Structural Health Monitoring of Local R.C Bridge using Global Dynamic Technique based on Frequency Change

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***Abstract* —** in this study, we concentrate on global health monitoring issues. Global health monitoring has been the traditional tool used to determine the safety of bridges. This technique is based on changed in frequencies and other modal parameters. However, there are several drawbacks of this technique like insensitiveness for initial damage and different frequency changes at same damage level for different location in the structure. In present search work, these drawbacks of global dynamic technique have been improved. For insensitiveness, PZT sensors were used on place of traditional sensors like accelerometer and strain gauge to real data that collected from the site. This real data was compared with analytical data that have been gotten by modelling the bridge with real dimension in analytical software like ANSYS. It was observed that numerical results are in close agreement with the experimental (real) results.
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Keywords— (R.C) Reinforced Concrete, Bridge, Health Monitoring, Global Dynamic Technique, *Numerical (ANSYS).*

I. INTRODUCTION

SHM is the process in which certain strategies are implemented for determining the presence, location and severity of damages and the remaining life of structure after the occurrence of damage; in other wards (SHM) is the implementation of a damage identification strategy to the civil engineering infrastructure. Damage is defined as changes to the material and/or geometric properties of these systems, including changes to the boundary conditions and system connectivity. Damage affects the current or future performance of these systems. The damage identification is the basic objective of SHM and the process is generally structured into the following levels:

- Determination of the damage detection, where the presence of damage is identified.
- Determination of the Damage location, where the location of the damage is determined.
- Determination of the Damage extent, where the severity of damage is assessed.
- Determination of the remaining service life of the structure.

SHM involves the observation of a system over time using periodically sampled dynamic response measurement from an array of sensor, the extraction of damage-sensitive response features from these measurements, and the statistical analysis of these features to determine the current state of the system health. For long term SHM, the output of this process is periodically updated to provide information regarding the ability of the structure to perform its intended function in light of inevitable aging and degradation resulting from operational environments. After extreme events, such as earthquakes or blast loading, SHM is used for quick condition screening and aims to provide, in near real time, reliable information regarding the integrity of structure. Hence, SHM offer great promise for civil infrastructure implementations.

II. LITERATURE REVIEW

Jittendera Kumar, (2011) Structural health monitoring (SHM) is the practice of monitoring a structure over its lifetime to detect damage in its deterioration is mostly the result of aging of materials, continuous use, overloading ,aggressive exposure condition , lack of sufficient maintenance , and difficulty encountered in proper structural health monitoring . Most traditional method of SHM is Global Dynamic Technic. The technic is based on change in frequencies and other modal parameter however there are several drawback of this.

Technique like insensitiveness for initial damage and different frequency change and same damage level for different damage structure.

In his work these drawbacks have been improved. For insensitiveness, PZT sensors were used in place of traditional sensors like accelerometer and strange cag for damage quantization two additional parameters have been added with frequencies change.

Rama Shanker et al., (2011) a new approach is proposed to effectively detect the initiation and progression of structural damage by combining the global dynamic and the local electromechanical impedance (EMI) techniques, using the same set of surface-bonded piezoelectric ceramic (PZT) patches as sensors. The PZT patches are used to determine the natural frequencies and the strain mode shapes of the structure (for use in the global dynamic technique) as well as to acquire the electromechanical admittance signature (for use in the EMI technique) to facilitate an improved damage assessment. Occurrence and location of the incipient damage are determined using the EMI technique, whereas for moderate to severe damages, the location and the severity are arrived at through the global dynamic technique. Finally, damage severity is determined in terms of the original stiffness of structure using the strain mode shapes directly determined using the PZT patches. The proposed technique is illustrated using two specimens a 4-m long steel beam and a mild steel plate 1260 mm × 630 mm × 6.5 mm in size. The integrated approach provides greater information about damage, is simple to apply, does not involve any numerical/analytical modelling a priori, and is at the same time very cost effective.

III. MATERIAL AND METHODOLOGY

A. Structural Modelling

Modelling of the bridge involves the modelling of its various dimensions. The model must ideally represent real bridge (R.C Bridge).

a. Material Properties

f_{ck} = 55.4 MPa grade of concrete and Fe-415 grade of reinforcing steel are used for all members of the bridge. Elastic material properties of these materials are taken as per Indian Standard IS 456(2000). The short-term modulus of elasticity (Ec) of concrete is taken as:

$$Ec = 5000\sqrt{fck}\ \text{MPa} \qquad (3.1)$$

Where

f_{ck} ≡ characteristic compressive strength of concrete cylinder in MPa at 28-day (55.4 MPa in this case).

