WASHBOARD ROAD: Corrugation on Dry Granular Sand and Snow Roadbed

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1. INTRODUCTION

Washboard road usually occurs on the granular road surface in a dry environment. Recently, our observation in Sapporo city has shown that corrugation can be developed over a snow-covered road surface, and it usually occurs near intersection during the temperature between 0 to -2 Celsius [1]. It was experimentally proved that washboard roads can be developed over a granular sand using the rolling wheel and incline plow moved along circular track [2]. Our previous works have successfully reproduced washboard phenomenon using oscillator running over rotating track filled with dry sand [3, 4]. In this study, washboard experiment is performed with real dry snow and wet snow respectively. Dynamic change of snow surface is investigated.

Figure 1 Left: Washboarding on dirt road (Photo by Leprechaun , The Navara Forum). Right: Snow corrugation (Photo taken at Hokkaido University)

2. EXPERIMENT

Our experiment consists of 50-cm diameter rotation track. The track can run at constant but adjustable speed. We introduced an oscillator with spring and counterweight to simulate the action of vehicle's wheel. Oscillator is fixed with the frame but it can rotate freely in vertical direction as in **Figure 2**. Natural frequency of oscillator can be adjusted by changing the counterweight at the tail, and in this study, natural frequency of oscillator is 1.66 Hz. Two different velocities, 12.0 and 15.0 round per minute (rpm), are used in the experiment. Material used to fill the track are dry granular sand with the particle size of 0.2 mm, real snow and real snow mixed with cold water.

At each experiment, surface was hand flatten and original surface level is measured via laser. Then, the oscillator is placed on the track and run at low speed of 6.0 rpm to stabilized roadbed for 2 minutes. Surface level is again measured to calculate deformation. After that, the track will run at specified velocity for 7 minutes or until the corrugation is fully developed. The height of surface is measured throughout the experiment and collected via datalogger. Results then are analyzed by Fast Fourier Transform (FFT), and changes in surface level and surface frequencies spectrum over time are obtained through the analysis. The experiment on dry sand was done at room temperature while the experiment on real snow was done in the cold room which temperature is controlled between -2 to 0 Celsius.

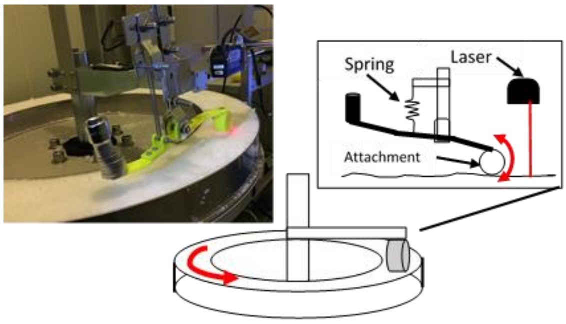

Figure 2 Schematic view of experimental apparatus and the oscillator.

3. RESULTS

For the experiment using dry sand, corrugation developed just after the beginning of the experiment for 15.0 rpm, but for the 12.0 rpm, corrugation started after several minutes. Corrugation gradually grows in amplitude and wavelength, and ripples spread over the entire length of the track. After several rotations, corrugation reached a transient state where corrugation become irregularity. The growth rate of corrugation is dropped and the predominant frequency of sand surface is changed in transient state. The corrugation switched between steady grow and transient state until it become stable. At the end, the amplitude of corrugation is measured to be 12 and 17 mm for 12.0 and 15.0 rpm respectively. The results correspond to our previous studies [3, 4].

