

# Development and Instrumentation of Low Cost Shake Table

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**Abstract:** For better analysis of earthquake laboratory facilities with better equipment is required. Earthquake simulation is achieved in laboratory by using shake table. Shake table is used to provide earthquake simulation and to test the prototype and scaled model of the structure. Shake table generates harmonic motion in required direction to study the behaviour of an earthquake of similar pattern. In order to reproduce actual earthquake data, a six-degree of freedom electro-hydraulic shaking table is essential. They are very expensive and require high maintenance and operational costs. One of the most effective ways to achieve this is to develop simple experimental setup with suitable shake table. It is a big challenge to develop shake table for the Earthquake Engineering laboratory at low cost. Single translation (horizontal) degree of freedom shaking tables is useful for laboratory testing to study behaviour of structures. From this perspective, low cost uni-axial shaking tables were designed and fabricated at SGSITS College of Engineering Indore. These low cost shake tables will be used to study behaviour of structure through models under harmonic as well as random excitation. The cost of shake table is very high and it is difficult for the institutes to acquire such facilities. Based on this fact, an effort has been made to fabricate a low cost shake table with required specifications to test models in Earthquake Engineering Laboratory along with a LVDT based instrumentation setup. The instrumentation setup comprises of LVDT and Data Acquisition System. Response of models studied through shake table testing. Shake table with 3 HP motor is costing around Rs 70,000/- respectively. The cost of instrumentation for such set up is only Rs 35,000/-. This effort will fulfil the basic need of the Earthquake Engineering laboratory in form of low cost shake table & required instrumentation, to study behaviour of structure through models by shake table testing.

**Keywords:** Uni-axial Shake table; simulation; single degree of freedom; accelerometer.

## 1. Introduction

It is a unidirectional shake table operates only in horizontal direction. The motion is simple harmonic and works in the principle of crank mechanism, converting the rotary motion of the motor to linear motion of the Table. It comprises of few important components namely: i) Sliding Table; ii) Driving mechanism; as well as iii) control panel.

Experimental study is required for the development of field of earthquake engineering for producing dynamic load a special instrument known as shake table is employed. Shake table is used to simulate earthquake ground motion, and the motion of structures excited by earthquakes. By placing equipment or model structures on these shake tables engineers can determine if they can survive earthquakes or if computer models accurately predict the earthquake response of test objects. A Shake table can be used to test the model of the structure which may be scaled or prototype to seismic shaking.

## 2. Literature Survey

In order to reproduce actual earthquake data, a six degree of freedom shaking table is essential. Shake table is a very complex electro-hydraulic system, which is very expensive and requires high maintenance and operational costs. As per Clause: 6.1.1 IS 1893-2002 [3], the random earthquake ground motions, which cause the structure to vibrate, can be resolved in any three mutually perpendicular directions, i.e. two horizontal and one vertical direction. The predominant direction of shaking is usually horizontal. The vertical direction is  $\frac{1}{2}$  to  $\frac{2}{3}$ <sup>rd</sup> of the horizontal vibration. The self weight of structure, i.e. gravity loads, compensates the effect of vertical accelerations. Movement of shaking table means

application of strong ground motions (accelerographs) to model of the structure to study their behaviour. Simulation of earthquake ground motion in all six directions of consideration (i.e.  $\pm X$ ,  $\pm Y$ ,  $\pm Z$ ) is complicated and costly. The effect of horizontal ground motion is significant on structure compared to the vertical motion which is almost  $\frac{1}{2}$  to  $\frac{2}{3}$ rd of the horizontal acceleration. Thus, ground motion consideration is left to major two orthogonal horizontal directions.

## 3. Earthquake motion and response spectra

Seismic or structure motion can be presented as accelerograms-time histories of acceleration. These can be actually measured earthquakes, result of structural calculations, or artificially generated time histories having certain desirable properties. Shake tables are typically asked to reproduce these motions within certain limits. Peak responses are typically about 3g, 1m/s and +/-8cm.

Most shake tables do not produce the actual frequency and long displacements of real earthquakes (which can reach several feet or meters). This means that most shake tables can only produce large earthquake scale models have resonant frequencies well above 1 Hz. Shake tables may be able to reproduce motion in only one horizontal direction (uniaxial), in one horizontal and the vertical direction (biaxial), or in both horizontal and the vertical direction (triaxial). Triaxial tables are the most realistic but also more expensive. Many tests and much research are consequently done on uniaxial or biaxial tables.