For the steel rebar, yield stress (fy) and modulus of elasticity ($Es=2\times10^{11}$) is taken as per IS 456 (2000).

b. Bridge Details

1. Bridge Geometry

The bridge compromises a 630 m cable stayed section with a 260 m long main span, a 515 m long approach bridge with spans of 60 m, and 360 long viaduct with spans of 25 m. All foundation is deep open wells except for the viaduct, where 1.2 m Dai bored piles are used. The concrete pylon are 90 m high with slender solid rectangular legs above the deck, and robust hexagonal shaped legs below the deck. The concrete girder in the cable stayed section comprises two 1.37 m high beams at each stay plane and a 0.25 m thick deck slab. In the approach bridge and in the viaduct the same girder concept is used, but the height of the beams is 3.5 m and 1.25 m, respectively .Cross girders are provided every 5 m, see figures (3.1, 3.2, 3.3, 3.4, 3.5, 3.6, and 3.7). The stays are arranged in semi-fan system with the use of locked coil galvanized ropes with diameter between 76 mm and 116 mm. At the upper anchorage, fork sockets are provided to allow the stays to rotate. At the lower anchorage, the stays have sockets with thread and nut for adjustment of the stay forces.

Special subjects such as settlements of the well foundation and wind stability during erection and at the final stage have been thoroughly investigated.

