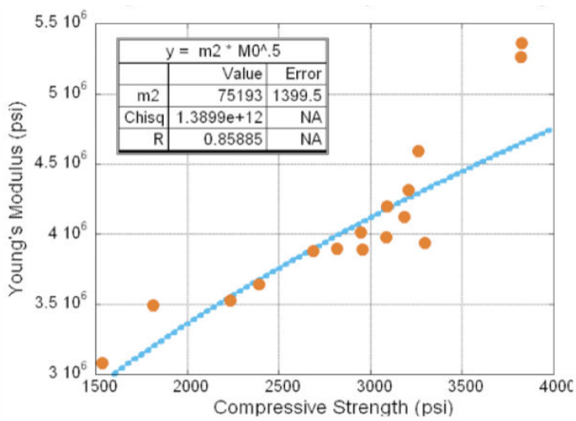

Figure 10: Young's modulus vs. compressive strength of concrete

Deterioration of bride can simulated as deduction of material properties as percentages. The maximum deformations of the bridges for varies level of deteriorations were taken into account and deformation changes against deterioration percentage was drafted. Results generates for original bridge conditions of Ginthota Bridge with standard moving load is shown in Figure 11.

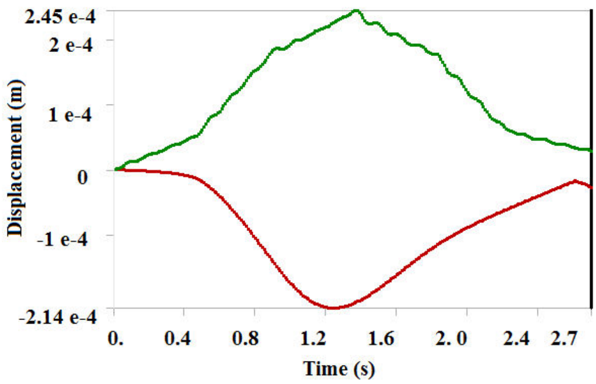

Figure 11: Deformation of deck at centre span

The deformations taken from the accelerations for each bridge were compared with the deformation vs. deterioration percentage curve and percentage of deterioration of the bridge is identified. Condition of the bridge can be predicted by comparing results from FEM model and actual measurements.

2.6 Validations of Results

For the validations of the model displacement derived from FEM model compared with deterioration level of the known bridge. Here newly constructed Magalle bridge was selected and assume that bridge exists its zero deterioration level. This was verified with visual inspection reports available [3, 5]. Measured deflection values and deflection that obtained from FEM model was obtained approximately shows equal distribution.

2.7 Bridge Management System (BMS)

A user friendly and accurate BMS was launched as a part of Dynamic response structure health monitoring. However, in real structures health monitoring system cannot be developed only based on dynamic loads. Visual inspections as well as non-destructive test data acquire major cause of SHM. Therefore another bridge assessment tool that used to predict SHM by using only visual inspection and non-destructive data was used to optimize dynamics load response SHM. Evaluate the current condition state of the bridge using NDT data and visual inspection, available BMS was used. [8](Kariyawasamm et al., (2013))

Table 4: structural health rating system of RC bridges

Number	Condition state	Physical Description
9	Excellent	A new bridge.
8	Very good	No problem noted.
7	Good	Some minor problem.
6	Satisfactory	Structural members show minor some deterioration.
5	Fair	All primary structural element are sound but may have minor section loss, deterioration, spalling, or scour.
4	Poor	Advanced section loss, deterioration, spalling, scour
3	Serious	Loss of section, etc. Has affected primary structural components. Local failures are possible. Fatigue cracks in steel or shear crack in concrete may be present.
2	Critical	Advanced deterioration of primary structural elements. Fatigue cracks in steel or shear crack in concrete may be present or scour may have removed structural support. Unless closely monitored it may necessary to close the bridge until corrective action is taken.
1	Imminent Failure	Major deterioration or loss of section in critical structural component or obvious vertical or horizontal movement affecting structural stability. Bridge is closed to traffic but corrective action may put back in light service.
0	Failed	Out of service. Beyond corrective action.

As a result of compiling all input data, overall rating of the bridge was evaluated. The rating number and conditions state are shown in Table 4 (Chase et al, 1999) [2]. Depend on that rating, decision about the condition state of the bridge can forced to change or user can make sure that structure is further keep its current condition.

5. Conclusions

Management and preservation of existing concrete bridges is a complex engineering concern with public safety and financial implications. Successful treatment to limit the rampant effects of structural defect, deterioration, and damage and control functional decline requires early diagnosis. The high replacement value of structurally deficient bridges justifies the cost of diagnostic evaluation. Instrumentation and monitoring is the only tool that can enable the reliable evaluation required before any intervention.

Bridge structures are evaluated by ordinary techniques cannot predict actual structural rating by itself. Either Static load test or dynamic response test is the way to optimize usual prediction. Structural evaluation of existing bridges is a complex process consisting of a series of integrated system components and procedures. Modern bridge management requires the development of integrated administrative and engineering solutions, which are not only technically and financially feasible, but also practical and rapid.

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