Low-Cost Vibration Chamber for Landslide Sensory and Alarm System

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Article Info

Article history:

Received Jan 4, 2018
Revised Mar 8, 2018
Accepted Mar 25, 2018

Keywords:

Low-Cost
Landslide Alarm
Of-the-Shelf
Vibration Chamber
Sensory

ABSTRACT

Many previous research works published in the open literature aimed at designing a system that could detect landslide in early stage before the landslide becomes catastrophic. This paper presents a work-in-progress landslide early warning system for Malaysian environment. The aim of this paper is to develop the most effeciencly reliable cost-effective system in which slight earth movements are monitored continuously. The challenge this work aims at is to work with a low budget system that produce efficient performance. Hence, the material used is of-the-shelf. Early design optimization result of the vibration sensor used is quite promising detecting the slightest faint tremors, which are amplified using the best vibration chamber available. It is shown that the choice of proper pipe length and diameter dimensions in combination to a gravel to exaggerate the produced higher sensitivity level of 5dB. Furthermore, both systematic and random vibration tests produced similar results.

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1. INTRODUCTION

Landslide, also known as slope failure, landslips or slums can be defined as movement of rock or debris down a slope. In other words, landslide is the changes of the condition of the slope from stable to unstable. Landslide can happen due to natural phenomenon and human activities. The factors that causes landslides naturally are earthquakes, groundwater, erosion and volcanic eruptions. Whereas, acts by human that result in landslides are deforestation, construction, blasting, earthwork and vibrations from machinery. In Malaysia, 1969 was the earliest landslide occurred and it was in Pahang. There were seventeen landslides were recorded in total now and the latest was the last year in Selangor. People were injured and killed in this natural hazard and had caused tremendous damages to the environment infrastructure. These would have cause a lot of money for the recovery. The purpose of invention of landslide early warning system is to reduce all the risks mentioned above. In fact, many lives could be saved from becoming the victim of this natural hazard. Many research papers were published regarding this landslide early warning system from time to time to develop the most reliable and efficient system in order to alert people in the prone area about this hazard while it is still early. This paper aims to design a vibration sensor and to investigate its different parameters to improve its capability in detecting landslides using commercial off-the-shelf materials. The optimum sensing structure dimensions were investigated for sensor casing for maximum acoustic density. The type of sensor that can detect ground movement is identified and it was decided to use vibration sensor SW-420. Next, as an effort to increase the accuracy and intensity of the vibration, gravels were placed inside a pipe before buried in the ground. In fact, several experiments were carried out to investigate this matter and the results obtained is positive. Lastly, in finding the optimum dimension of pipe, numerous experiments were conducted for three different lengths of pipes with four different diameters for each length. The paper is organized as follows. Section 1 briefly explain the concept of landslide monitoring system and the sensors used in different projects. Section 2 introduces the methodology. Section 4 presents the results and discussion. Section 5 concludes the paper.

1.1. Concept of Landslide Monitoring System

Landslide can be described as a movement of soil, debris or rock down a slope caused by earthquake, rainfall or rapid snow melt [1], [2]. Since 50 years ago, the speed of the movement in the ground have been changing from slowest to very slow [3]. Furthermore, every year, landslides has affected many countries over the world in fact has endanger even killed many human life and destroyed the environment. The complex interaction of many factors such as lithology, soil properties and elevation have made the landslide occurrence is hard to predict [4]. For this reason, the development of landslide sensor has been evolving every day in order to produce the most reliable and effective system in detecting landslide hence alert the people in the prone area at the same time. Therefore, data transmission in real-time regarding the status of stability of slope in the prone areas has become a major concerned in research area in the hope that an efficient landslide early warning system could be developed. Landslide monitoring system is basically requiring experimental studies to test the sensors together with the data transmission from the sensor node to the base unit before deploy those sensors in the prone area. Data transmission is the communication from sensor node to base unit. It lets the base unit to know when there are changes in the ground. Nowadays, wireless sensor node (WSN) has been widely used because of its capability to transmit data in real-time. Once a data is received at the base unit that indicates there is potential landslide, early warning system (EWS) plays a major role to alert the people to save their lives. EWS can be defined as to instantly spread meaningful warning information so that people nearby that are exposed to a hazard can prepare and act accordingly to reduce the possibility of danger or loss [5]. This alarm system is very important because this is the only way to alert the people in the prone area that a natural hazard is about to happen and their lives are in danger. By the time the alarm is generated, the hazard is still in early phase and before it become catastrophic, the people would have enough time to save their lives and valuable belongings. Since the focus of this paper is on the sensor itself, we will limit our discussion to it.