Fig. 3.1 Pylon at Construction Time

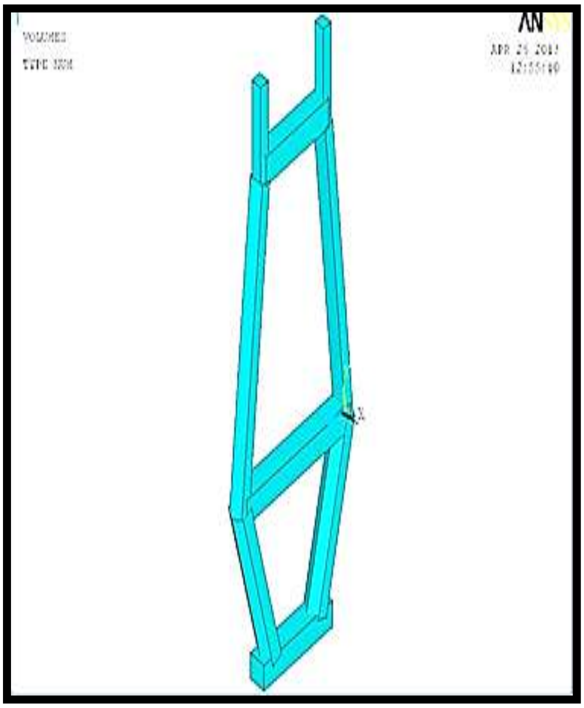

Fig. 3.2 Pylon Detail In ANSYS Software

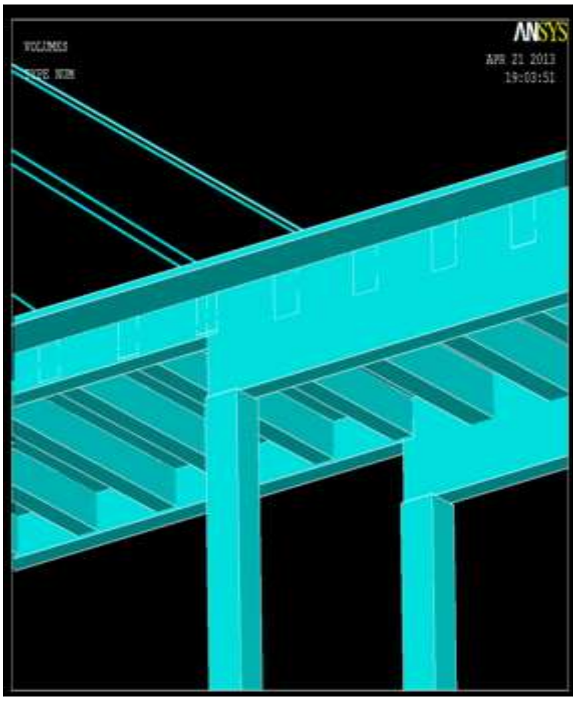

Fig. 3.3 Cable Stayed Cross-Girder Side Beam and Approach Side Beam

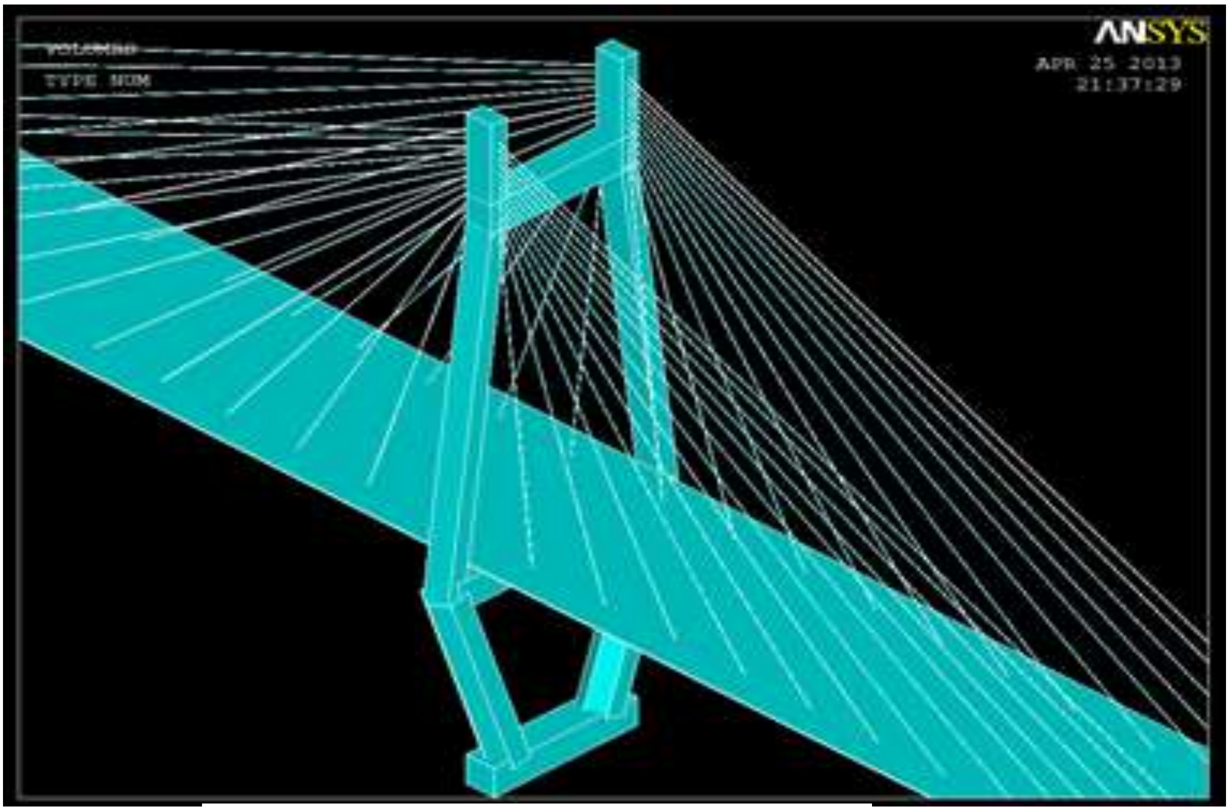

Fig. 3.4 Cable Stayed Portion in ANSYS Software

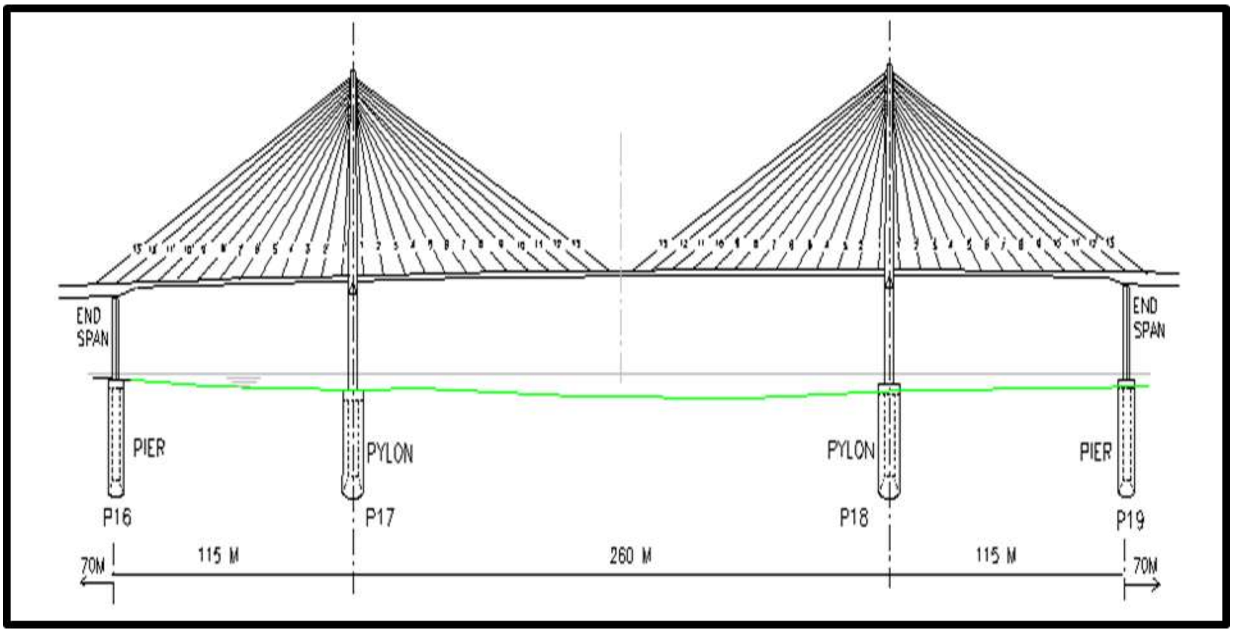

Fig. 3.5 side view of the bridge

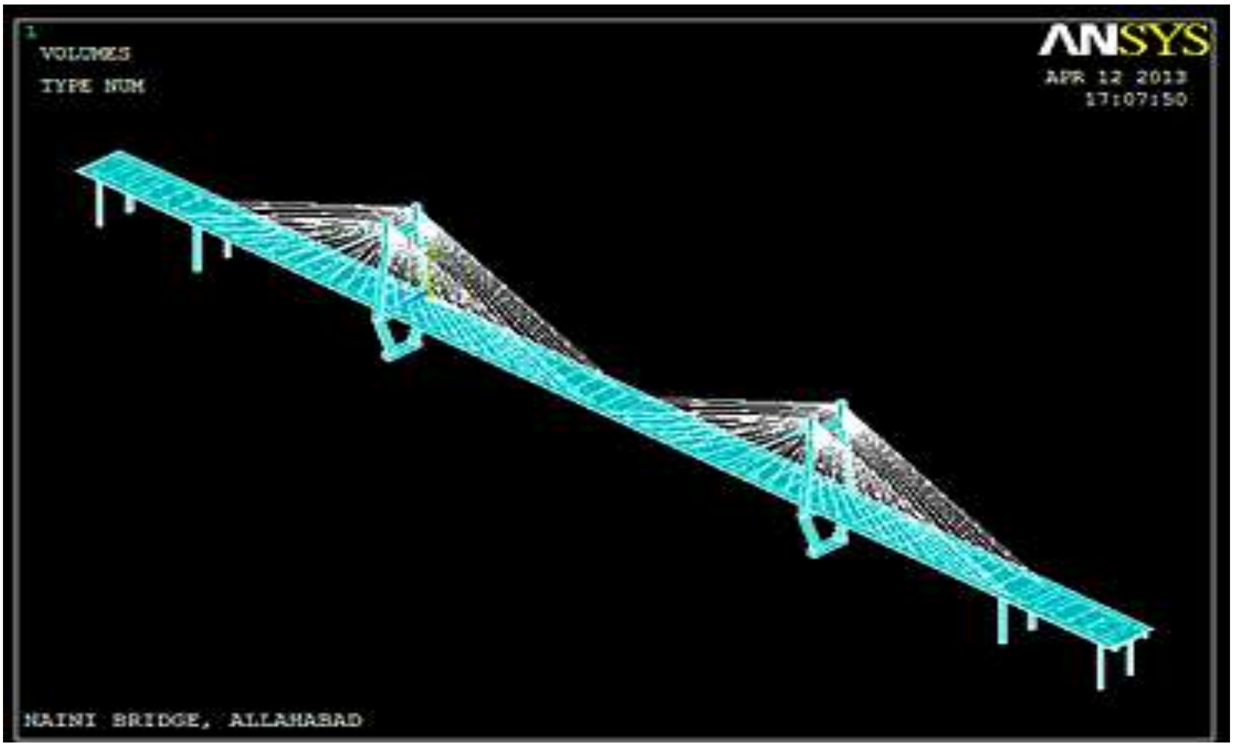

Fig. 3.6 Cable Stayed Portion Side View In ANSYS Software

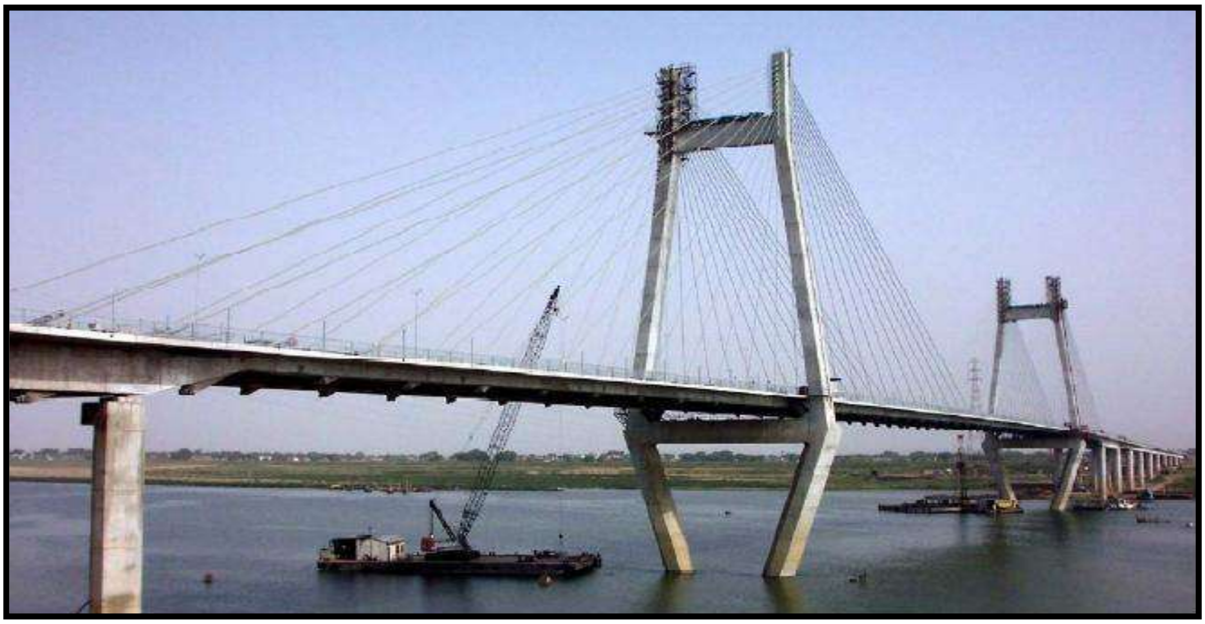

Fig. 3.7 the Bridge Cable Stay Portion during Maintenance Time

2. Instrumentation

This work concerns the independent Wind and Structural Health Monitoring System (WSHMS).

The WSHMS comprises of two parts i.e. the monitoring part and evaluation part. The monitoring part refer to the real time monitoring lead effects, environmental effects and bridge responses through the usage of an On-structure Instrumentation System (OSIS) and a Portable Data Acquisition System (PDAS) for use in the