Design and Development of Shake Table for Earthquake Simulation

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Abstract: It has become necessity to study the behaviour of structure under earthquake. Since earthquakes are uncertain and unpredicted, it becomes mandatory to study various aspects of earthquake time histories. When earthquake encounters, vibrations generated travel in all possible directions, but to study vibration effect in all possible directions in beginning will be very complex work. So an attempt has been made to prepare a setup which generates unidirectional excitation (i.e. horizontal direction). For that purpose a small scale shake table which gives unidirectional harmonic motion has been prepared. The motion is generated in the table by cam follower mechanism. D.C. motor is used to drive the cam follower mechanism because; speed of a D.C. motor can be controlled easily which in turn controls the frequency of shake table. An aluminium frame model has been prepared for testing purpose. The responses of model are recorded with the help of data acquisition system and accelerometers. The responses obtained from experimental studies are compared with the responses obtained from analytical studies. All programs are compared with examples given in textbooks. Responses of SDOF system for different earthquakes are evaluated and compared with each other in LabVIEW, NONLIN and SAP2000. The results obtained from LabVIEW and NONLIN is almost same but the results obtained from SAP2000 are showing slightly higher variation.

Keywords: Earthquake simulator, shaking table, SDOF, Labview

I. Introduction:

Earthquake or seismic analysis is a subset of structural analysis which involves the calculation of the response of a structure subjected to seismic excitation. This is required for carrying out the structural design and structural assessment of the structures in the regions where earthquakes are common. Different seismic ground motion data's are necessary to carry out the seismic analysis of the structures. These data are available in two forms viz. in deterministic form or in probabilistic form. Data in deterministic form are used for design of structures; whereas data in probabilistic form are used for seismic risk analysis, study of structure subjected to random vibration and damage assessment of structures under particular earthquake ground motion. Major seismic parameters include ground acceleration, velocity, displacement data, magnitude of earthquake, peak parameters and duration. The seismic response of the structures is evaluated under earthquake excitation expressed acceleration, velocity and displacement. The responses of a system for earthquake ground motion can be obtained by,

1. Time domain analysis (Time history analysis).

2. Fourier method of analysis.

The first method is called the time history analysis (THA) of structures under earthquake excitation. The method of analysis can provide responses for both linear and non-linear structures. Both linear and nonlinear analysis of the structure can be carried out by THA. In particular, the method is adopted for finding the seismic response of structures in the inelastic range. In this method, by using numerical techniques (time integration schemes), equation of motion are integrated for finding the responses at discrete time intervals. For linear systems, two such methods such as, Newmark integration schemes and Duhamel integration are mainly employed. Newmark's integration scheme is popular in earthquake engineering. There are many other time integration methods such as Alpha method, Houbolt's method, Adam's integration scheme, Wilson y-method, and Argary's large time step integration schemes. Using the LabVIEW (simulating software), numerical integration of the equation of motion can be performed.

1.1 Earthquake ground motion:

For the design of structures to resist earthquakes, it is necessary to have some knowledge of ground motions. Earthquakes motion can be recorded in terms of ground displacement, velocity or acceleration. During earthquakes, the ground movement is very complex, producing translations in every direction combined with rotations about arbitrary axes. Modern strong motion accelerographs are designed to record three translational components of ground acceleration, switching on by themselves automatically once an earthquake ground motion reaches a certain threshold level, usually about 0.005 g. The first complete record of strong ground motion is obtained during the 1940 El-Centro earthquake (Figure 1-1) in California. Over a period of years increasing numbers of strong motion recorders have been installed in many parts of the world and have yielded much useful data.

