WASHBOARD ROAD: EFFECT OF NATURAL FREQUENCY TO THE DYNAMIC BEHAVIOR OF SAND SURFACE

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1. INTRODUCTION

Corrugation can be spontaneously formed when unpaved road is subjected to traffic passage. This phenomenon is called washboard roads or corrugation of the roads. Causes of washboard roads are lack of moisture, driving habits and poor gradation of gravel[1]. Linear stability analysis on a plow dragged on circular sand track shows the existence of critical velocity which cause corrugation[2]. A study on rotating wheel on circular sand track has shown that the amplitude of ripples can be affected by number of ripples on the track[3]. Our previous work on an oscillator running on sand track has focused on amplitude and frequency of sand bed[4]. Herein, this paper will focus on the effect of natural frequency of oscillator to the dynamic behavior of sand profile.

2. EXPERIMENT

A 50-cm-diameter rotating track is used in experiment. An oscillator with circular shaped attachment is used to simulate action of the vehicle. Spring and counterweight are attached to the oscillator as shown in **Figure 1.** The oscillator will drag along the track filled with dry sand which particle size is 0.2 mm. The track will rotate at constant velocity during the experiment. Velocities used in this experiment are ranging from 7.5 to 19.5 round per minutes (rpm) with 1.5 rpm step increment in each set of experiment. Natural frequency of oscillator can be changed by adjusting the counterweight at the tail of oscillator. In this study, natural frequency used are 1.367, 1.464 and 1.660 Hz.

First, sand surface is flatted and original sand level is measured via laser. Then oscillator is placed on the track and travelled at low speed to stabilize sand surface. Sand level after placing oscillator is measured for calculating the force applied on sand. After that, the track will rotate at a specified velocity for 7 minutes to observe the corrugation. Finally, height of sand is collected through data logger, and frequency spectrum of sand surface is calculated by using Fast Fourier Transform (FFT). From this analysis, transformation of sand surface and dynamics of corrugation can be obtained.

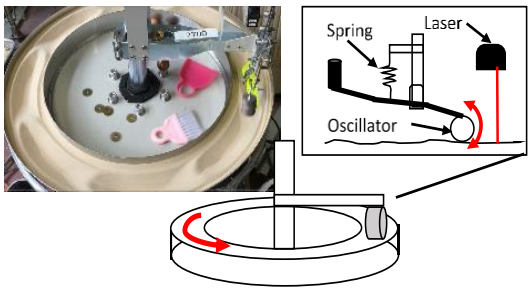

Figure 1 Schematic view of experimental apparatus and the oscillator.

3. RESULTS

3.1 Final wave number of corrugation

Wave number can be obtained from predominant frequency of sand throughout the experiment to predict expected number of ripples on the track. Final wave number at the end of each experiment is calculated and compared with different velocities and natural frequencies. As shown in **Figure *2***, the wave numbers of 1.660Hz indicated with circular marks decrease from 15 for 9.0 rpm to 7 for 19.5 rpm. For the case of 1.367 Hz (triangular marks), the wave numbers similarly reduce from 13 to 6. For the same natural frequency, final wave number shows decreasing trend as velocity increase. Furthermore, increasing in natural frequency of oscillator makes final wave number becomes larger for all velocities. However, some wave numbers are overlap between different natural frequency.

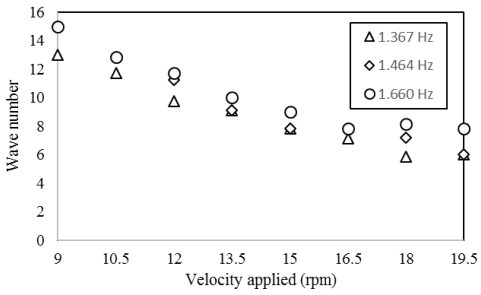

Figure 2 Final wave number with respect to velocities and natural frequencies of oscillator

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3.2 Increasing in height of corrugation