1.2. Type of Sensors Used for Landslide Monitoring System

Different types of sensors have been introduced for landslide detection in every research paper. The first type of sensor is called vibration sensor and it is used to sense any movement in the ground. Reference [6],[7] propose to place a vibration sensor, SHOCK-801S in a stainless steel pipe. The pipe then is buried in the ground together with the sensor. The utilization of this pipe can be the solution to prevent the sensor from broken during the landslide phenomenon. On the other hand, ADXL 202 biaxial accelerometer can be used to measure both inclination angle and acceleration of ground movement [2]. Figure 1 shows different types of sensors that can be used to detect landslide.

Equally important, extensometer and inclinometer can be used to measure the slope surface displacement and slope movement respectively. Above all, for slow and sudden ground movement, tiltmeter is the best choice [1], [6]. On the contrary, landslide rainfall-induced can be detected by sensors like osmometer, dielectric moisture sensor, pore pressure piezometer, strain gauge and rain gauge [1], [8]. Table 1 shows list of sensors and their corresponding functions.

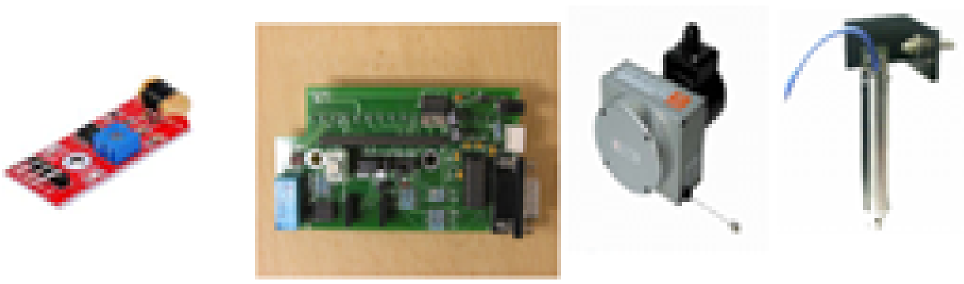

Figure 1. From left to right: Vibration Sensor (SHOCK-801S) [6], Accelerometer sensor (ADXL 202 biaxial accelerometer) [2], Extensometer and Tilt Sensor

Table 1. Sensors and their functions

Sensor	Function
Vibration	To detect debris vibration in the ground.
Accelerometer	To obtain the acceleration of the ground movement.
Extensometer	To measure the displacement of the slope.
Inclinometer	To measure vertically and horizontally the movement of the slope.
Tiltmeter	To measure slow and sudden movement of soil layer
Osmometer	To measure pore water pressure.
Dielectric moisture sensor	To measure the permitivity or dielectric constant of the soil.
Pore pressure piezometer,	To measure pore water pressure.
Strain gauge	To measure the deflection of soil layer when the ground has a movement.
Rain gauge	To measure the accumulative of rainfall.
Geophone	To measure vibration.