The strong ground motion is recorded with the help of accelerometers. When the natural frequency of the instrument is very high compared to that of the vibrations to be measured, the instrument picks up the acceleration of the motion measured. Hence accelerometers have high natural frequency. Alternately this implies that stiffness K of accelerometer should be very large and mass m should be small. Therefore, the accelerometers are compact in size. Before the arrival of digital era, the accelerations are recorded on light sensitive paper. However, these records are often exposed to stray light and during large high frequency oscillations, the optical density of the trace become faint due to faster movement of light beam. With the advent of new technologies, the design strong motion instruments have taken large strides in terms of types of devises used for triggering of recording, measurements of motion and recording of motion. The recent digital instruments are also capable of recording certain length of pre-event history, thus including data before exceedence of trigger level. However, any strong motion instrumentation essentially requires the following components:

1. Vibrating machine

2. Vibration transducer

3. Signal conversion

4. Display / recording

5. 5. Data analysis

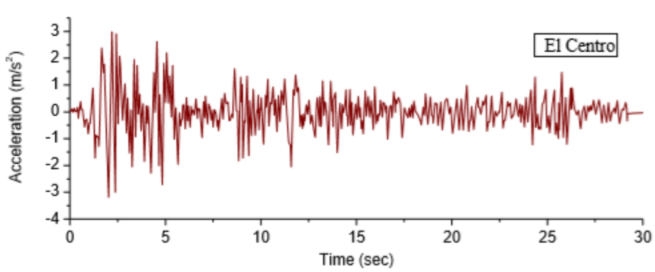

Figure 1-1 El-Centro earthquake ground motion time history

II. Structural Systems:

2.1 SDOF System:

- **Linear Analysis:**

A typical SDOF system, shown in figure below consists of a mass 'm', a weightless frame which provides lateral stiffness and a viscous damper (called a dashpot) for dissipating the vibrational energy of the entire system. The beam and columns are assumed to be axially inextensible. In this system, all these properties are concentrated in three separate components i.e. mass component, stiffness component and damping component. This structure has only one DOF when it is idealized with mass concentrated at one location and hence this is a single degree of freedom (SDOF) system.

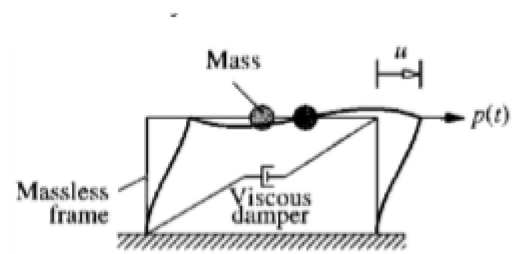

Figure 2.1 Idealized SDOF system

- **Nonlinear Analysis**

The nonlinear response (time-varying response) of a structural system is important in the resolving for the structural forces in the system. In nonlinear dynamic analysis, the loading is a function of time. It is an essential procedure to design a reliable structure, when it is subjected to dynamic load such as earthquake. Time History Analysis (THA) is applicable for both linear and non-linear range. This method is particularly used for finding the seismic response of structures in the inelastic range. Time integration schemes for the integration of the equation of motion are used for finding the responses at small time intervals. For linear systems, two such schemes are namely, the Duhamel integration and the Newmark's integration schemes. Newmark's integration scheme is popular in THA so it is preferred. Using LabVIEW (simulation software), numerical integration scheme for the equation of motion can be established.

2.2 MDOF System:

A typical MDOF system with n degrees of freedom is shown in Figure (3-2). However in case of mass distributed throughout the height of the structure, multi degree of freedom systems are considered for analysis. This system when subjected to ground motion undergoes deformations in number of possible ways. These deformed shapes are known as modes of vibration or mode shapes. Each shape is vibrating with a particular natural frequency. Total unique modes for each MDOF system are equal to the possible degrees of freedom of system. In MDOF system DOF are considered only in one direction. Mass, stiffness and damping are considered in matrix form.

