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Dynamic characterization of Shock Table

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ABSTRACT: During earthquakes, structures experience base motion has the potential to damage the structure to different degrees. Understanding the dynamic response of the structure to the base motion is quite important. This is achieved by mounting a scaled model of structures on the Shake Table capable of simulating an earthquake scenario in the laboratory. However, such a facility is quite costly from both a development and operational point of view. The dynamic response of a structure can alternatively be determined using the Shock Table wherein impacts of various degrees are applied. The present study focuses on dynamic characterization of Shock Table in terms of acceleration, force, and dominant frequency. The experimental results extracted are compared with the analytical results derived using the Finite Element (FE) model of Shock Table through ANSYS. A good agreement between experimental and analytical results is observed. Shock Table was subjected to a force of about 1500 kN and has a dominant frequency of about 1 Hz.

1 INTRODUCTION

Earthquakes have a potential to damage most all manmade structures. Determining the response of structures during an earthquake is an important part of structure dynamics and earthquake engineering (Chopra 2009). It is usually obtained by testing scaled models of structures on Shock Table. In the absence of a sophisticated Shake Table, the study on the behavior of structures and damage caused due to earthquakes were attempted by using a non-sophisticated Shock Table. Shock Tables of various forms were used by researchers to carry out dynamic testing of scaled models of structures (Ersubasi & Korkmaz 2010). The Shock Table is a much cheaper alternative as compared to a costly Shake Table but gives a good enough insight to the dynamic problem. One such Shock Table testing facility as shown in Figure 1 was developed at the Civil Engineering Department, Institute of Technology, Nirma University, Ahmedabad, where the table was mounted on a roller and given shocks through a freely falling pendulum.

The Shock Table is 3.6 m wide and 6 m long and is mounted on four rollers that move on a reinforced cement concrete column of 350 mm × 300 mm fitted with a base plate. The table has two big cutouts of size 700 mm × 1700 mm placed symmetrically on the table to provide ease in construction of testing models. A pendulum (weight 1500 kg) made up of a steel box with a steel plate casing contributes to the pendulum, pivoted from top, to allow it to fall freely. On the other side of the shock table a reaction beam 250 mm wide by 400 mm depth and 3440 mm long is kept that helps to rebound the table and simulate an earthquake type of motion (Purohit & Patel 2005).

1.1 *Impact force estimation*

Shock Table facility consists of a pendulum pivoted at the top and weighs about 1500 kg. It is made up of a steel box having steel plates. The pendulum is pulled by a pulley system to different degrees of height and then allows it to fall freely. The free fall of pendulum produces an impact on the Shock Table and thus imparts an energy to it.

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Figure 1. Shock Table facility and its components.

Table 1. Impact force and contact time of pendulum for different angle of swing.

Angle of swing	Force (kN)	Contact time (s)
10	178	0.0065
20	460	0.005
30	860	0.004
40	1514	0.003

Estimate of impact load is crucial in order to calculate acceleration produced in the Shock Table. In the present study, the impact load is estimated using impulse momentum principle. An important variable is duration of impact, which is obtained experimentally. Equation (1) states the impulse momentum principle.

$$F = \frac{m \times v}{\Delta t} \quad v = \sqrt{2 \times g \times h} \tag{1}$$

where m = mass of pendulum; v = velocity of pendulum; Δt = contact time between pendulum and table, and h = height of pendulum from mean position; g = gravitational acceleration.

Table 1 shows impact force and contact duration of pendulum with Shock Table for various degrees of angle. Note that maximum impact force is produced with maximum rise of pendulum.

2 FINITE ELEMENT (FE) ANALYSIS

FE analysis of Shock Table is done using ANSYS 14.5 software. Transient dynamic analysis is carried out to determine response of the Shock Table. Shock Table is modeled using SOLID187 element which is a 10-node tetrahedral element having three degrees of freedom at each node. Material properties used in FE Modeling are for concrete—M15 grade of concrete and Fe 250 grade for steel section used.

A mesh size of 75 mm is considered based on convergence analysis. Dynamic analysis is carried out for 0.1 s and acceleration (in "g") is extracted at a time interval of 0.001 s for various locations as shown in Figure 2. The location of external acceleration is in line with experimental instrumental setup.

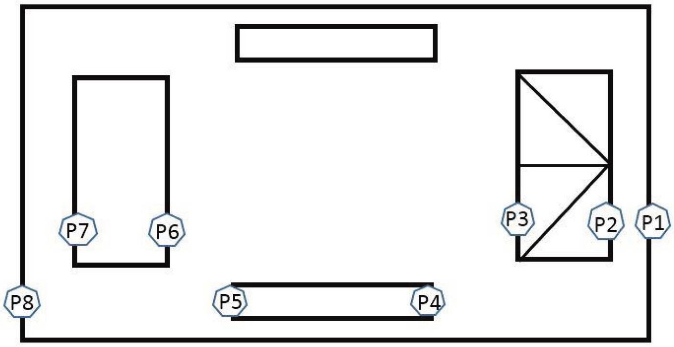

Figure 2. Point of measurement for acceleration on Shock Table.