current load and health condition of the bridge based on measured and analysed results through the usage of a Computer System for Operation and Control (CSOC) Construction and operation period. The evaluation part refer to evaluate the system monitors the following parameter:

a) Load-Effect.
   Wind measurements.
   Temperature measurements.
   Traffic measurements.
b) Environmental effects.
   Humidity.
   Rainfall.
   Barometric Pressure.
   Air Quality.
c) Bridge response.
   Displacement
   Stresses and strains.
   Dynamic characteristics.

Table (3.1) Instrumentation Details

WASHM	Hardware Description	Location	Parameters For Monitoring	Monitoring
Wind Speed	3 Anemometer and wind vanes	Pylon top: level 160 m Central node: level 101 m	Wind speed and wind direction	Load effect
Air Temperature And Air Quality	3 Temperature sensors: model HMP45C	Above deck	Air temperature and relative humidity	Metrological effect
Rainfall	1 Precipitation sensor: model TE525MM	PYLON TOP	Rainfall	Environmental effect
Barometric Pressure	1 Barometric pressure sensor: Visla PTB100B	Pylon top: level 305 m	Barometric pressure	Metrological effect
Air Quality	1 Air quality sensor: Campbell Scientific	Pylon top: level 305 m	Air temperature and relative humidity	Metrological effect
Accelerometers	10 servo accelerometers: Kistler 8390A triaxial	Wind responses. Deflections for deck and cable	Central main span: level 90 m at deck center 3/5 main span level 89 m at deck center	Load effects bridge responses
GPS	3RTK GPS resistive: Leica MC500	Pylon top: level 100 m	Wind and bridge responses: deflection of pylon	Load effect Bridge responses
Displacement Sensor	2 displacement transducers: RH and RP Series Analogue Position Sensor, RDP group	longitudinal expansion joints and displacement expansion joints	Bridge responses	Bridge responses
Stresses And Strains, Bridge Deck Cross Section	9 vibrating wire strain gauge sensors:	One between pylons and one at each approach deck	All key structural components for bridge deck	Bridge responses: parallel to bridge alignment