Keywords: Washboard road, Corrugation of roads, Snow-covered roads, Road maintenance
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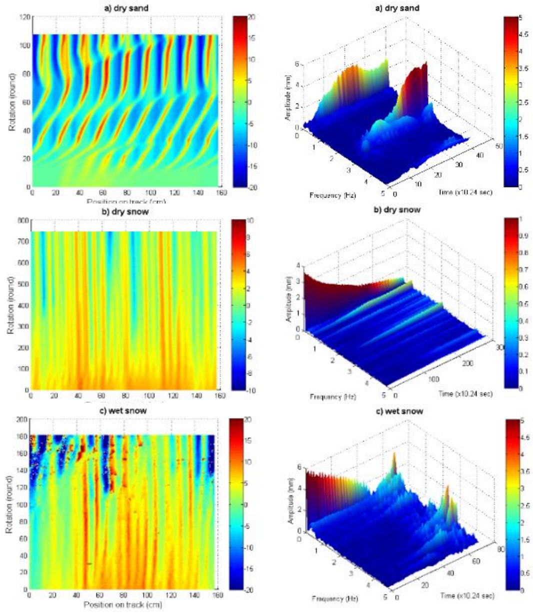

Figure 3 (Left) Contour plot of surface height and (right) frequency of surface 15.0 rpm for a) dry sand, b) real snow and c) wet snow.

Changes in surface height and the spectrum of the surface for the experiment with dry sand, dry snow and wet snow at 15.0 rpm is shown in **Figure 3**. For the case of 15.0 rpm, corrugation on dry sand usually take place just after the beginning; on the contrary, corrugation on dry snow may take up to 1 hour while wet snow may take about 15 to 30 minutes. For wet snow, higher temperature makes snow melt faster and the corrugation takes a shorter time to be developed. Contour plots show that both dry snow and wet snow have the same behavior which corrugation stay at the same position in the track contrary to dry sand which ripples move forward. There is no transient state presented in the case of dry snow and wet snow. Moreover, the height of ripples for dry snow and wet snow are slightly decreasing but the surface level is gradually decreasing over the time in contrast to the case of dry sand which surface level remains the same and the height of ripples increasing overtime.

Final amplitude, predominant peak frequency which is calculated from FFT and wavenumber of corrugation from all experiments are shown in **Table 1**. Wave number represent an expected number of ripples on the track which is calculated from predominant frequency, and the initial deformation is the deformation of sand level due to the weight of oscillator. Wet snow cause highest amplitude of corrugation at 20 mm with the predominant frequency of 2.83 and 3.03 Hz for 12.0 and 15.0 rpm, respectively. Corrugation on dry snow has a relatively low amplitude which is 6 mm for 12.0 rpm and 4 mm for 15.0 rpm, and the predominant peak frequency is far from those in dry sand or real snow. The frequency for dry sand is 2.344 and 2.246 Hz for 12.0 and 15.0 rpm respectively.

Table 1 Results summary for the experiment on dry sand, real snow and wet snow

Material	Velocity (rpm)	Snow temp. (c)	Final peak frequency (Hz)	Corrugation amplitude (mm)	Calculated wave number	Initial deformation (mm)
Dry sand	12.0		2.344	12.41	11.7	1.06
	15.0		2.246	17.64	9.0	1.50
Dry snow	12.0	-0.3	0.781	6.00	3.9	0.25
	15.0	-0.3	0.488	4.00	2.0	0.20
Wet snow	12.0	-0.4	2.832	20.00	14.2	0.19
	15.0	-0.4	3.027	20.00	12.1	0.27

4. CONCLUSIONS

We have demonstrated that it is possible to create washboard phenomenon experimentally on dry sand, dry snow and wet snow in this study; however, its dynamic behavior is different. First, comparing to dry sand, dry snow require much more time to develop corrugation. The present of water cause corrugation to develop faster, and melting process may have some effect on the development of corrugation as seen in the case of wet snow. Secondly, there is no transient state for dry snow and wet snow which ripples collide and merge contrary to dry sand. Particle bonding and deformability of material should be considered. Third, the formation of ripple for dry snow and wet snow come from surface settlement while ripple in dry sand comes from the deposition of sand material. Finally, the predominant frequency was affected by material and velocity. For the case of dry sand and wet snow, the predominant frequency of corrugation is in range and close to each other for the same material, and the difference comes from the effect of velocity and penetrating force. We could not find any relationship of predominant frequency in the case of dry snow. This study gives us a preliminary understanding of corrugation on snow-covered roads; however, further studies are required to understand its behavior and factors causing corrugation.

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