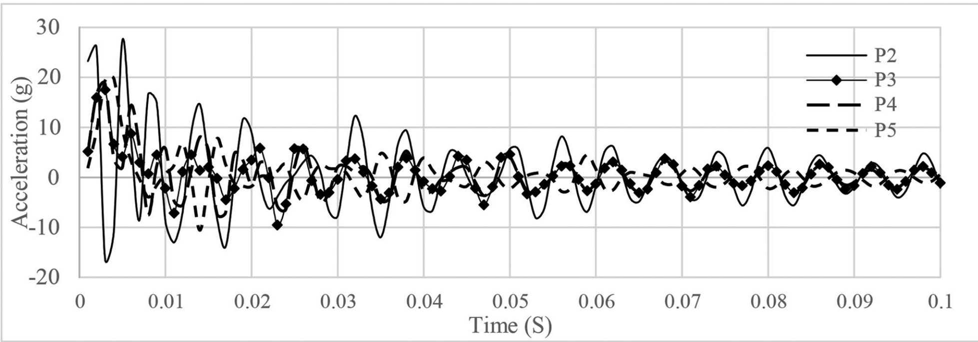

Figure 3. Numerical acceleration time history at various locations of Shock Table for pendulum swing at 20°.

Figure 3 shows the acceleration time history response of Shock Table for pendulum swing of 20° at location number 2, 3, 4, and 5.

It is seen from Figure 3 that peak acceleration of 28 g is produced at location 2.

3 EXPERIMENTAL PROGRAM

An experimental program is evolved for Shock Table facility available at Institute of Technology, Nirma University. Experimental program consists of application of shocks to the Shock Table through a pendulum weighing 1500 kg freely falling from varying degrees of swing at 10°, 20°, 30°, and 40°. Six Uniaxial and one Triaxial accelerometers are used to capture acceleration at various locations as shown in Figure 2. Acceleration time history is captured through data acquisition system and Lab VIEW software.

Figure 4 shows the complete experimental setup with instrumentation used for characterization of Shock Table.

Note that Figure 5 includes acceleration time history as given in Figure 2 for comparison. It is evident that acceleration time history shows a good agreement between experiment and FE solutions. The predominant frequency content of Shock Table subjected to impact is also determined through FFT analysis. Figure 6 shows FFT analysis of acceleration time history captured for all locations on Shock Table. It is found that predominant frequency of Shock Table is 1 Hz.

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Peak acceleration obtained at location 2 for different degrees of pendulum swing by experimental and FE analyses is summarized in Table 2. It is clear that peak acceleration value shows good agreement between experimental and FE analyses. Note that peak acceleration has not been captured for pendulum swing of 40° as it has crossed the upper threshold value of accelerometer. It is evident from Table 2 that peak acceleration obtained experimentally shows good agreement with FE analysis value.

Table 2 shows comparison of maximum acceleration for different degrees of shocks.

Response obtained experimentally as well as analytically for various shocks is plotted as shown in Figure 7.

It is seen from Figure 7 that peak value of acceleration obtained is in good agreement with FE analysis results. It is also evident that the time history plot obtained experimentally shows fair agreement with the plot derived through FE analysis.

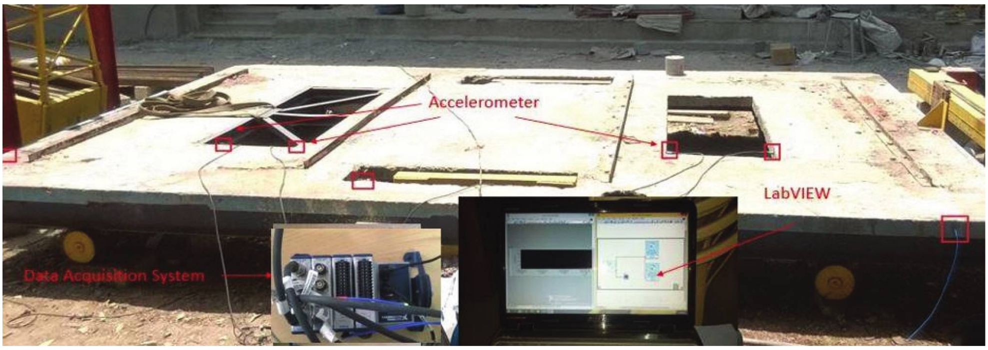

Figure 4. Experimental setup with instrumentation for measurement.

