Weighbridge Vibration Analysis Using 3 Accelerometer Sensors and Single Excitation

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Abstract. Weighbridge was a measuring instrument that was widely used by the Ministry of Transportation to scale the weight of loaded vehicles on the roadways. Due to being traversed by vehicles with various kind of weight and sizes, weighbridges often experience resonance due to the vibrations of vehicles above it. This will potentially cause damages to weighbridges. To anticipate it, researches regarding vibration analysis on weighbridge were needed to decrease resonance on weighbridges. The Vibration Analysis was done by Modal Analysis Method using three accelerometers and one shaker as the measurement sensor. In testing, weighbridge was modeled into a cylindrical beam shape with a length of 724 mm and a diameter of 16 mm. As the supports, Fix-fix Support was used at both ends of the beam. Next, Accelerometer measurement sensor mounted in three positions with a distance of 181 mm, 362 mm, 543 mm from beam supports. Then, Excitation force with four frequency variations (1 Hz, 3 Hz, 5 Hz, 10 Hz) was applied to the four measuring points located between the accelerometer sensor. The measurements result in the form of FRF graph can be obtained by QuickDAQ. From the FRF graph, the five lowest natural frequency of the weighbridge was obtained that equal to 89.9 Hz, 91 Hz, 69.9 Hz, 75 Hz, and 96.9 Hz.

1. Introduction

Weighbridge was a structure used to scale the weight of trucks on the roadways. This was to make sure for trucks not to be overloaded so that the asphalt lifetime will be sustained according to design. Weighbridge was included as a structural design that receives resonances caused by vibration from trucks traversing above it. If the vibration frequency from the truck is close or equal to the weighbridge’s natural frequency, this might lead to the increased vibration amplitude of the weighbridge, that potentially do some damages to it.

The negative impact that might happen from the resonances could be minimized by doing tests and analyzing the natural frequency of the weighbridge. After obtaining the weighbridge’s natural frequency, next, we can do some actions so that the natural frequency will not get close or even equal with disturbance frequency, example by adding some mass or increasing rigidity to the structure design and etc. The same research ever being done before in which the disturbance signal was coming from earthquakes. And not from vehicles. [1]

In this research, measuring the vibration was done by putting a cylinder beam with fix support underneath the weighbridge, so that the beam could receive the vibration. Next, we use accelerometer and shaker as the input sensor dan the test output. After testing the natural frequency of the beam, we can use it to know the vibration characteristic that happens on the weighbridge.

2. Literature Review

2.1. Weighbridge

Weighbridge was a device to scale the weight of loaded vehicles that can be assembled permanently or portable [2]. The bridge construction was shown in Figure 1, where the device was consist of the load cell, bridge structure, RCC pillar, and ground level.
2.2. One DOF Free Vibration Analysis

Figure 2 shows the schematic structure of one DOF free vibration that consist of a load (m) and supported by a spring with rigidity (k) and excitation force (x, \dot{x}, \ddot{x}). Using motion differential equation, natural frequency can be determined by the following equation [3].

\[ m \ddot{x} + kx = 0 \]  \hspace{1cm} (1)

And assuming the result as:

\[ x = A \sin \omega t \]  \hspace{1cm} (2)

Natural Frequency can be obtained by substituting Equation 2 to Equation 1 that expressed to be Equation 3

\[ w_n = \sqrt{\frac{k}{m}} \]  \hspace{1cm} (3)
2.3. Modal Analysis

Modal Analysis was a process to determine the dynamical characteristic or a modal parameter of a structure. This modal parameter consists of Natural Frequency (ω), mode shapes (ф), and damping ratio (ξ). Some of the common methods to be used were by a test using a shaker as the excitation force like shown in Figure 3. [4].

![Figure 3. Measurement set-up with shaker excitation](image)

Schematically, devices of the loaded impact method consist of
1. Shaker, a device that can produce an excitation force to the structure.
2. Accelerometer, a device that collects responses from the structure due to excitation force.
3. FFT analyzer, a device to be used for FRF computation.
4. PC and modal testing Software to identify the modal parameter and show it in the form of graphs.

In the modal analysis test, accelerometer’s sensors were placed on the determined spots of the structure. Next, the excitation force was given by shaking the specimen with the shaker on the determined spots. Due excitation force, there will responses from the structure that will be collected by the accelerometer. Excitation force and the measurement responses are graphically shown in Figure 4.