B. Outline of the Computer Program:

In the present study, ANSYS computer program Version 14.0 is used for performing the dynamic or modal analysis. ANSYS (analysis system) is comprehensive general-purpose finite element computer program that contains over 100,000 lines of code and more than (180)different element. It is capable of performing static, dynamic, heat transfer, fluid flow, and electromagnetism analysis. It is a leading finite element analysis program for well over 20 years. ANSYS can be used in many engineering fields, including structures, aerospace, electronic, nuclear problem and it is very powerful and impressive engineering tool that can be used to solve a variety of problems **(Moaveni, 1999)**.

C. Material Idealization:

a. Concrete Idealization:

SOLID65 is used for the 3-D modeling of solids with or without reinforcing bars (rebar). The solid is capable of cracking in tension and crushing in compression. In concrete applications, for example, the solid capability of the element may be used to model the concrete while the rebar capability is available for modeling reinforcement behavior. Other cases for which the element is also applicable would be reinforced composites (such as fiberglass), and geological materials (such as rock). The element is defined by eight nodes having three degrees of freedom at each node: translations in the nodal x, y, and z directions. Up to three different rebar specifications may be defined. The concrete element is similar to a 3-D structural solid but with the addition of special cracking and crushing capabilities. The most important aspect of this element is the treatment of nonlinear material properties. The concrete is capable of cracking (in three orthogonal directions), crushing, plastic deformation, and creep. The rebar are capable of tension and compression, but not shear. They are also capable of plastic deformation and creep. The geometry, node locations, and the coordinate system for this element are shown in Fig. (3.8), **(ANSYS Help, 2010).**

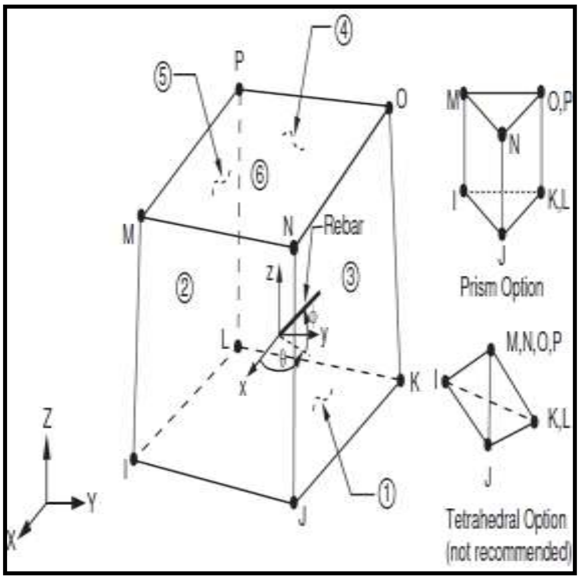

Fig. 3.8 SOLID65 Geometry (ANSYS Help, 2010).

b. Reinforcement Idealization:

LINK180 is a spar (or truss) that can be used in a variety of engineering applications. This element can be used to model trusses, sagging cables, links, springs, etc. This 3D spar element is a uniaxial tension-compression element with three degrees of freedom at each node: translations in the nodal x, y, and z directions. Tension-only (cable) and compression-only (gap) options are supported. As in a pin-jointed structure, no bending of the element is considered. Plasticity, creep, rotation, large deflection, and large strain capabilities are included. This element is used for simulate the behaviour of steel reinforcement in resisting the flexural as a main reinforcement and resisting vertical sheer as stirrups. The geometry, node locations, and the coordinate system for this element are shown in Fig. (3.9), **(ANSYS Help, 2010).**

The element is defined by two nodes, the cross-sectional area (AREA), added mass per unit length (ADDMAS), and the material properties. The element X-axis is oriented along the length of the element from node I toward node J.

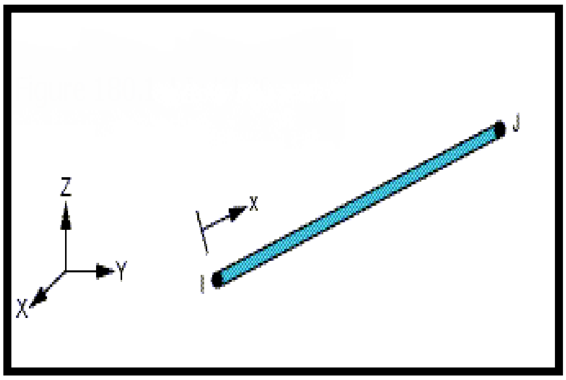

Fig. 3.15 Link180 Geometry (ANSYS Help, 2010).