The desired motion on the shake table is often indirectly specified by a Response Spectrum. This is a plot of the maximum absolute response of a single-degree-of-freedom oscillator excited by a particular ground motion, such as an

earthquake. These plots are typically acceleration response and plotted as a function of the resonant frequency of the oscillator. Multiple curves are typically presented, each one for a different value of damping of the oscillator.

#### 4. Types of Shake Tables

Seismic tables are typically uniaxial, biaxial, or triaxial, as discussed above. They can be driven by servo-hydraulic actuators, servomotor actuators, Electro-dynamic actuators, or mechanical actuators. Servo-hydraulic actuators are the most common and can handle large tables with large test object masses and high acceleration requirements. Their disadvantage is higher noise, high oil pressure, oil leakage, maintenance, and requirement for special maintenance training.

Servomotor driven tables are cleaner and less noisy than servo-hydraulic tables and require no special maintenance training. However, they have limited payload mass capacity and can be more expensive than servo-hydraulics for larger tables. Electro-dynamic actuators have limited stroke (except for certain newer models) and are generally limited to uniaxial tables. Hence they are seldom used for seismic qualification, except for relatively small and rigid equipment.

Mechanical actuated tables (eccentric mass and eccentric cam) can only produce sinusoidal motion and so have been largely abandoned for seismic testing. They are significantly less expensive than the other types of tables and so are sometimes used to test equipment, if the sinusoidal forcing can be justified.

#### 5. Digital table controllers

A servo controller will accept a user supplied signal (program) and cause the table to follow this signal closely. Until about 1975 most shake tables accepted this fit. Since then, however, a number of firms have offered a variety of digital controllers that significantly improve this fit and make the testing process easier and faster. First, the digital controller is a signal source. It provides an earthquake time history that is connected to the servo controller. The digital controller can be provided with a library of historical earthquakes, with programs for calculating new ones, and with the ability to import digital or analog time histories supplied by others.

Second, the digital controller will record the actual motion achieved on the table and then modify the drive program to cause the table motion to more closely fit the desired motion. This is an iterative process called equalization.

Third, the digital controller will be able to record several channels of data (typically between 3 and 16) for processing, display, analysis, and documentation purposes. Hence the test object response as well as the table motion can be monitored.

These controllers typically use a standard PC for test set up and data display and storage. The PC is typically augmented by fast ADC, DAC and FFT boards and with transducer amplifiers and anti-aliasing filters. Digital controllers can control tables with 1-8 degrees-of-freedom.

#### 6. Data acquisition systems and filters

The digital controllers discussed in the previous section are often sufficient for all data acquisition for many shake table test labs. These controllers can be augmented by a variety of PC based data acquisition and display systems to allow even hundreds of channels of data acquisition, display, and storage. Note that in addition to the multi-channel ADC required, extra transducer amplifiers and anti-aliasing filters may be added. Anti-aliasing filters are low pass filters that prevent distortion of the sampled signal by high frequency components of the signal.

#### 7. Instrumentation for Shake Table

Shake tables use a variety of transducers to control the table and to monitor the response of the test object. The most used transducers are accelerometers (including piezoelectric, piezo-resistive, capacitive servo, and strain gage accelerometers). Displacement transducers include string pot devices, LVDT/RVDT, Laser and Ultra sonic non-contacting devices, and magnetostrictive non-contacting devices. There are few direct velocity measurement devices. Velocity is typically found by integration of an acceleration signal. Strain is typically measured with strain gages. Occasionally crack growth gages are used. Most instruments have associated electronics that provides a Voltage signal proportional to the sensed parameter (a few use a 4-20 ma current indication). A data acquisition system with an ADC (Analog to Digital Converter) is often used to convert these analog signals into a digital form. A few instruments directly produced digitized data.

