WASHBOARD ROAD: DISPLACEMENT AMPLITUDE AND FREQUENCY OF SAND BED

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1. INTRODUCTION

When unpaved road is subjected to the traffic flow, flat surface becomes ripples. This phenomenon is called corrugation of road or washboard road. Washboard phenomena can be dangerous to road users since tire may lose contact with road surface. Many studies have been conducted and various models were proposed. From linear stability analysis, corrugations will develop when the speed of the cars exceeds a critical value [1, 2]. Also an experiment study on rolling wheels has demonstrated that ripples would appear when the speed is higher than critical speed. However, compaction and segregation are inessential for ripple phenomenon [3]. On the other hand, a study concerning lift and drag forces acting on an inclined plow has concluded that lift and drag forces are dependent on mass of the plow rather than velocity [4].

2. EXPERIMENT

The experiment apparatus is a rotation circular track that is 50 cm in diameter. The track is 9 cm in width and 5 cm in height. It is filled with dry granular sand with particle size of $200 \pm 100\,\mu$m. An oscillator is attached with counter weight and spring to simulate wheel system of a car. A laser is fixed for measuring displacement of sand bed, as shown in **Fig. 1**.

A wooden circular shaped object which is 3 cm in diameter and 1.5 cm in width is used as a contact surface to simulate a tire of vehicles. During experiment, sand track is moved with constant horizontal velocity and the oscillator can oscillate freely in vertical direction. Before the experiment, surface was levelled (within $\pm$ 2 mm). Then, the oscillator is placed on sand track and the track travels at 3.0 rounds per minute (rpm) for 2 minutes to stabilize the sand bed. This velocity is low enough for the oscillator to move along the track without any ripple. Without stopping the track, after sand bed is stabilized, rotation rate will be increased to a specified value. In this experiment, rotation rates are from 6.0 rpm to 19.5 rpm (equivalent to 0.15 and 0.51 m/s respectively) with 1.5 rpm step increasing in each test. The track will move at constant rotation rate for 7 minutes, to develop ripples. Displacement of sand bed will be collected by data logger (WAVE LOGGER) with a frequency of 100 Hz.

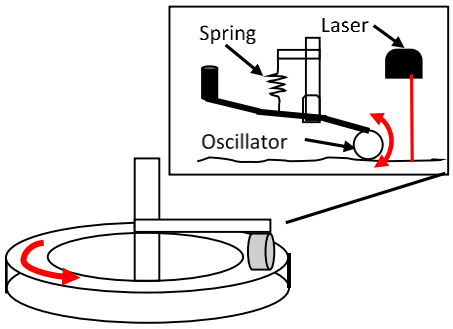

Fig. 1 Schematic view of experimental apparatus and the oscillator.

3. RESULTS

Displacement with respect to time is measured from each test. Then, the Fourier analysis program is applied (FFT-sorobanV102). The program will apply Fast Fourier Transform (FFT) to measured data. In each calculation of Fourier analysis program, 1024 data set is used and counted as 1 round (equivalent to 10.24 second). Output of this program will be in form of amplitude and its frequency of each round. The average, maximum and minimum displacement amplitude from each round can be computed by the program. Each test has approximate 41 rounds. With this measurement, the development of washboard phenomenon and the transition of sand bed can be observed.

The spectrum of amplitude is shown in **Fig. 2**. There are two peaks observed at round 15. First peak is at 1.66 Hz and the second peak is at 3.22 Hz. However, the first peak frequency at round 15 is different from that in round 9. At round 9, the first peak is at 1.95 Hz. At round 12, peak at 1.95 Hz decrease as the development of new peak at 1.66 Hz.

