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AN ELECTRIC SHAKE TABLE SYSTEM FOR DISASTER AND EMERGENCY PREPAREDNESS TRAINING

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Graphical abstract

Abstract

This study presents the design and development of an electric shake table system. The system was used to train civilians and professional responders for disaster preparedness and emergency training. The developed system can simulate actual ground shaking by combining both horizontal and vertical shaking motions produced by the two induction motors. Moreover, the table simulation can produce intensity ranging from III to VIII in accordance to the Philippine Volcanology and Seismology (PHIVOLCS) Earthquake Intensity Scale (PEIS). The table's motion was tested using a wireless digital seismograph to measure its effectiveness in tracking different earthquake intensities.

Keywords: Earthquake, disaster preparedness, seismic shaking, shake table

1.0 INTRODUCTION

When two earth blocks suddenly slip past one another caused by the sudden release of energy in the Earth's crust, an earthquake occurs. To record earthquake activities, a seismograph is used. This instrument is very useful in finding the quake's location and magnitude. Nowadays, most earthquake observations are digitally recorded wherein the data can be stored electronically and at the same time, they are easy to manipulate compared to analog readings [1].

According from the historical data of the United States Geological Survey (USGS), the world's largest earthquake ever recorded in a seismograph was in Chile on May 22, 1960. The earthquake has a 9.5 magnitude that killed approximately 1,655 persons [2]. In the Philippines, a deadly earthquake of magnitude 7.2 hit the Central Visayas region, particularly Bohol and Cebu. From the reports submitted by the National Disaster Risk Reduction and Management Council (NDRRMC), 222 were reported dead, 8 people were missing and almost a thousand people were injured brought by this tremor. For the past 23 years, this disaster was considered to be the strongest and deadliest earthquake that struck the country [3]. This only shows that the country is definitely lagging behind in addressing and providing people's awareness in reducing disaster's risk. Compared with other neighboring countries in the Pacific Ring of Fire, like Japan, they have already developed and employed hundreds of earthquake simulators.

With that, this study will focus on the development of a shake table system that will be used in disaster and emergency preparedness training. The system will provide seismic simulation in accordance with the standard employed by the Philippine Institute of Volcanology and Seismology (PHIVOLCS) Earthquake Intensity Scale (PEIS). This simulator, focusing not only on the mechanical structure and controls, will also serve as the foundation in the field of earthquake engineering research in the country.

2.0 SHAKE TABLE SYSTEM

A shake table or earthquake simulator system is a structural device used in simulating seismic events [4]. These tables are used primarily in testing the sensitivity of large structures like bridges and buildings during earthquakes [5, 6]. The first shake table that was invented was in 1893 at the University of Tokyo by Omori and Milne. The system employed a simple wheel mechanism system and wooden residential construction (see Figure 1) [6].

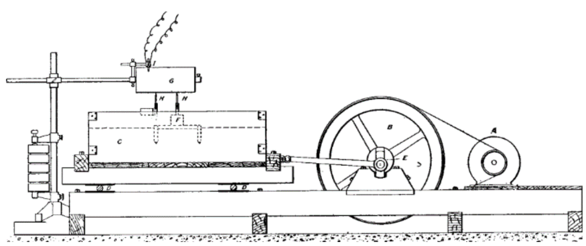

Figure 1 Shake table employing a simple wheel mechanism structure [6]

According to Reitherman, a typical shake table consists of mechanical structure, actuators and electronic components. Furthermore, these systems are also limited by its payload capacity, actuators and mechanical structure [7]. One example of a complex design of a shake table system is the Large High-Performance Outdoor Shake Table (LHPOST) of the University of California, San Diego - Network for Earthquake Engineering Simulation (UCSD-NEES). The system contains various types of transducers, signal conditioning and data acquisitions units [5].

3.0 METHODOLOGY

The development of the shake table was brought due to the problem that exist from the previous shake table employed in PHIVOLCS (see Figure 2) [8, 9].

