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EARLY WARNING AND FAILURE DETECTION IN BRIDGE USING WIRELESS VIBRATION SENSOR

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Infrastructure of transportation has become an important aspect in Indonesia. Indonesia needs to maintain this infrastructure. The bridge is one of the important infrastructure need proper maintenance. Indonesia has over 89,000 bridges with a total length of 1,050 km. In order to maintain all the bridges, an integrated structural health monitoring system (SHMS) needs to be built. The aim of this system is to provide early warning for degradation of bridge. Hence, Kutai Kartanegara bridge failure will never repeat. The aim of this research is to detect failure in a bridge and provide adequate warning using wireless vibration sensor. Vibrations information of a bridge is main purpose of this study which enables to determine health of a bridge. A device has been built for this task from accelerometer sensors. Vibration from an accelerometer has been used to find out bridge behavior. Research of this has been done in the laboratory and field. Finite element methods and propose spectral finite element methods have been applied in this research. The finding shows that the vibration information of a bridge has a lot of important information, such as spectral type of vibrations, frequencies, damping and mode shape of structures. Several conditions in laboratory and field have been analyzed. This study shows that vibration information can be used for early warning of bridge health and failure or damage in bridge.

Keywords: SHMS, Accelerator Sensor, SFEM.

1 INTRODUCTION

The bridge is an important factor in transportation infrastructure. These two sides are usually divided by a river or valley. Bridge construction is designed in order to maintain design loads. It depends on span length and vehicle load in a bridge. It is used to control the lifetime of a bridge or bridge reliability.

Lifetime of bridge in application is not along with bridge lifetime design. Several factors are influence this conditions. Understanding lifetime of bridge in application becomes a primary research nowadays. This happens due to a lot of impact in transportation and economy if bridge fails.

Development in sensor technology at this time has become a key to get bridge condition as fast as possible. Sensors have become a tool to get information from bridge. A development of structural health monitoring system (SHMS) has become a need. Even though structural health monitoring system in bridge has been adopted several years ago, there are some problems to be solved. For example, how to use sensor output to get bridge health information. Second, how output of sensor in bridge predict bridge condition in an instant. Finally, how cost of sensor development can be economically decreased without losing first and second option above.

Structural health monitoring system at this time is using only getting output data from bridge. It is used only for long span bridge due to system cost. This is because of non-economical sensor and complicated assembling. Sensor development now days has eliminate both interfere aspect. This is a time of sensor and civil engineering to gain knowledge. A development of sensor is needed for large use of sensor for determine bridge conditions. Development of structural health monitoring has increase to protect bridge investment and transportation.

One of sign of failure should be unusual vibration in bridge. People were sensing unusual vibration in bridge. For example, failure in Kutai Bridge in Indonesia. Before it was collapse, vibrations in bridge were giving information. Due to lack of analyze. These data of vibration are not defined to find out bridge health.

This tragedy awakes a need of a warning system of bridge that can fulfill three concept of structural health monitoring. This means an integrated system that can give an understanding output from sensor, a report that can give bridge health information and in a low cost.

Three needs in an integrated health monitoring system are aims in this ongoing research. This research is focused in define bridge behavior that can be use for bridge health monitoring. Accelerometer sensor has been choosing to learn about bridge behavior.

Research is focusing in accelerometer sensor for dynamic data. This is because accelerator sensor provides vibration data from bridge. Vibration data are different from other sensor output. Vibration data might be used to extract bridge health information. This research becomes important in order to maintain bridge healthy and protect asset of investment.

2 BASIC THEORY

2.1 Structural Health Monitoring System

Structural health monitoring system (SHMS) is a system to monitor behavior of structure. This system is the implementation of damage identification in structure (Wenzel 2009). This system is multidiscipline from civil engineering and electronic engineering. Capture any behavior in structure is the aim of this system. A lot of sensors are use to detect this behavior.