Keywords: washboard road, corrugation of roads, natural frequency
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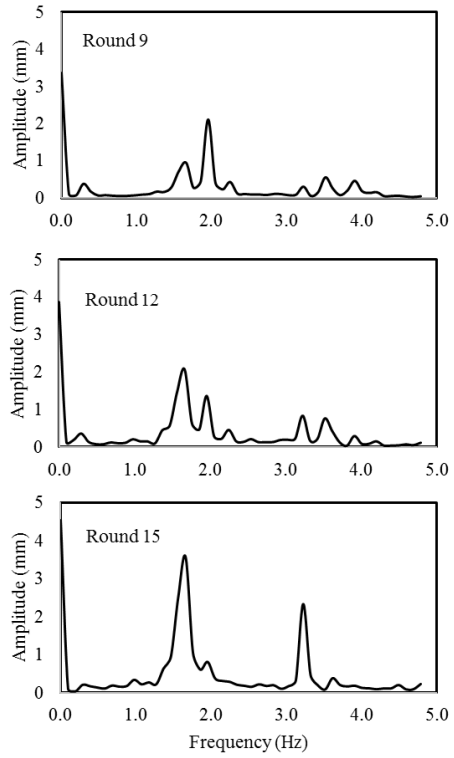

Fig. 2 A Spectrum of amplitude of round 9 (top), round 12 (middle) and round 15 (bottom) from 19.5 rpm test.

There are some appearances of second peak between 3.00 - 4.00 Hz. At round 15, it can be clearly seen that there are two peaks are at 1.66 Hz and 3.22 Hz respectively. From round 15 to the end of experiment, the spectrum shows the same tendency with slightly increasing in amplitude, but the peak frequency is not changed anymore.

The overall maximum, average and minimum amplitudes from 19.5 rpm test are shown in **Fig. 3**. Maximum amplitude increases at the beginning then slightly decreases. On the contrary, minimum amplitude decreases then becomes stable. The average amplitude constantly decreases throughout the test. The maximum and minimum amplitude from each test is averaged and shown in **Fig. 4**. With the increasing of rotation rate, the maximum amplitude increases significantly. The highest rotation rate has the largest amplitude.

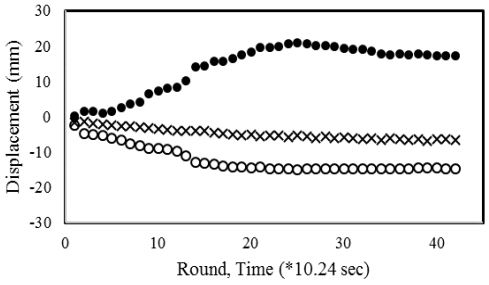

Fig. 3 Maximum (●), average (x) and minimum (○) displacement of 19.5 rpm test

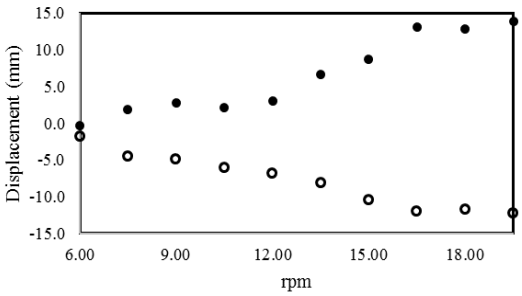

Fig. 4 Maximum (●) and minimum (○) displacement of all tests

After the experiment, the natural frequency of this oscillator is measured and the natural frequency of oscillator is 1.66 Hz.

4. CONCLUSIONS

Higher rotation rate contributes to larger displacement which means the height of ripple in washboard road will increase with the velocity. The increasing in amplitude is corresponding to the increasing of peak spectrum. It is clearly seen that peak spectrum will shift to lower frequency comparing to initial stage. Furthermore, at the final stage, first peak has the same frequency as a natural frequency of oscillator. During shifting, there is a transition of sand bed. After peak frequency matched with natural frequency of oscillator, the amplitude increases dramatically.

To be concluded, the peak spectrum could adjust itself to match with the natural frequency of the oscillator. Once it meets the natural frequency, the increasing rate of amplitude is accelerated. Comparing to reality, if the frequency of wheel system meets the frequency of ripple in washboard road, the amplitude of washboard becomes more severe.

REFERENCES

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