2. RESEARCH METHOD

The type of sensor used to detect ground movement is vibration sensor, SW-420 and it is well known as highly sensitive sensor. When there is no vibration, the output signal is low and the LED will not turn on. Whereas, when there is vibration the output signal is high and the LED will turn on. As shown in Figure 2, the vibration module consists of the sensor itself, an LM 393 chip and a potentiometer. LM 393 chip is a comparator and it is used to detect vibration if it is exceeded the threshold. This threshold can be adjusted by the potentiometer. Turning the potentiometer in clockwise direction will decrease the sensitivity while anticlockwise direction will increase the sensitivity. Off-the-shelf PVC pipe was selected as the casing of the sensor and several experiments were conducted to determine the optimum dimensions in terms of length and diameter in producing the highest vibration intensity. The dimensions chose to be tested are diameter of 15mm, 32mm, 50mm and 80mm for each of 1m, 2m and 3m length. Other than that, other advantage of using this pipe is, it can protect the sensor during the landslide so that it can continuously function during the landslide phenomenon.

2.1. Components

a) Vibration module sensor (SW-420),
b) LED,
c) Arduino UNO board
d) Jumper wire
e) Gravel
f) Laptop
g) Shaker machine
h) PVC pipes:

Table 2. Dimensions of pipe

Length (m)	Diameter (mm)			
1	15	32	50	80
2	15	32	50	80
3	15	32	50	80

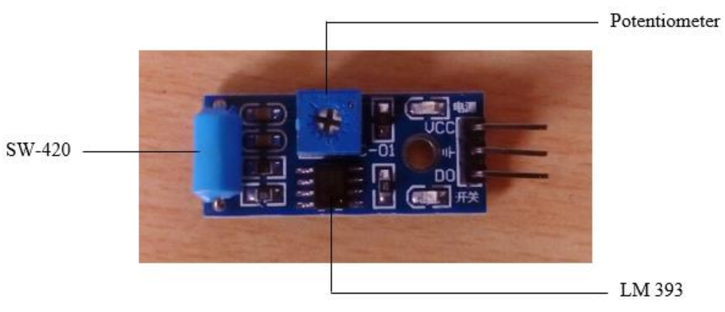

Figure 2. Vibration sensor module SW-420

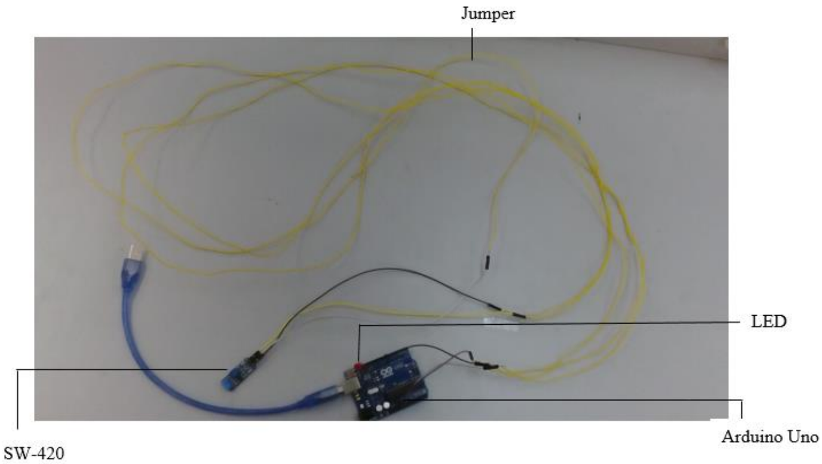

Figure 3. Components used in the experiment (SW-420, jumper, LED, Arduino Uno board

Figure 4. Shaker machine

2.2. Experiments

The programming code to enable the laptop read the measurement from the sensor is compiled and uploaded by using Arduino Integrated Development Environment (IDE) software. Serial monitor on the Arduino software was used to obtained the measurements of the sensor and the measurements were recorded for ten seconds. The experiments conducted can be classified into four categories.