Gopalakrishnan (2011) defines key for structural health monitoring is combination between sensor technologies and modeling analysis. There are five stage of developing which are:

Level 1: Confirming damage present
Level 2: Determination of damage location
Level 3: Evaluation of damage
Level 4: Reducing damage
Level 5: Determine remaining life

2.2 Accelerometer

An accelerometer is a sensing element. It is sensing an acceleration or velocity to time (m/s – s). Accelerator is measuring in unit of g (gravitation). This sensor is sensing vibration, shock, tilt, impact or motion. Result from an accelerometer is a graph between acceleration versus time. This data will be used to gain bridge behavior information.

2.3 Vibration Data

Vibration data taken from accelerometer sensor are valuable. Data can be used for bridge investigation. Spectral analysis was the first method to identify basic understanding of vibration. Spectral analysis gives type of vibration across a bridge. Type of wave classified into five types.

2.4 Bridge Behavior

Bridge behavior can be identified using vibration data captured from accelerator sensor. This data are taken by doing a simulation. Data can be acquire are frequency of structure, deflection, rotation and stress-strain. They are all important aspect for bridge healthy information.

2.5 Finite Element and Spectral Finite Element

Finite element method is often used to find out element behavior. This method is commonly used for static load. Meanwhile, spectra finite element is used for wave load in structure. Spectral finite element was believed are giving better information about bridge with analysis of vibration sensor (Matsuo 2012).

3 RESEARCH METHODOLOGY

3.1 Wireless Vibration Sensor

Wireless vibration sensor has been made for this. A wireless system has been choosing for research. Wireless has been choosing because of flexibility of placement in bridge. This is a low cost device. Figure one shows component of accelerometer in this test.

3.2 Laboratory Test

Bridge in laboratory test was made by using steel girder. Figure 2 shows detailed concept for this. Several conditions have been done to find out more about vibration in bridge. It is consist of weight of load and height of free fall.

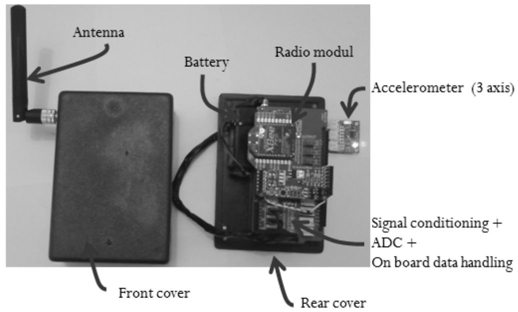

Figure 1. Wireless vibration sensor.

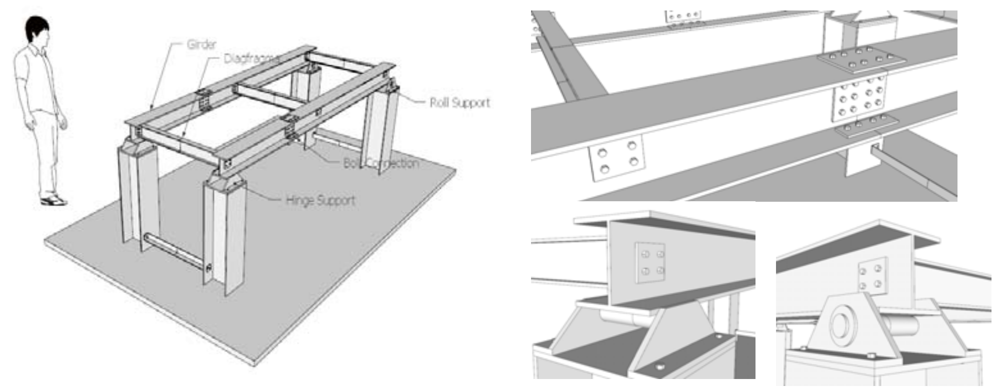

Figure 2. Laboratory Model.

3.3 Field Test

Field test has been done in truss bridge. Bridge was made from steel. One bridge is in good condition while the other is in failure due to overload condition. Load for this test is truck with same weight and speed. Temperature and wind are same in both tests.