2.3 Base Isolated System:

Base isolation is a passive control system; means for its activation it does not require any energy or external force. It is important to understand reason behind the need of base isolation to enhance performance levels of the structure subjected to seismic excitations. To design structure in such a way, that it may withstand the actual force by fixed base structure elastically, is not feasible in two ways. First, the construction cost of the structure will be highly uneconomical. Second case is, if the overall strength of the structure is increased by making it more rigid, then it will be at the cost of imparting actual ground forces to the structural contents, thus causing heavy nonstructural damage. Apparently, as the name implies base isolation tries to decouple the structure from the damaging effects of ground motion during earthquake. In base isolation complete isolation of the structure from the ground is not there, as with magnetic levitation, which may be very rarely practical. Most of the base isolation system only provides partial isolation, which have been developed over the years. 'Partial' in the sense, by providing flexibility and energy dissipation mechanisms with the addition of base isolation devices to the structure much of the force transmitted, and the consequent responsive motions are only reduced.

III. Proposed methodology

3.1 Development of small scale shake table:

It has become necessary to study the behaviour of structure under earthquake. Since earthquakes are uncertain and unpredicted, it becomes mandatory to study various aspects of earthquake time histories. When earthquake encounters, vibrations generated travel in all possible directions, but to study vibration effect in all possible directions in beginning will be very complex work. So an attempt has been made to prepare a setup which excites only in one direction. For that purpose a shake table which gives unidirectional harmonic motion has been prepared. Unidirectional motion is given with the help of cam follower mechanism. D.C. motor is used to drive the cam follower mechanism. D.C. motor is used because speed of motor can be controlled easily which infact control frequency of shake table. For shake table, there is requirement of sliding mechanism below the board on which model rests. Wheel mechanism which is used in sliding aluminium window is used for shake table.

Figure 3.1: RPM controller of D.C. motor and Shake table setup

3.2 LabVIEW Graphical User Interface:

Designing in LabVIEW is completely different from other programming softwares. In LabVIEW there is no need of remembering commands which is very tedious work. Instead of commands in LabVIEW modules are provided which carries out all mathematical, iterative and other functioning required for programming purpose. These modules are interconnected to each other to keep all process in sequential format. The module developed in LabVIEW for simple SDOF system is shown below.

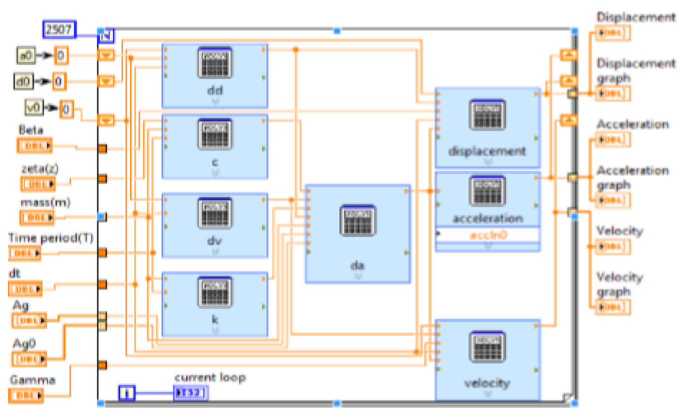

Figure 3.2: Block Diagram for the flow of information in LabVIEW

3.3 NONLIN Graphical User Interface:

Developed by Advanced Structural Concepts, Inc., NONLIN is software specially prepared for earthquake related analysis. It has a default option of SDOF system and hence required values of parameters can be directly entered in it. Same parameters are selected as in the case of modeling in LabVIEW. Time History data present in the software is selected for the before mentioned earthquakes and analysis is done to obtain the response plots in terms of acceleration, velocity and displacement. These values of responses are then exported and used in Origin to prepare the final plot.

3.4 SAP2000 Graphical User Interface:

A damped SDOF system for analysis using Newmark's method in SAP2000 has been modeled using a special joint option. Same parameters are selected as in the case of modeling in LabVIEW. This joint is assigned with mass and stiffness parameters and also degree of freedom (DOF) is assigned base on the direction required. Ground motion data is assigned along the direction of DOF. Earthquake ground motions obtained from PEER Ground Motion Database (CESMD, PEER). Linear direct integration has been done and acceleration parameter is used to apply the loads.