2.2.1. Experiemnt 1: To Test the Functionality of the Sensor

A good vibration sensor is not supposed to record any measurement when there is no motion applied to the pipe. This is important to avoid the people receive false alarm. The sensor was placed in a pipe of 2m length and 15mm diameter and was left with no motion applied to it for a time.

2.2.2. Experiment 2: To Increase the Sensitivity of the Sensor

Even though the potentiometer on the board can be adjusted to increase the sensitivity, but it is not enough to detect the slightest faint tremor. To increase the sensitivity, 10 pieces of gravels were placed inside the pipe to induce stronger acoustic vibration. When the pipe is moving, these gravels are moving as well and hit the inner wall of the pipe hence produce more vibration inside the pipe.

2.2.3. Experiment 3: To Find the Optimum Dimension and Position of Pipe in Producing Highest Acoustic Intensity

This experiment was conducted to determine which length and diameter can produce the highest acoustic intensity when the gravels hit the inner wall of the pipe. All the 12 pipes were shake manually and systematically to simulate the ground movement.

2.2.3.1. Random Shaking

This experiment was performed with two different position of pipe and two different direction of shaking. The vibration was induced vertically and horizontally by shaking the pipe randomly back/forth and up/down motions for ten seconds. The positions of pipe and directions of shaking can be illustrated in the table below also in Figure 4 and Figure 5. Furthermore, these 12 pipes were tested with both gravel inside the pipe and without gravel inside the pipe.

Table 3. Positions of Pipe and Direction of Shaking Performed During Manually Shaking

Position of pipe	Direction of shaking	Gravel
Horizontal	Back and forth	No
		Yes
	Up and down	No
		Yes
Vertical	Back and forth	No
		Yes
	Up and down	No
		Yes

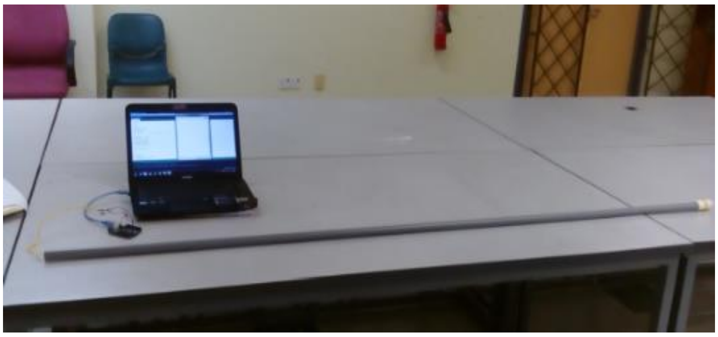

Figure 5. The experiment set-up when the pipe is laid horizontally

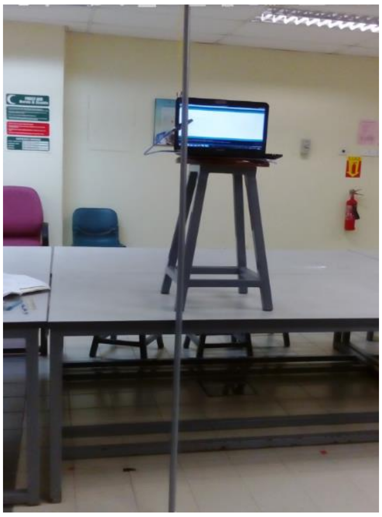

Figure 6. The experiment set-up when the pipe is held vertically

2.2.3.2. Systematic Shaking

Shaker machine in lab was used to emulate earthquake and strong landlside. The pipe was taped on top of the machine as shown in Figure 7. Measurements were obtained for four different speed which were speed=6, speed=8, speed=10 and speed=10. Speed=6 was the slowest movement that the sensor can sense.

Figure 7. The experiment set up for systematic shaking

3. RESULTS AND ANALYSIS

3.1. Experiment 1: To Test the Functionality of the Sensor

Part of the results reported here has speared in [9]. Based on Figure 8(a) there was no measurement recorded in Experiment 1 since there was no motion applied to the pipe. When there is motion applied to the pipe, there was measurements recorded as shown in Figure 8(b). Therefore, it can be confirmed that this sensor is working perfectly hence it can be used for the next experiments.