3.4 Method of Analysis

Vibration data are analyzed to find information. Target to compare are frequency and deflection of bridge. Finite element has been choosing for this research to define bridge information. Finite element method is using in this analysis to find out bridge behavior. Models are creating and analyze to find out mode of bridge for their bridge standard. Basic consideration in bridge healthy was mode change cause by time history (Arredondo 2013, Whelan 2008).

4 TEST RESULT

4.1 Spectral Analysis

Accelerator sensor gives vibration data. This data are acceleration in Y-axis and time in X-axis. Three data are acquired from this sensor. These are vibration in X, Y and Z-axis. Figure three show vibration data from acceleration sensor. A vibration filter is made in this data to clean vibration data. Vibration data then analyze by using spectral type of wave. Vibration data taken from laboratory and field are approaching to impulse wave.

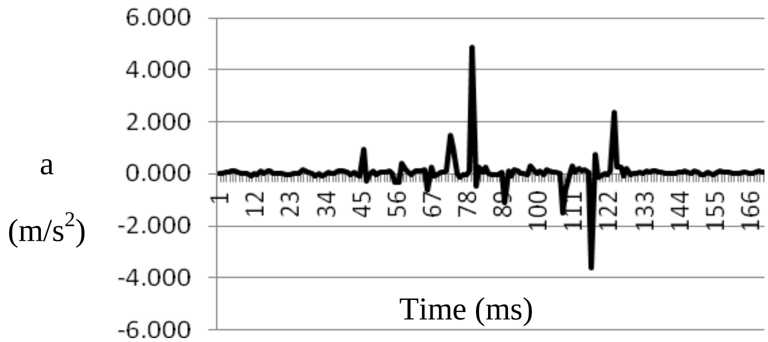

Figure 3. Vibration of X axis.

4.2 Laboratory test

In order to get bridge information, several cases has been done. Cases are consisting of weight of load and height of falling. They are show as below in Table 1.

Table 1. Comparison of bridge behavior.

Case	Average Translation (mm)	Average Rotation (mm)
C1: Weight 565 gram	0.00123	0.000200
C2:Weight 810 gram	0.00166	0.000325
C3: Height 20 cm	0.00040	0.000082
C4: Height 40 cm	0.00040	0.000006

Table 1 shows that weight of load can create information of bridge condition. An early warning of bridge can be getting from this data. Weight changes of load create an increase of translation and rotation. Meanwhile Impact load show a major changes in rotation.

4.3 Field Test

Two truss bridges had been used for this test. Bridge load in field test are a truck with same speed and weight for consistent load in both bridge. Specification, element and material from both bridges are same. The different is one of the bridge is already in plastic mode due to overload use. Vibration sensor has been attached in main girder to capture data from both bridges. Environment condition in field is nearby the same. Wind speed and temperature are normal.

Table 2. Frequency from truss bridge.

Bridge Model	Frequency	Remarks
M1 : Design bridge	m1 = 4.84 m2 = 7.32	Natural frequency
M2 : Failure bridge	m1= 4.52 m2 = 7.32	Natural frequency

Design = bridge base on technical draw Failure = bridge with field measurement

Table 3. Bridge health information.

Bridge Model	Translation	Rotation
M1 : Design bridge load V1	0.00230	0.00010
M2 : Design bridge load V2	0.00104	0.00004

V1 = vibration data in bridge without failure V2 = vibration data in bridge with failure

From table two and three above, a change in frequency due to element failure is shown. Failure element creates a change in element. Meanwhile, a vibration data in simulation model shows that vibration data captured by sensor are recording decrease of translation and rotation. This information might need more understanding using spectral finite element.

5 CONCLUSIONS

Based on the test results several conclusions to discuss are:

1. Laboratory test result shows that vibration data define a change in bridge health.
2. Load in bridge is the key to understanding condition of bridge. A change of load in bridge model can create different vibration data.
3. Failure of bridge does changes natural frequency of bridge. This mean an early warning and failure detection can be used by using vibration data.
4. There is a change of translation and rotation when a design model in simulation applied with different vibration captured by sensor.

This is an ongoing research for creating a bridge monitoring system. Several condition bases on this test report are now being done. A package of spectral finite element is built to define more about bridge health using wireless vibration sensor.

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