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Low Cost Uniaxial Shake Table for Harmonic Excitation

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Abstract - *Shake table is a mechanical device that is used to produce simple harmonic excitation or motion. It is a uniaxial shake table, operating only in single direction, i.e. in horizontal direction. It works on the principle of crank mechanism where rotatory motion of the motor is converted into linear motion of the table. Shake table has variety of applications such as*
to get earthquake simulations of test objects, to study if the structure can survive during an earthquake and to predict the earthquake response of a structure. In our project we deal with only simple harmonic excitation to avoid complexity.

Key Words: Shake table, uniaxial shake table, simple harmonic excitation

1. INTRODUCTION

Shake table is a mechanical device that is used to produce simple harmonic excitation or motion. In other words, harmonic simulation can be achieved in laboratory by using
shake table and to test the prototype and scaled model of the structure. Shake table can also be used to study the resonant frequencies of buildings. It is very important for the engineers while designing a structure that the resonant frequencies of the component part do not match with the oscillating frequency of the vibratory parts as it may cause violent swaying motions thereby leading to catastrophic disasters and failure of structure. So, in order to check this resonant frequency shake tables can be used.

Shake table is an experimental approach to understand the various parameters and process that lead to the prototype failure at a real time scenario. An electro-hydraulic shaking
table is essential for higher degrees of freedom. They are very expensive and require high maintenance and operational costs.

The cost of a shake table depends on its size, performance and its supporting components. Generally, the cost of a shake table is several hundred thousand rupees and maintenance cost are also high. From this perspective, we have prepared a low-cost uniaxial shake table having nearly the same features as that of a large vibration table but with much lower cost primarily for laboratory purpose.

2. PROBLEM STATEMENT

2.1 Problem Definition

A shake table is essential in assuring the performance of a structure under vibrational conditions. Since, for industrial purpose testing the structure is a very huge and complex process as the models are large scaled. So, in any engineering laboratory experimentation in terms of monitoring and controlling small scaled models when subjected to harmonic excitations becomes easier and simpler by using a uniaxial shake table as translation is only in the horizontal direction.

The advantages of a uniaxial shake table are:

1. It is used to test the performance of the structure during any real-time event when subjected to excitations.
2. The shake table can be used for analyzing the structure for various frequencies and amplitudes.
3. Provide data to validate analytical models.
4. Tests performed by shake tables are popular in areas of earthquake engineering, structural dynamics and testing of smart materials.

2.2 Problem Statement

The main aim of this project is to develop a low-cost uniaxial shake table which gives simple harmonic excitations to serve the purpose of the laboratory for testing of structural models.

2.3 Objective of the project

The primary objective is to prepare a low-cost shake table for laboratory purpose with all the necessary features and demonstrating its working.

2.4 Methodology

1. A Structural model having table platform of size .3m x .8m and ISMC sections length .9m by providing a 4 number of roller support in order to move table in a uniaxial direction.
2. The model is analyzed and designed in such a way that a table platform can withstand a maximum load of 50kg
3. Estimation of the materials based on the drawings and specifications.
4. Procuring all the necessary materials and then fabricating and assembling them to get the final output.

3. LITERATURE SURVEY

1. "Development and Instrumentation of "Low Cost Shake Table" by Tiwari Darshita, Patel Anoop from Shri Govindram Seksariya Institute of Technology & Science Indore,Madhya Pradesh, India

This paper deals with how earthquake simulation is achieved by using a shake table and test the prototype placed on it. When a structure is subjected to random ground motions, it vibrates in three mutually perpendicular directions. So, considering all these six directions for simulation becomes complicated and costly. Hence, single translation (horizontal) degree of freedom shaking table is made to study the behavior of structure. (Tiwari Darshita, 2014) A data acquisition system with an ADC (Analog to Digital Converter) is used to convert analog signals into digital form. The limitation of the study is that the table can give only sinusoidal motion. Smooth repetitive oscillations (Tiwari Darshita, 2014). However, the paper provides vision to experience the subject of dynamics practically which will further help in dynamic response of the structure in one direction. For future work, the authors Tiwari Darshita, Patel Anoop recommends that artificial earthquake can be simulated on the footing which will help to create better and ever-lasting infrastructure. (Tiwari Darshita, 2014)

2. "Development of Low-Cost Shake Tables and Instrumentation Setup for Earthquake Engineering Laboratory" by C. S. Sanghvi, H S Patil and B J Shah