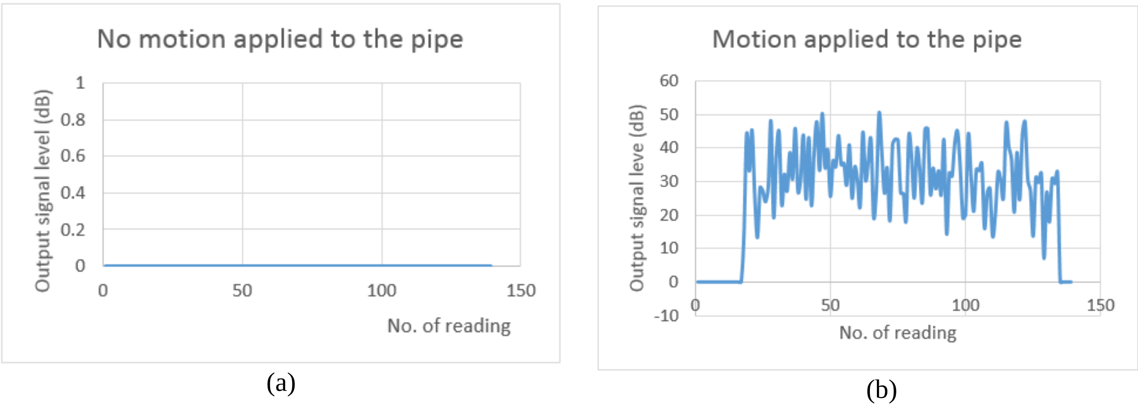

Figure 8. (a)Vibration measurement when no motion applied to the pipe and (b) vibration measurement when motion applied to the pipe

3.2. Experiment 2: To Increase the Sensitivity of the Sensor

In Experiment 2, the value of mean, variance and standard deviation were calculated from the measurements obtained. Table 4 shows the value of mean, variance and standard deviation for pipe of 2m length and 15mm diameter. From these values, it can be seen that the pipe with the gravels inside has higher value compared to pipe without gravels inside for both horizontal and vertical position of the pipe. This means, the gravels produced vibration as well when the pipe was shaking and results in vibration intensity increases. For this reason, it can be confirmed that the gravels can increase the sensitivity of the sensor in detecting landslide. Other than that, this table clearly shows that when the pipe is laid horizontally with the gravels inside the pipe produce the most vibration intensity. The average values of these measurements were plotted in a graph for better visualization and comparison as shown in Figure 9.

Table 4. Comparison of Vibration Measurement for Horizontal and Vertical Position of Pipe

Horizontal		Vertical	
With gravel		With gravel	
Average	15096.709	Average	4208.340741
Variance	759911221	Variance	135802130.4
Standard deviation	27566.487	Standard deviation	11653.41711
Without gravel		Without gravel	
Average	8039.777	Average	1748.291667
Variance	305353399	Variance	20824466.71
Standard deviation	17474.364	Standard deviation	4563.383252
With gravel (dB)		With gravel (dB)	
Average	35.197631	Average	28.94987849
Variance	71.56194	Variance	67.12980137
Standard deviation	8.4594291	Standard deviation	8.193277816
Without gravel (dB)		Without gravel (dB)	
Average	31.997333	Average	24.80375801
Variance	89.095055	Variance	63.220448
Standard deviation	9.4390177	Standard deviation	7.951128725