IV. Result and Discussion:

a) Earthquake ground motion (El Centro 1940)

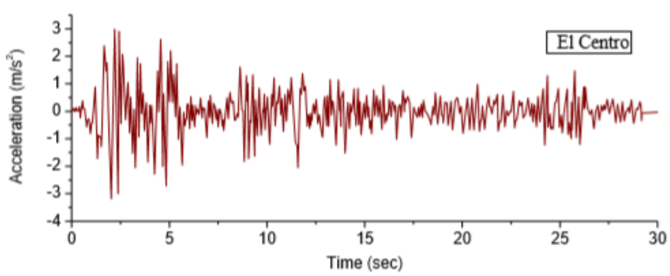

Figure 4.1: Ground motion time history of El-Centro

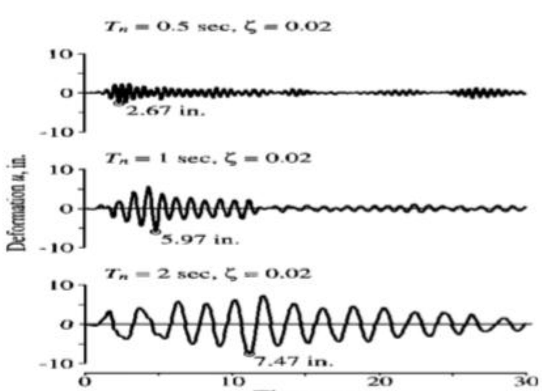

Figure 4.2 Displacement response time history of SDOF system

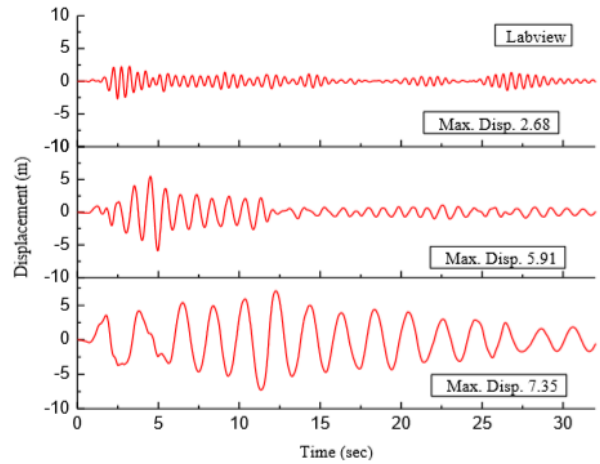

Figure 4.3 Displacement response time history of SDOF system from LabVIEW

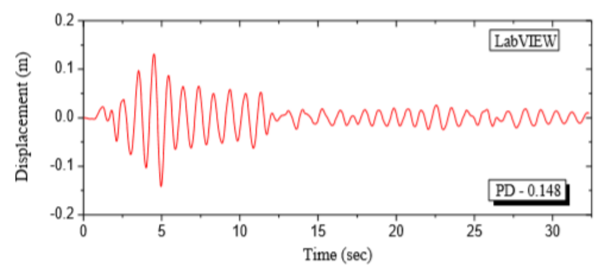

Figure 4.4: Displacement response time history of SDOF system from LabVIEW

b) Loma Prieta:

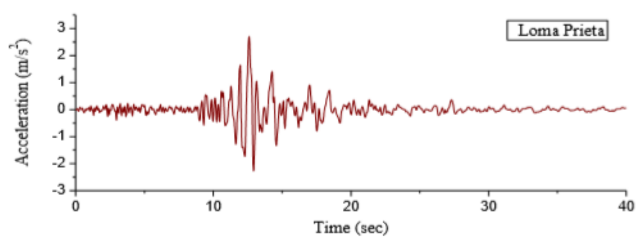

Figure 4.5: Ground motion time history of Loma Prieta

c) Santa Monica:

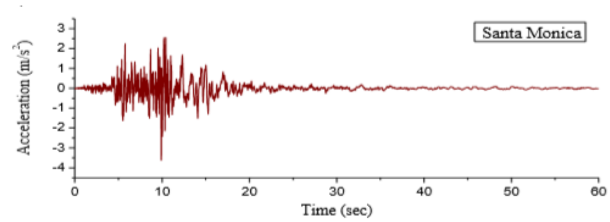

Figure 4.6: Ground motion time history of Santa Monica

d) San Fernando:

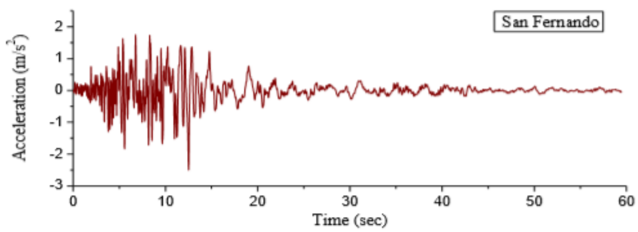

Figure 4.7: Ground motion time history of Santa Fernando

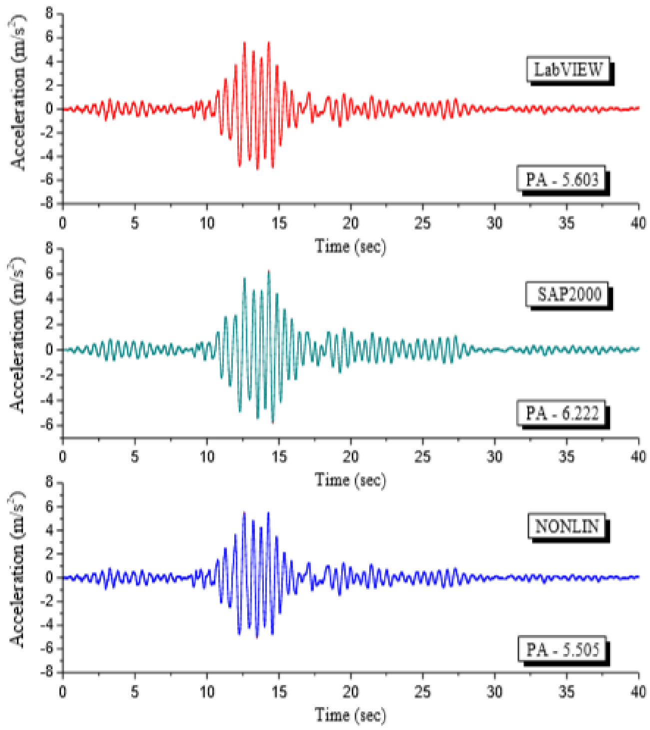

Figure 4.8: Acceleration response time history for Loma Prieta earthquake

The percentage variations of the Peak Acceleration obtained from SAP2000 and NONLIN with respect to LabVIEW are 11.05% and 1.75%. The variation of NONLIN With respect to LabVIEW is almost same but variation of results from SAP2000 with respective to LabVIEW is slightly more.

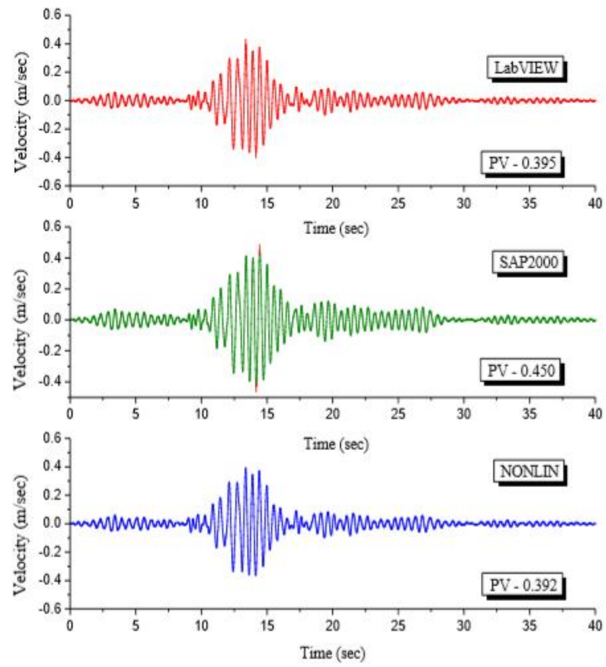

Figure 4.9: Velocity response time history for Loma Prieta earthquake

The percentage variations of the Peak Velocity obtained from SAP2000 and NONLIN with respect to LabVIEW are 13.92% and 0.76%. The variation of NONLIN With respect to LabVIEW is almost same but variation of results from SAP2000 with respective to LabVIEW is slightly more.