D. Global Dynamic Techniques or Methods

In these techniques, the test-structure is subjected to low-frequency excitations, either harmonic or impulse, and the resulting vibration responses (displacements, velocities or accelerations) are picked up at specified locations along the structure. The vibration pick-up data is processed to extract the first few mode shapes and the corresponding natural frequencies of the structure, which, when compared with the corresponding data for the healthy state, yield information pertaining to the locations and the severity of the damages. A damage in a structure alters its modal parameters such as modal frequencies, modal damping, and mode shapes associated with each modal frequency. Changes also occur in structural parameters, namely stiffness and damping matrices. These techniques have obvious advantages over the static response techniques and they are easy to implement. Even the ambient vibration data can be utilized to derive modal data. Depending on modal parameter, global dynamic response can be divided in to:

1. Global dynamic response based frequency change.
2. Global dynamic response based mode shape changes.
3. Global dynamic response base damping change.
4. Global dynamic response base matrix update method.

IV. RESULT AND DISCUSSION

This chapter deals mainly deal with the analysis of the R.C Bridge with real dimension using ANYSIS software. Then using global dynamic technique monitoring the bridge and determining strength real bridge (R.C. Bridge).

A. PRESENT WORK

In this thesis global dynamic technique based on frequency change has been used for monitoring R.C. Bridge. Frequency can be collected or calculated in to three ways:

1. From the sensors systems (accelerometer, strain gauge and Piezoelectric sensor) that distributed on different position on the bridge the real values of frequency can be collected from them.
2. Using ANSYS V.14 software numerical values of frequency can be collected.
3. Using analytical methods values analytical values of frequency can be determined.

In present work, two type of frequency were calculated real frequencies that collected From the sensors systems that distributed on the different positions of the R.C. bridge and numerical frequencies by modelling of the R.C. bridge with real dimensions in ANSYS V.14 software, after that a comparison would be made to determine the damage level in the real bridge.

Change in frequency depend on the health of the structure , with time health of the structure will changed due to environmental impact and deterioration so that strength and frequency will be changed.

Frequencies of structure change with the damage and frequency of the structure is the function of stiffness and mass of the structure. Generally changes in the mass of the structure are negligible with time. Hence, frequency is directly related to stiffness of the structure/ bridge.

B. EXPERIMENTAL DATA COLLECTING

Three type of sensor are equipped in the bridge:

- Strain gauge.
- Accelerometer.
- Piezoelectric sensor.

Data logger is connected to extract the data and the First 10 frequencies of the bridge are displayed by PZT sensor. The first or actual displayed frequency by sensor equal to 0.350 Hz and the actual deflection equal to 9.455mm.

Fig. 4.1 Accelerometer on the Cable

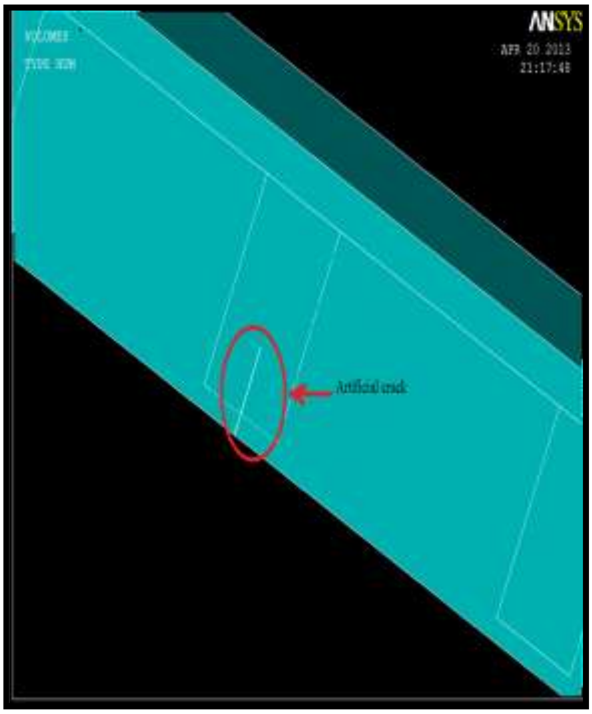

Fig. 4.2 Artificial Crack

C. Numerical Data Collecting

Steps involved in the analysis:

a) The bridge was modelled with the real dimension in ANSYS program as mentioned in Chapter 3.the beam has meshed with solid65.
b) Modal analysis of the bridge has been done.
c) The value of first 10 natural circular frequencies and corresponding mode shapes were obtained for healthy state are obtained.
d) The first or actual displayed frequency by sensor equal to 0.3318 Hz and the actual deflection equal to 8.687 mm.
e) Artificial damage was created in the modelled Bridge.
f) For each damage level for different (location, crack width and the crack numbers) the value of first 10 natural circular frequencies and corresponding mode shapes were obtained.
g) Comparison has been made for the frequency data of the bridge having artificial cracks at different location and having different magnitude (crack width or number of cracks) with corresponding data’s of healthy structure.