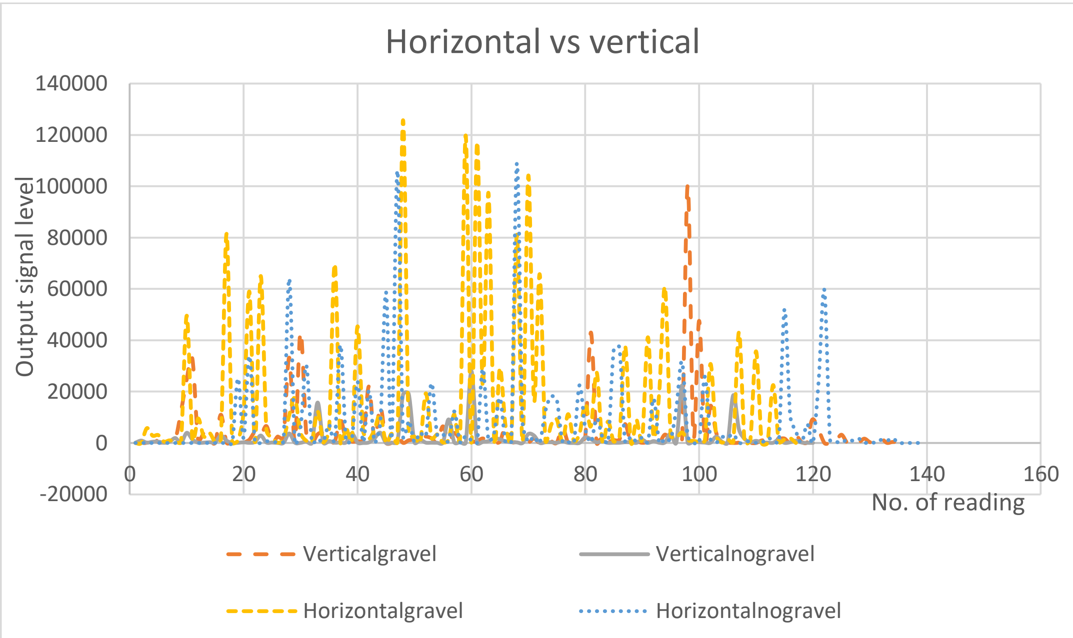

Figure 9. Comparison graph

3.3. Experiment 3: To Find the Optimum Dimension and Position of Pipe in Producing Highest Acoustic Intensity

3.3.1. Random Shaking

In this experiment, the vibration measurements were plotted into graphs for every dimension, position and direction. Based on these graphs, horizontal (up/down) is the dominant signal compared to horizontal (back/forth). On the contrary, vertical (back/forth) is the dominant signal compared to vertical (up/down). The average value of these measurements were calculated. Table 5 shows the average value only for the dominant signal which are horizontal (up/down) and vertical (back/forth). Again, the average values for horizontal position were always outranked vertical position as has been clarified in Experiment 2. Given these points, horizontal position is more favorable than vertical position. In order to find the best dimension, he average values for horizontal position were plotted for all diameters and lengths as shown in Figure 10, Figure 11 and Figure 12. Based on these graphs, they were all peak at 50mm diameter for every length and the highest value is when the length is 2m. Therefore, it can be confirmed that, the optimum dimension in producing the highest acoustic intensity is 2m length and 50mm diameter.

Table 5. Average values from dominant output signal level

Pipe length	Diameter (mm)	Horizontal (up/down)	Vertical (back/forth)
1 m	15	11477.15929	3447.957746
	32	18674.85106	8761.093023
	50	19415.27586	7725.948529
	80	13349.20952	11968.59091
2 m	15	7213.244275	10701.80992
	32	15707.84259	9907.015625
	50	22741.28889	15162.71304
	80	5122.768595	9528.75
3 m	15	9366.97479	3732.014184
	32	13015.28462	3964.978102
	50	14940	7846.96063
	80	3697.046296	3956.823129