This paper deals with the development of laboratory equipment in earthquake engineering laboratory. In order to study the effects of earthquake on a structure, development in earthquake engineering laboratory is very important. Laboratory testing of physical models is an effective way to study the complex phenomena. Correlation of results from experimentation and analytical modeling will boost the researcher's confidence. Instead of getting into complex nature of analysis, the behavior of structure is analyzed when horizontal ground shaking occurs. Horizontal shaking of the table represents horizontal shaking of ground. (C S Sanghvi, 2012)

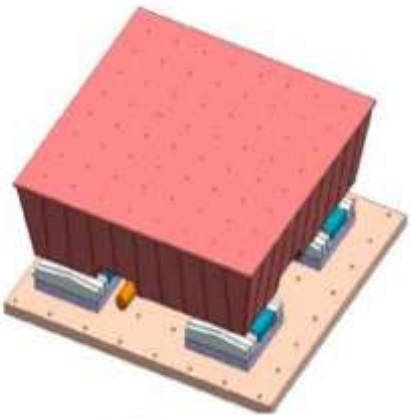
3. "Shaking Table Tests in Earthquake Geotechnical Engineering" S. K. Prasad, Towhata, G. P.Chandradhara and P. Nanjundaswamy

This paper discusses how manual shaking table developed very economically can be used as an alternative to a more sophisticated shaking table. The authors S. K. Prasad, Towhata, G. P. Chandradhara and P. Nanjundaswamy mentioned the advantages of shake table as well controlled large amplitude, easier experimental measurements and their use is justified if the purpose of the test is to validate the numerical model or to understand the basic failure mechanisms. It also deals with the comparative study of manual shake table and laminar box for model testing.

4. CONCEPT GENERATION AND SELECTION

The concept generation can be explained as the general ideas that strike our mind. There are many shake tables being manufactured for the industrial purpose, which are huge and expensive. One such example is the shake table manufactured by BISS (Bangalore Integrated System Solution) located at 4th Phase Peenya Industrial Area, Bangalore.

BISS have designed and manufactured the shake table for large scale purpose in order to perform seismic simulation, soil liquefaction and vibration tests on models. They have manufactured uniaxial, biaxial as well as triaxial shake tables. For our study we have looked upon only uniaxial shake table. It is designed for a natural frequency of 100Hz and payload capacity up to 10000kg costing lakhs together. The system is powered by an electronically servo controlled low noise, variable flow and pressure, energy efficient pump and a digital control with data acquisition system. (BISS, Unknown date).



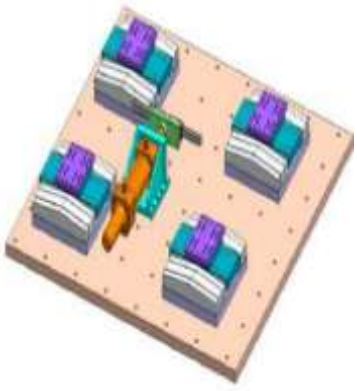


Figure 4.1: BISS Uniaxial Shake Table (BISS, Unknown date)

5. DETAILED DESIGN, ANALYSIS AND ESTIMATION

5.1 Components

Components are key elements in making any model. The components used for making the shake table include steel plate, aluminum plate, MS flat strip, AC motor, bearing assembly, connecting rod, AC motor driver circuit or speed controller, hollow square pipe and nuts and bolts.

The various components used and their functions are discussed in the upcoming section: -

1) Steel plate: A 3mm thick steel plate of dimension 1250mm by 400mm is fixed on the rectangular base frame. Steel plate is used because of its cheap cost and high strength carrying capacity.

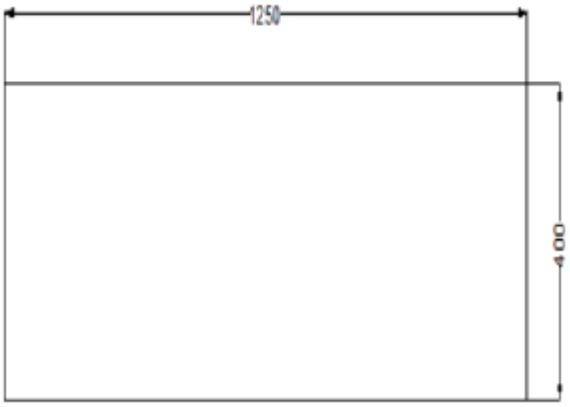


Figure 5.1a: Top view of steel plate 3mm

2) Steel plate: A 3mm steel plate of dimension 800mm by 300mm which forms the main plate where the structure will be placed is used as it is lightweight in nature.