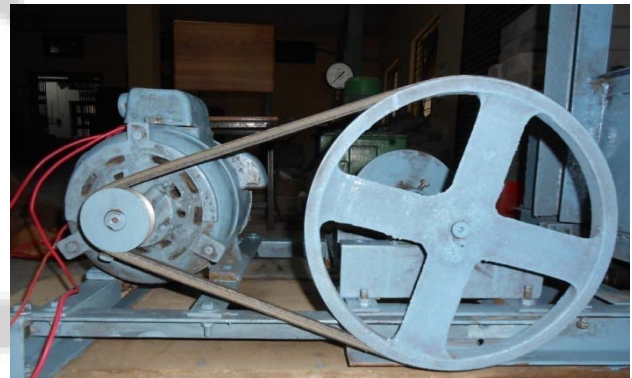


Figure 3: Belt and pulley arrangement

#### 8. Specifications of the Shake table

Specification of fabricated shake table is shown in the table below:

Table 1: Specification of Shake Table

Motion	Horizontal (uni-directional)
Max pay load	200Kg
Top table size	500mm x 500mm
Frequency range	0 – 5Hz
Frequency control	± 5%
Amplitude	± 75mm (total amplitude 150mm)
Maximum height of models	1500mm
Motor rating	3HP, 3Phase, 440V, 1440rpm
Control penal	4 wires, 3 phases, 440v input
Controller mechanism	auto transformer

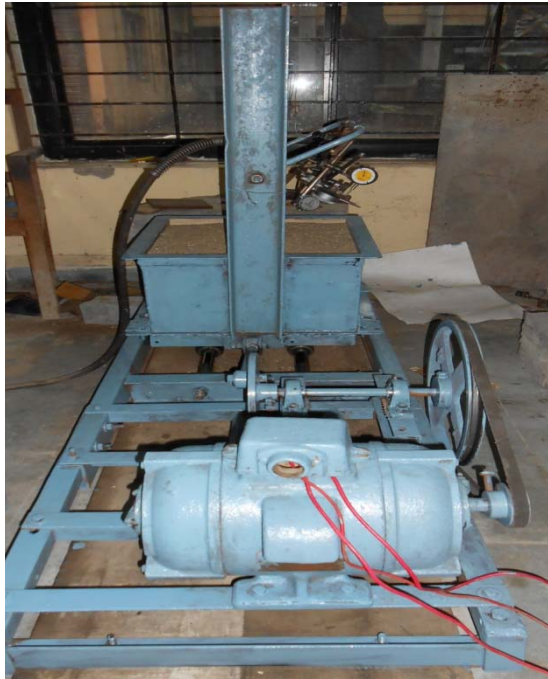


Figure 2: Horizontal shake table

### 8.1 Practical limitations

Practically, frequency can be varied from 1 Hz to 22Hz; but as per the motor characteristics, it is stable only when the motor runs at a minimum of 10% of its rated speed, implying that amplitude variation can be  $\pm 1\text{mm}$  to  $\pm 20\text{mm}$  achieving  $g$  value as 0.05 to 2. The Table can give only input of sinusoidal motion, whose amplitude and frequency can be set for the desired  $g$  value; for example, see the following illustration:

$$x = A \sin \omega t$$

$$\frac{dx}{dt} = A \omega \cos \omega t$$

$$\frac{d^2x}{dt^2} = -A \omega^2 \sin \omega t$$

For frequency,  $f=0.53\text{Hz}$  and amplitude of 50mm, Table shall receive an input of

$$\frac{d^2x}{dt^2} = (2\pi f)^2 (50/1000) = 0.056g$$

Where,

$\omega$  = Angular velocity (rad/sec)

$x$  = Movement in one direction (mm)

$A$  = Constant

$t$  = Time (sec.)

### 8.2 Operating procedure

- 1) Ensure that there is no power supply to the Table
- 2) Switch the mains On
- 3) Press Start Button
- 4) Increase the frequency count, slowly by rotating arm the Increase Button; observe the motion of the shake table for any frictional noise, relatively slow movement, oil leak etc
- 5) Then slowly increase the frequency to the desired value.

- 6) Now the Table is receiving the desired input for which response of the model can be measured.
- 7) After recording the response, to Stop the Table, Press Reset Button; not the STOP button. You will notice that the Table shall come to rest gradually.
- 8) Press STOP button and then switch off the Mains.

### 9. Conclusions

This low cost shake table and instrumentation setup is the first step for the development of earthquake engineering laboratory which will provide the vision to experience the subject of dynamics practically. It will help:

- 1) To develop understanding of dynamic response of structures to undergraduate students;
- 2) To reinforce theoretical concepts through the use of "hands-on" laboratory experiments;
- 3) To provide an opportunity to use modern engineering tools including sensors and data acquisition/analysis equipment.

### 10. Future Scope

Shake table is very important to analyse the earthquakes in a better way. It will also be very helpful for designing the earthquake resistance building by using shake table. Artificial earthquake can be created on footing and its behaviour can be studied. This will help to create better and long lasting infrastructure.

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