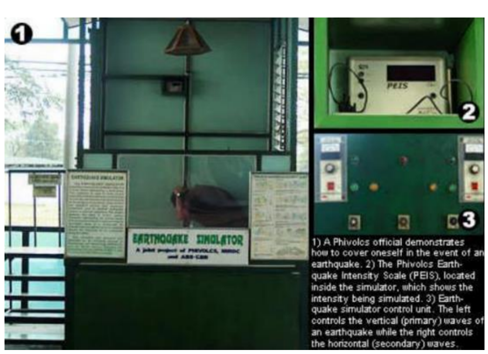

Figure 2 PHIVOLCS shake table [8]

Underneath the platform's base is an induction motor that drives the shake table. The system can generate both horizontal and vertical motions. Based from the designer. According to PHIVOLCS, the design and development of the shake table was inspired from Japan's E-Defense [10]. The problem seen with the PHIVOLCS simulator is the actuation system. Only one actuation is used that provides the overall shaking from intensity III to VIII. This is very difficult to achieve since the amount of intensity is not only dependent on the speed of oscillation produced by the motor but also on the amount of swing which is dependent on the height relative to the ground.

3.1 FBD Process Flow

In order to design the dynamics and controls of the shake table, its basic operation was determined first. Figure 3 illustrates the basic shake table operation used in the study.

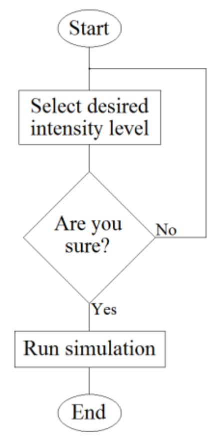

Figure 3 Shake table flow chart operation

The first block is the intensity selection that enable the user to choose the preferred earthquake intensity for shake simulation. The intensity selection range from Intensity III to IV of the PEIS (see Table 1).

Table 1 PEIS as of May 09, 2008 [11]

Int.	Description
I	Scarcely Perceptible – Perceptible under favorable circumstances.
II	Slightly Felt – Felt by few individuals at rest indoors.
III	Weak – Felt by many people indoors esp. in upper floors of buildings.
IV	Moderately Strong – Felt generally by people indoors.
V	Strong – Generally felt by most people indoors and outdoors.
VI	Very Strong – Many people are frightened; many run outdoors.
VII	Destructive – Most people are frightened and run outdoors.
VIII	Very Destructive – People panicky.

Int.	Description
IX	Devastating - People are forcibly thrown to ground.
X	Completely Devastating - All man-made structures are destroyed.

PEIS measures the amount of shaking felt in a certain location based on the relative effect to people and surroundings. It uses a 10-point range to describe the earthquake intensity. The range starts from Intensity I, being the weakest, to Intensity X, being the highest. Using this intensity scale as guide, people will have knowledge on the severity of the earthquake [12].

3.2 Mechanical Design and Structure

The mechanical design and drawing of the shake table can be seen in Figure 4 with an area of 9 m^2 (length = 3 m, width = 3 m) which has a capacity of up to 10 people.

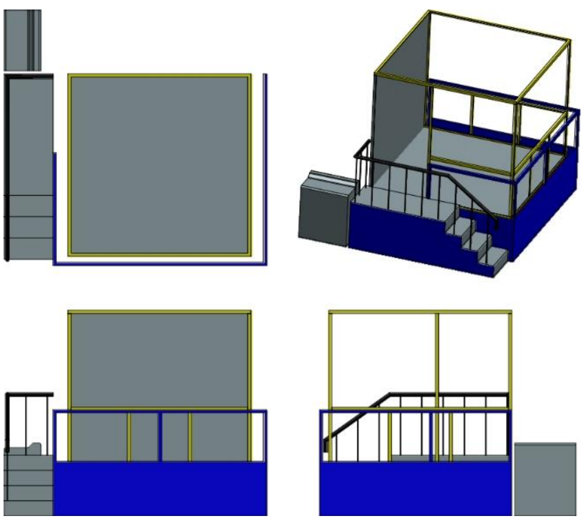

Figure 4 3D design and drawing of the shake table

Figure 5 Actual image of the developed shake table

Most of the materials used in constructing the shake table were steel and plywood (see Figure 5). Steels were used as supports while the plywood for the platform base and the walls. The actuations and transmission systems were placed underneath the base of the shake table (see Figure 6).