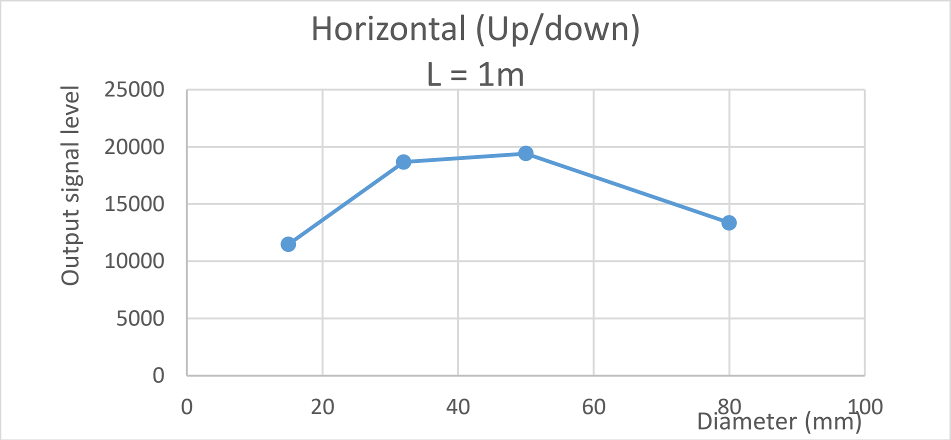

Figure 10. Graph of average values for 1m pipe when the pipe is in horizontal position and is shake up/down

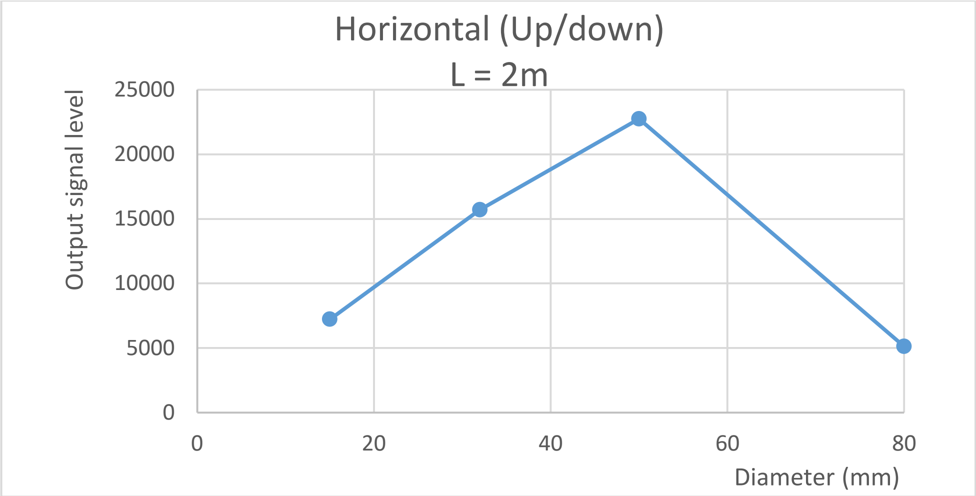

Figure 11. Graph of average values for 2m pipe when the pipe is in horizontal position and is shake up/down