D. NUMERICAL RESULTS

The bridge was analysed with different damage level (crack width or number of cracks) and with different location. The frequency data for both real values from site and healthy state from the program has been found and compared with each other see fig. (4.3) and table (4.1) .The frequency data for the modelled bridge in both healthy state and different damage level with different locations, crack width and number of cracks has been compared. Change in frequency is noted in tables (4.2).

Table 4.1 First Ten Real and Numerical (Healthy State) Frequencies

Numerical Value HZ	Real Value HZ
0.3318	0.350
0.89071	0.901
1.2233	1.2956
1.5502	1.5898
1.6454	1.6663
1.6575	1.6215
1.8271	1.858
1.9924	2.023
2.1048	2.1852
2.1559	2.2254

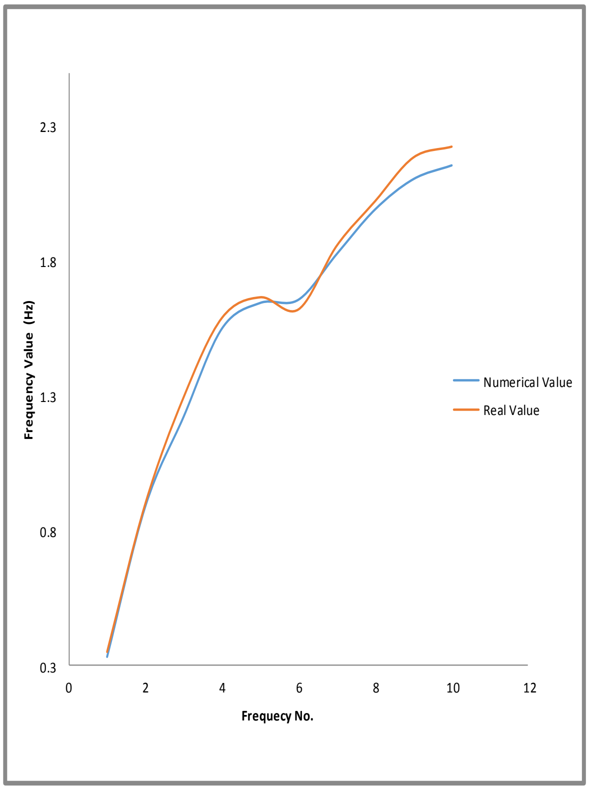

Fig. 4.3 Comparison between Real and Numerical Values (healthy state)

Table 4.2 First Ten Frequency with Different Crack Width at Center of the Bridge

Frequency no.	Healthy State(Hz)	1mm	2mm
First	0.3318	0.33080	0.33075
Second	0.89071	0.88164	0.88130
Third	1.2233	1.1742	1.1721
Fourth	1.5502	1.5109	1.5087
Fifth	1.6454	1.5965	1.5941
Sixth	1.6575	1.5990	1.5974
Seventh	1.8271	1.7897	1.7874
Eighth	1.9924	1.9524	1.9502
Ninth	2.1048	2.0654	2.0637
Tenth	2.1559	2.1073	2.1058

VI. CONCLUSION

The major conclusions arising from the research have been summarized:

1. A model of R.C. Bridge has been modelled successfully in ANSYS software with real dimension.
2. The first 10 frequencies of R.C. Bridge were determined numerically with help of ANSYS software and the real values have been collected from the site with help of the instruments that put on the bridge.
3. Numerical and real frequencies were compared. It was found that numerical results agree with real result that means the structure in healthy state, there is no sever damage in the bridge and the damage level still low till now.
4. Since the numerical values agree real values, which means the ANSYS software is very good for modal analysis.
5. Global dynamic techniques are important just for knowing that damage has occurred and for further examination of the structure to find the exact location and severity of the damage can be taken by other technique.
6. Global technique has sensitivity to detect the damage at severity and failure stage.

Local techniques are better than global to detect the damage from the incipient stage.

7. Global techniques should be used with the local techniques for improving structural health monitoring and observing incipient, moderate and sever damages

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