3.3 Actuation and Transmission System

The main actuator used in the developed shake table is a 3-phase, 5-hp induction motor (see Figure 6a) that is connected to a belt drive transmission system (see Figure 6b) to provide more efficient torque. The torque produced by the induction motor can drive the whole shake table platform together with its maximum loading capacity of 10 persons.

Figure 6 a) The 5-hp induction motor used with magnetic coupling and b) belt drive transmission system

Before the motor is connected to the transmission system, a magnetic coupling was used to transfer its torque via magnetic field. This coupling is used to enhance the reliability of the system by providing high precision and smooth performance. This is critical especially to the condition of the shake table where the load and the effect of shaking is nonlinear.

3.4 Controls System

The developed controls system of the shake table, as seen in Figure 7 and 8, is mainly based on sequential programming.

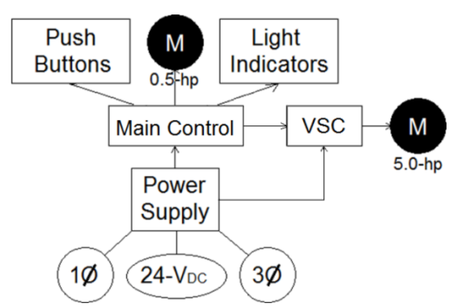

Figure 7 Developed controls of the shake table

The instruction used to program the intensity selection and motor control is very straight-forward wherein the user can easily debug or troubleshoot if there will be errors. The main driver for the 5-hp motor is a variable speed controller (VSC) that is adjust depending on the value of the selected intensity level.

Figure 8 Actual wiring control

A small 0.5-hp motor was also added to the system to introduce the amplitude or height. This variable will be responsible in producing the amount of swing which also affects the amount of intensity generated by the simulator. The orientation of the said motor is vertically-mounted that is connected to a ball screw transmission for precise level adjustment.

Figure 9 Control panel with start, stop, e-stop and intensity buttons from III to VIII

Figure 9 displays the designed control panel of the shake table. The design includes a selector switch, from intensity III to VIII, in which the algorithm follows the Last-In First-Out (LIFO) computing principle. This algorithm is applied to ensure the user have selected his preferred intensity before running the simulation.

3.4 Calibration

The amount of earthquake simulation was measured and calibrated using a seismic intensity meter (see Figure 10). The instrument is wirelessly connected to a laptop receiver for data monitoring and analysis.

Figure 10 Seismic intensity meter used during testing and calibration with wireless data transfer capability

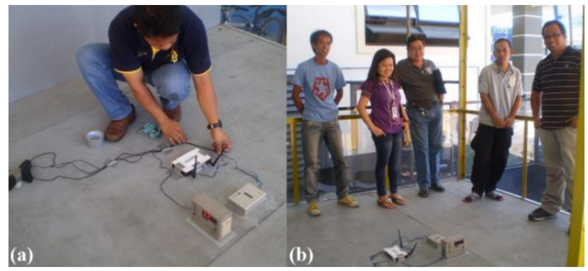

Figure 11 Actual runs: a) calibration and b) testing of the system using the seismic intensity meter

Figure 11 shows actual runs: a) calibration and b) testing of the system using the seismic intensity meter. After the calibration, actual runs were conducted to actual people to determine its dynamic behaviour.

4.0 SIMULATION RUNS AND TESTING

The actual setup and testing of the shake table were performed in Pasig City (see map in Figure 12).

Figure 12 Actual test site of the shake table in the Rescue Emergency Disaster (RED) Training Center, Pasig City

Table 2 provides the measurement of the resistance seen from variable speed controller.

Table 2 Average rotational speed of the motor with calculated potentiometer (pot) tap percentage (%)

Intensity	Average Speed (rpm)	Resistance Value (Ω)		
		Maximum	Actual	Pot Tap %
III	180	1000	832	16.80
IV	190	966	839	13.15
V	205	964	826	14.32
VI	210	971	853	12.15
VII	200	987	854	13.48
VIII	220	971	823	15.24

The table only shows that the effect of increasing the speed of the induction motor is not that much dependent on the amount of intensity produced by the simulator. This can be seen from the following intensities VI and VII. Intensity VII has an average rotational speed of 200 rpm which is lower compared to Intensity VI, having 210 rpm (see Figure 13).