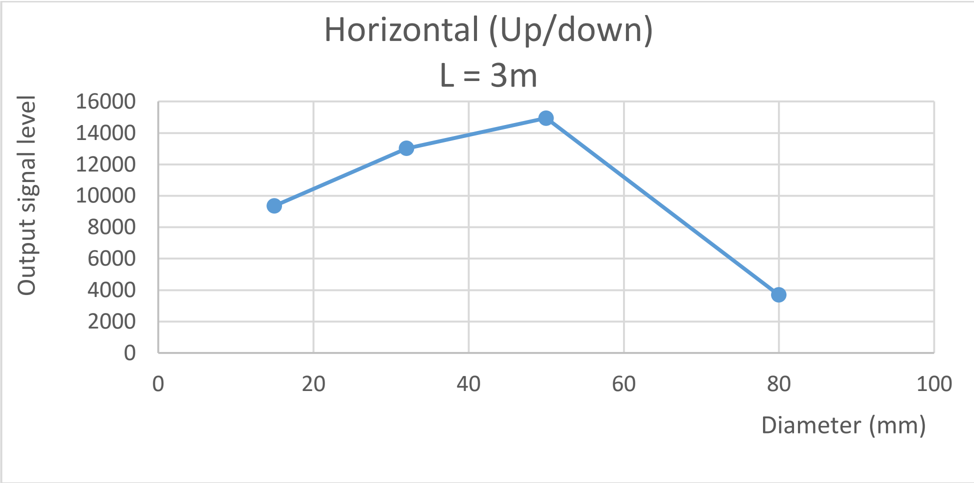

Figure 12. Graph of average values for 3m pipe when the pipe is in horizontal position and is shake up/down

3.3.2. Systematic Shaking

Table 6 below shows the comparison of average values for both systematic and random (e.g., manual) shaking. This experiment was conducted to the 2m length and 50mm diameter pipe only. The speed of the shaker machine was varied from the slowest (speed=6) to the highest (speed=12) to emulate earthquake and strong landslide. The four measurements obtained from random shaking were arranged in ascending order. For random shaking, the directions and positions of pipe can be controlled while for systematic shaking, the speeds of vibration can be controlled. Based on Table 6, it can be concluded that, the average values for random shaking and systematic shaking increases as go down the table because the gravels produced more vibration. From the Figure 13, it clearly shows that, lower earth shaking speeds when manual produces a higher noise-like signal level. In a word, systematic shaking by machine or random hand shaking have almost similar effect on noise-like signal intensity at the output.

Table 6. Comparison of Average Values for Systematic and Random Shaking

Systematic		Random	
Speed	Average value	Event	Average value
6	208	Vertical (up//down)	13275.3
8	10976.4	Horizontal (back/forth)	13409
10	11848.75	Vertical (back/forth)	15162.7
12	32641.97	Horizontal (up/down)	22741.3

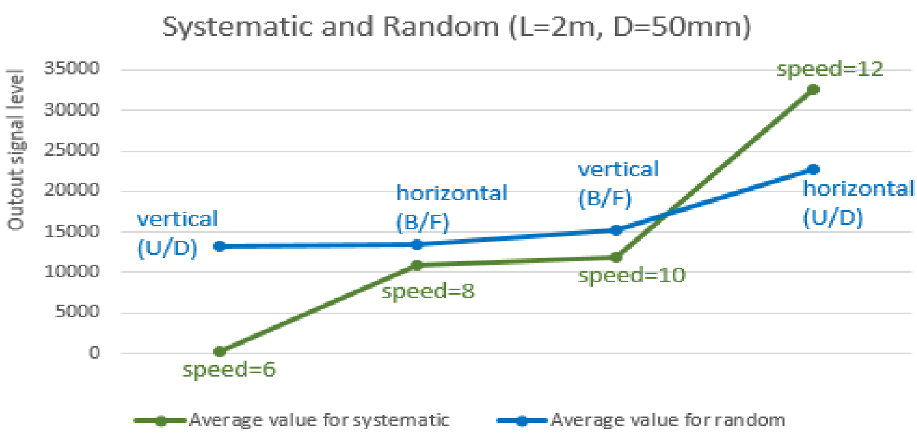

Figure 13. Comparison of average values for sytematic and random shaking

4. CONCLUSION

This work introduced a new design for vibration chamber made using low-cost material to detect and alert of landslides. Extensive systematic and random vinbration tests were conducted on the vibration chamber. Measurement results produced by vibration sensor SW-420 has clarified that PVC-based pipe of length 2m and diameter 50mm stuffed with gravel and laid horizontally produced the best signal. Hence, our future test-bed will take this information into consideration during the final system design process.

ACKNOWLEDGEMENT

This work is sponsored by International Islamic University Malaysia Grant No. RIGS16-362-0526.

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