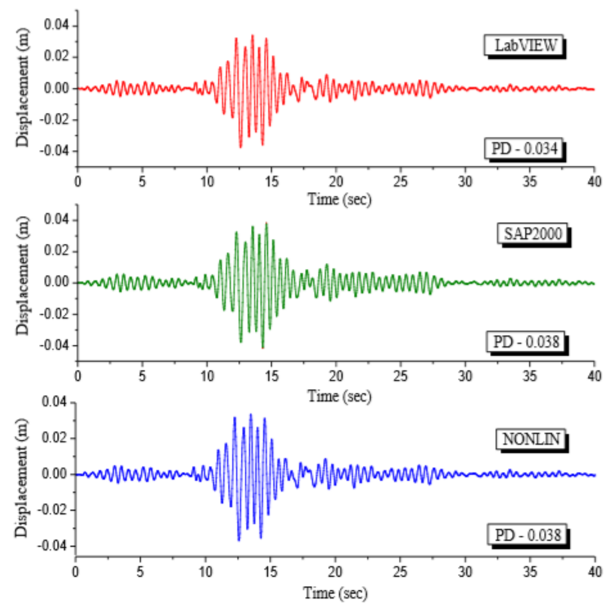

Figure 4.10: Displacement response time history for Loma Prieta earthquake

The percentage variations of the Peak Displacement obtained from SAP2000 and NONLIN with respect to LabVIEW are 11.76% and 0%. The variation of NONLIN With respect to LabVIEW is almost same but variation of results from SAP2000 with respective to LabVIEW is slightly more.

Comparison of Top Acceleration of Aluminium Frame Model i.e. Analytical and Experimental results:

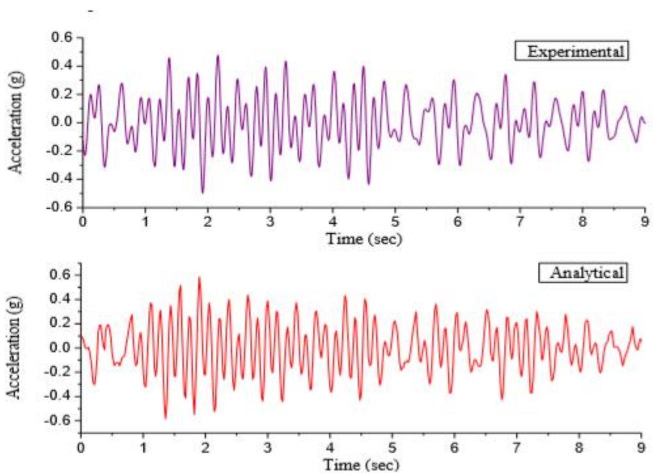

Figure 4.11: Acceleration response time history of aluminium model at top, experimentally and analytically

V. Conclusion:

Accelerometer attached at top of the model records top acceleration of the aluminium frame model. The data recorded experimentally with accelerometer is shown the ground acceleration data which is calculated above is given as input ground motion data to the program of SDOF system. The various parameters of the aluminium frame model which are calculated above given as input. The response (in terms of acceleration) of top of the model (top plate) is calculated is calculated analytically. The response obtained analytically is shown in the. Hence it can be concluded that phase of both experimental and theoretical graphs is fairly same. Peak acceleration of experimental result is 0.5g and peak acceleration of analytical result is 0.58g. The Peak Accelerations obtained from both theoretical and experiment has variation of 13.79%.

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