![Figure 4. (a). Excitation force graph (b). Responses graph](image)

Excitation forces and measured responses will be sent to the FFT analyzer. Input in the time domain will be converted to the frequency domain. By this, measured FRF is obtained like shown in Figure 5. From the graph, we can obtain the natural frequency of the structure. If we connect a point on the imaginer part of measured FRF into another measuring point, we can obtain the structural vibration modus.
3. Methodology
Modal analysis to measure the personal frequency of the weighbridge structure was ideally performed directly on the measuring object. However, due to the various problem, the measurement is not yet possible to be implemented. So as an alternative measurement was done on the beam cylinder that was modeled under the weighbridge. After that, the beam cylinder was given an excitation force to model the outer vibration causing resonance at the weighbridge. At the capital analysis test setup, it was then used 2 units of the laptop, data acquisition, Arduino Uno, relay, 3 units accelerometer CMCP770A, solenoid valve CAMSCO TAS-15, and beam cylinder with aluminum material as in Figure 5 below. In this case, the accelerometer and shaker (solenoid valve CAMSCO TAS-15) function as the input and output test sensors shown by Figure 6.

Figure 5. FRF Graph [5]

Figure 6. Experiment set up
The cylindrical beam used in this experiment has a length of 724 mm and a diameter of 16 mm. Then the cylindrical beam was supported by fix-fix support at both ends. The next beam cylinder was divided into 4 test points, namely points 1, 2, 3 and 4, where the point will be used as a reference point for the installation of shaker (solenoid valve CAMSCO TAS-15) which serves as an excitation style. Then the three accelerometer output sensors were placed on beams with a distance of 181 mm, 362 mm, 543 mm respectively from the left beam as shown in Figure 7.

![Figure 7. Sensor installation on the measuring object](image)

Information:
Acc1=Accelerometer1(Distance181mm)
Acc2=Accelerometer2(Distance362mm)
Acc3=Accelerometer3(Distance543mm)
1,2,3,4 = Point of excitation force

Modal analysis was done by giving the excitation force at point 1 four times with each different frequency that was 1 Hz, 3 Hz, 5 Hz, and 10 Hz. Then, the structural response due to the excitation force excitation was captured by three accelerometer sensors displayed in FRF graphic form. Next three FRF graphs from each accelerometer were compared to get the best results. The same test was continued at the next test point 2, 3 and 4 as shown in Figure 8.

![Figure 8. Modal analysis on beam cylinder](image)

4. Result And Discussion
Based on the tests result, some obtained FRF graphs derived from four test points with four variations of excitation force frequency. The graph was subsequently grouped by the excitation force frequency of each test starting from the lowest frequency of 1 Hz as shown in Figure 9. In the test with the excitation force of 1 Hz, the response captured by the accelerometer tends not well, where the peak of the five lowest frequencies of the structure on the graph FRF was not clearly visible. This condition
occurs because the frequency of excitation force given was relatively low, so the noise coming from outside the system was captured by the accelerometer sensor.

In tests with excitation force frequency 3 Hz, the results obtained tend to be better, which was the top five lowest natural frequencies of structures can be seen clearly on the FRF graph. This was because, at the 3 Hz excitation force, the difference in magnitude of each personal frequency was relatively lower so that the peak of the five lowest personal frequencies can be displayed as well as in Figure 10.
While in the test with the 5 Hz and 10 Hz excitation force, the FRF graphs that were obtained have a magnitude difference that tends to be greater than the previous test, so that some of the lowest natural frequency peak structures cannot be presented well as shown in Figure 11 and Figure 12.

![Figure 11. FRF Graph with 5 Hz excitation force](image)

![Figure 12. FRF Graph with 10 Hz excitation force](image)

Based on FRF graph, it was obtained five lowest beam cylinder frequencies. It was 82 Hz, 85 Hz, 87.5 Hz, 91 Hz, and 94 Hz. The best natural frequency values were displayed by the accelerometer no 2 which was located at the center of the beam cylinder 362 mm from the beam support. It was due to
accelerometer position from the beam support, so that accelerometer response to the excitation force becomes better. Furthermore, in order to avoid the resonance that can harm the structure, the excitation force acting on the structure must be controlled in such a way that its frequency was not close to or equal to the natural frequency of the structure. Otherwise, the resonance amplitude can be minimized by increasing the stiffness of the structure, or leaving the additional masses so that the natural frequency of the structure becomes changed.

5. Conclusion
Based on modal analysis with one excitation force and three accelerometer sensors, we got the five lowest frequency of weighbridge structure 82 Hz, 85 Hz, 87.5 Hz, 91 Hz, and 94 Hz. The best response of the sensor was obtained on accelerometer no 2 with a 3 Hz test excitation force.

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