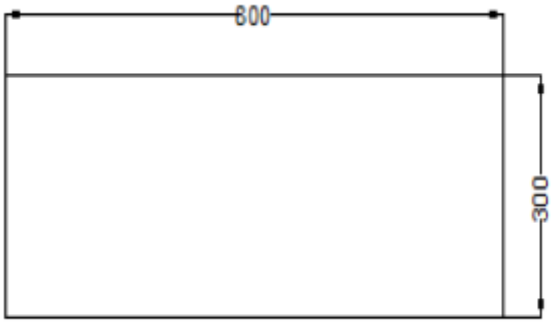


Figure 5.1b: Top view of steel plate

3) Three phase AC motor: The AC motor consists of two parts, one the stator which consists of coils having alternating current to produce the magnetic field, the other is a rotor which is attached to a shaft producing another magnetic field. It is a 2HP motor with 220 volts and gives 1440rpm.

Figure 5.1c: Three phased AC motor

4) AC motor driver circuit or speed controller: It is a speed controller which is used to control the speed of the motor by varying the motor input frequency. It works for frequencies varying from 0Hz to 50Hz.

Figure 5.1d: AC motor driver circuit

5) Bearings: They are provided to produce a linear motion freely in one direction. They also help in reducing friction due to its high friction coefficient.

6) Connecting rod: The connecting rod of dimension 175mm by 20mm with a thickness of 4mm is used for the

purpose of connecting the main shake table frame to the rotary steel plate connected to the motor shaft. It is made of mild steel.

7) Square hollow pipe: A square hollow pipe is used to make the base rectangular frame on which the shake table rests. The square pipe is 40 mm in size. For the shake table frame also a square pipe of size 20mm is used. It also acts like stiffeners to support the steel plate resting on it.

Figure 5.1f: Square Hollow pipe

8) Nuts and bolts: They are used as fasteners to connect various parts of an object. The 8mm diameter, 2 inches long nut and bolt for connecting motor to base rectangular frame, and also for connecting the structure to the table.

5.2 Step by step procedure for constructing shake table

1) Shake table top:

1. The shake table frame 800mm by 300mm was made using the hollow square pipe. The ends were connected by welding connection.
2. Once this rectangular frame was formed MS flat strips 4 in numbers were added which acted like stiffeners and to take the weight of the model. From either ends 100mm offset is given and center to center distance is 200mm.
3. Then 3mm steel plate was fixed on it by means of 6 self-treading bolts, 3 on either side of the plate.

Figure 5.2 a: Shake Table top

2) Rectangular base frame:

1. Square hollow pipes are used to make the base rectangular frame 1250mm by 400mm and are welded. Another set of square pipes are used to connect the legs of the frame.
2. L- angles 1 ½ inch by 1 ½ inches were attached to the frame through welding, and the motor is connected to these L angles by nut and bolt connection.
3. A hole of 5cm was drilled to accommodate the shaft of the motor projecting upwards.
4. Similar to the shake table frame, here also 4 metal tube stiffeners ¾ inch square were used. The ends of the metal tubes were welded to the frame and the rest of the connection was done by using 12 bolts 3 on each stiffener.
5. Then, a steel plate of 3mm thick is welded.

Figure 5.2 b: Rectangular base frame with motor

3) Connection of shake table frame and Rectangular base frame:

1. Over the steel plate, two linear bearing shaft support rails were attached by welding connection.
2. To connect the shaft support rail to the shake table frame 4 bearing mounters, 2 on each side were attached using a square steel plate 2mm thick and 66mm in size.

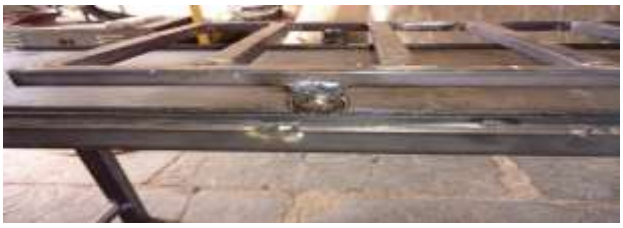


Figure 5.2 c: Bearings on rectangular frame

4) Connection of motor shaft with the shake table frame:

1. A small steel plate 9mm by 4mm, 2mm thick is attached to the motor shaft through nut and bolt connection.
2. Three holes of 3mm diameter are drilled at a distance of 8mm two in number and a 25mm

center to center which represent the amplitude value.

3. Then a connecting rod of 180mm length, 4mm thick is attached from the steel plate to the shake table frame by making a small projection of 5mm metal strip and to this strip the connecting rod is connected by bolting to ensure that it is fixed permanently.

Figure 5.2 d: Connection of motor shaft to shake table frame

5) Finishing:

1. Once every component is assembled, all the edges are chamfered off to give it a smooth finish.
2. Then painting is carried out to give it an aesthetic pleasant appearance.
3. Bushes are added to the legs of the frame and the wiring connections are done.