Changes in maximum height of sand surface with time are shown in **Figure 3** for each natural frequency. From the beginning, maximum height of sand (i.e. height of ripples) increasing with time. For the natural frequency of 1.367 Hz, height of ripples for the velocity of 10.5 rpm is steady increasing with time. However, when velocity becomes more than 12.0 rpm, height increasing abruptly from the beginning. There is a transition velocity which height of ripples changes from gradually to abruptly increase. In the case of 1.367 Hz, transition velocity is between 10.5 and 12.0 rpm. But for the case of 1.660 Hz, transition velocity is between 13.5 and 15.0 rpm. The increasing in the natural frequency of oscillator causes the transition velocity increase. Especially for 1.367 and 1.660 Hz, the difference in growth of maximum height of sand when velocity is increasing is clearly seen.

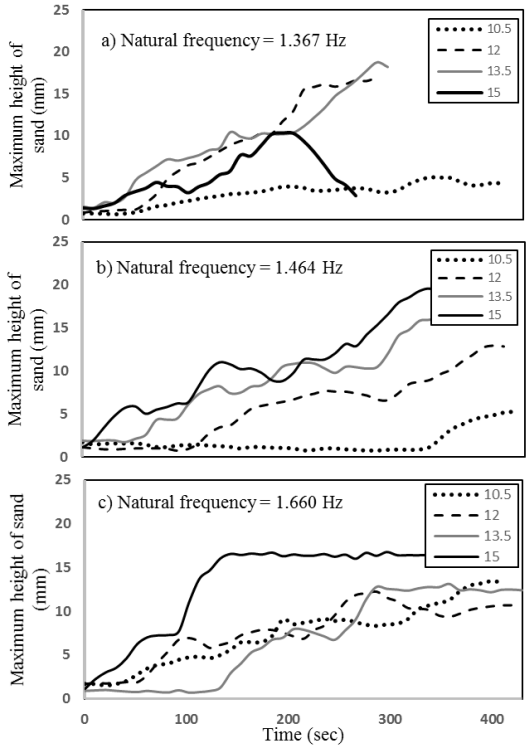

Figure 3 Maximum height of sand surface for the natural frequency of (a) 1.367 Hz, (b) 1.464 Hz and (c) 1.660 Hz

3.3 Change in wave number

Change in wave number and height of sand surface throughout the experiment is shown in **Figure 4**.

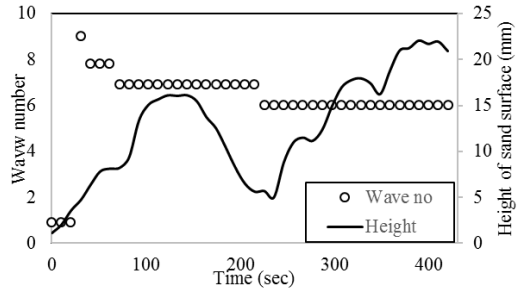

Figure 4 Wave number and height of sand surface from 19.5 rpm experiment with natural frequency of 1.464 Hz

Wave number is decreasing overtime. On the contrary, height of corrugation has some drop but shows increasing trend at the end. Sudden drop in height of corrugation occurs with change in wave number.

4. CONCLUSIONS

We have presented washboard phenomenon based on oscillated attachment[4]. From our previous works, height of corrugation will increase with the increasing in velocity applied. Predominant sand frequency will be shifted lower and finally match with the natural frequency of oscillator. Moreover, in this study, we found that final wavenumber was affected by velocity and natural frequency of oscillator. Change in natural frequency of oscillator also affects the growth rate of the height of corrugation and the transition velocity in which corrugation become abruptly generated. Final wave number is directly related with predominant frequency and reduce over time during the experiment. Change in wave number will slow down or even reduce the growth rate of the height of corrugation. We have confirmed that final predominant frequency will be shifted to lower frequency; however, in this study, it did not match with natural frequency of oscillator. Our suggestion is to extend the duration of experiment and confirm condition of the corrugation at the steady state.

This study indicates that natural frequency and velocity of oscillator or vehicles play important role to the washboard phenomenon. Our further study is to apply these relationships into dynamic numerical model.

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