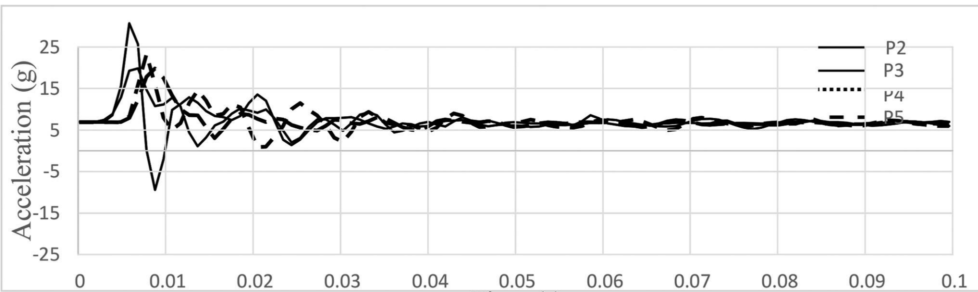

Figure 5. Experimental acceleration time history at various locations of Shock Table for pendulum swing at 20°.

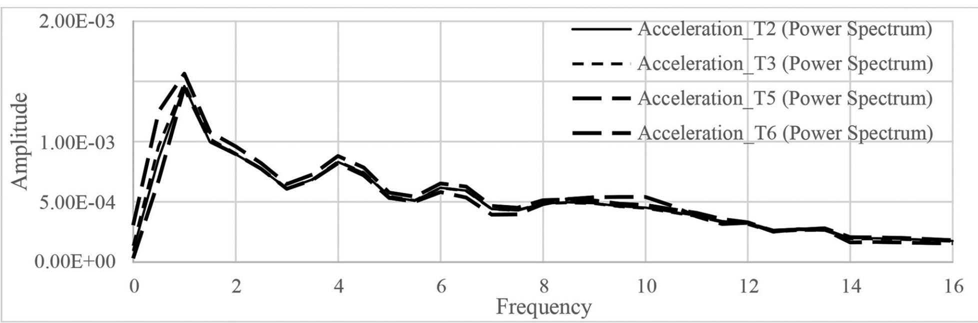

Figure 6. FFT analysis of acceleration time history of various locations.

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Table 2. Comparison of peak acceleration for various degrees of pendulum swing.

	Peak acceleration (g)	
Angle of awing	Experiment	FE analysis
10	9.45	10.4
20	26.35	27.08
30	35.39	50
40	–	85

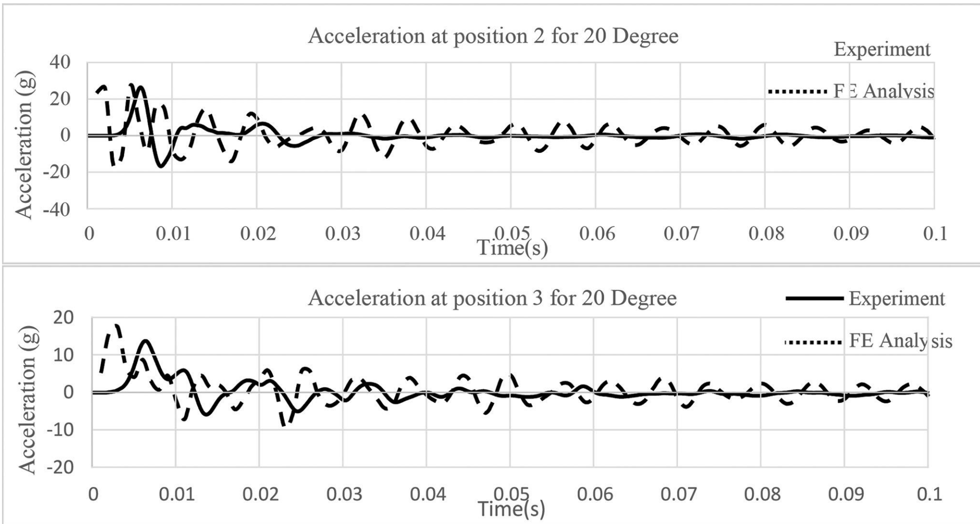

Figure 7. Comparison of experimental and FE analyses results at various locations.

4 CONCLUSION

An experimental evaluation of acceleration at various points on the Shock Table is carried out in order to characterize it. An analytical solution to determine acceleration of various points on the Shock Table is carried out using FE analysis through ANSYS. We derived the following conclusions based on the study:

- Peak acceleration value obtained through experiment and analytical solutions shows good agreement.
- Acceleration time history derived through experimental and analytical solutions shows good agreement.
- Shock Table is capable of producing a force of about 1500 kN.
- Predominant frequency of Shock Table ranges between 0.75–2 Hz.
- Shock Table has the capacity to produce peak acceleration as high as 35 g.

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