Figure 5.2 e: Shake table before and after painting

6) Drilling holes to connect the structure:

1. For fixing the structure on the shake table, a paper template 150 by 300mm was made and holes were marked with offset of 50 and 25mm with respect to 300 and 150mm dimensions.
2. Then 21 holes were drilled using a drill bit size 9.5mm and connected using nut and bolt of diameter 8mm. the nut was welded to the metal strip on the shake table frame and the bolt could be fixed by tightening for easy fixing of structure.

Figure 5.2 f: Holes drilled on plate for the structure

Figure 5.2 g: Final Shake table

5.3 Working Principle

1. The shake table works on the crank mechanism, converting rotatory motion into linear motion of the table. It also depends upon the frequency inputs given by the user through the AC circuit driver speed controller.
2. The motor is connected to the speed controller so as to control the revolutions per minute so that we get the required frequency.
3. Suitable required frequency input can be given by using controller pad and "RUN" option is selected to operate the shake table. Variation of frequency can be done using the touchpad

5.4 Design Specification

Table 1: Design Specification of Table

Specification	Value	Units
Table Dimension	800*300	mm
Maximum Amplitude	50	mm
Operating frequency of table	0-10	Hz
Motor capacity	2	HP
Payload	50	Kg

5.5 Cost Estimation

Table 3: Cost estimation

Description	Size/No's	Cost/ unit	Total cost (Rs)
Steel Sheet	800*300 mm	LS	300
Bearing Assembly block	4	500	2000
Bearing Assembly rail	2no's of 1000 mm	LS	180
2 Hp AC Motor (3 Phase)	1	LS	5000
AC Motor Speed Controller Unit	1	LS	11000
Steel Sheet	1200*400 mm	LS	500
1.5*1.5" MS Sq.Hollow pipes for frame	-	LS	950
Metal for Fabrication	-	LS	4000
Screws for tightening the motor and for table	20	15	300
Paint	-	LS	400
Electrical plug and wire	-	LS	90
Total Cost of Shake Table			**24720**

6. VALIDATION AND CONCLUSION

6.1 Validation:

Validation is necessary to be taken up to check or to ensure the prospective of the final product. Usually validation of the product is justified based on its successful working.

Table 4: Comparison of TCE and SGSITS Specifications

Specification	TCE	SGSITS College of Engineering
Table motion	Uniaxial	Uniaxial
Maximum payload capacity	50Kg	200Kg
Table size	800mm x 300mm	500mm x 500mm
Frequency range	0-10 Hz	0-5Hz
Amplitude	50mm	75mm
Motor rating	2Hp, 3 phases	3Hp, 3 phases with instrumentation setup

As seen from table 3 the specifications are nearly the same our shake table costs around Rs 24720 and that of SGSITS college was Rs 1,05,000.

Also, our shake table can be used for testing various models and the test results can be compared with the theoretical results.

Shake table prepared by C. S. Sanghvi, H S Patil and B J Shah as Low-Cost Shake Tables and Instrumentation Setup for Earthquake Engineering Laboratory. (C S Sanghvi, 2012). According to them, Single translation (horizontal) degree of freedom shaking table (Belt and pulley arrangement) is designed &fabricated at L.D College of Engineering, Ahmedabad, Gujarat and S V National Institute of Technology, Surat, Gujarat, India. The total cost of the Shake table with servo motor control & shake table with 1.0 HP motor including instrumentation is costing around **Rs.4,50,000/-**

6.2 Conclusions:

Shake table forms an essential part in various laboratories. Construction and development of shake table can prove beneficial for testing. This project gave a detailed understanding about the different types of shake table.

1. Detailed literature survey carried out helped to build focus and inculcate more information regarding various shake tables.
2. A careful study of various components was done. The compatibility of these components was done in STAAD pro software
3. Our shake table 800mm *300mm can take a payload capacity of 50Kg and can be used to amplitude of 50mm distance. Holes on the top of shake table are drilled in such a way that two structures can be placed at the same time for testing.
4. Shake table can be used for laboratory purpose.
5. Pounding of structures can be further studied since two structures can be mounted simultaneously.
6. Parametric study of structures can be done.
7. Shake table prepared by us in TCE has single translation degree of freedom shaking table (crank mechanism) is designed and fabricated at the cost of **Rs. 25000/-**
8. This uniaxial motorized electro-mechanical shake table has three phase 2 HP motor and frequency ranges 0 to 10 Hz. It can be used for amplitude varying between 0 to 10mm. The mechanism is such that at a particular instance of testing, the amplitude remains constant and frequency can be regulated to provide mode shapes for the test models. The main advantage of this shake table is

it is very economical setup when compared with industrial shake table of same application.

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