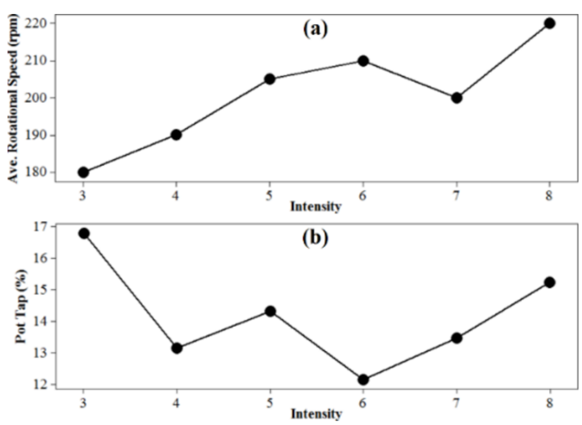

Figure 13 Intensity measured using a) average rotational speed and b) potentiometer tap percentage (%)

The correlation produced by the motor's rotational speed to the amount of intensity produced is not that strong. This only shows that the effect of increasing the height, as for the small 0.5-hp motor, greatly affects the amount of acceleration records in Table 3.

Table 3 PGAa and PGVb for each earthquake intensity level derived from the acceleration data per channel (ch)

Intensity	PGA			PGV		
	ch1	ch2	ch3	ch1	ch2	ch3
III	31.3	101.7	100.1	1.47	8.18	7.35
IV	39.6	197.5	99.2	0.97	14.59	4.42
V	79.3	322.7	245.5	2.24	17.24	6.15
VI	264.8	569.0	444.6	7.99	30.30	13.10
VII	370.6	758.0	438.0	10.68	38.54	14.45
VIII	662.2	1354.0	1167.6	15.79	53.79	28.27

[a]Peak Ground Acceleration, or PGA, is the measure of earthquake ground motion in cm/s^2.
[b]Peak Ground Velocity, or PGV, measures the peak of the 1st integration of the acceleration record in cm/s.

In the table, channel 2 was used as the reference point by the accelerometer in which it has the same orientation with the table movement. In terms of motion, channel 1 and 2 are the two horizontal components of the accelerometer while channel 3 is the vertical component. A sample seismograph reading of intensity III can be visualized in Figure 14.

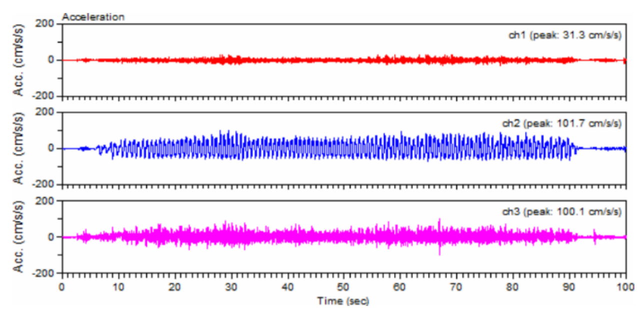

Figure14 Actual seismometer readings for intensity III

Moreover, the vertical movements represented the earthquake primary waves while the horizontal motions for the secondary waves.

5.0 CONCLUSION

In this study, the developed shake table system was able to mimic different earthquake intensity level from Intensity III to VIII in accordance to PEIS. The seismic simulation produced by the platform is due to the combined horizontal and vertical shaking motion as seen from the acceleration data results.

Furthermore, another good feature of the simulator is its capability to train civilian and professional rescuers to respond when an earthquake occurs. Thus, helping people to be more aware in the context of disaster preparedness.

One good recommendation that can be applied in the system is the use of hydraulic actuators that can solve the problem of varying motor speed. The variation effect is due to the fluctuation of the magnetic coupling and mechanical transmission system (belt-type) of the 5-hp motor every time there is an increased in loadings.

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