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Parametric Evaluation of Responses on Single Degree of Freedom System

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Abstract— Structures must be designed to resist a variety of loads. Some of the loads are static (e.g., gravity and snow loads) while others are dynamic (e.g., wind and earthquake loads). Every structure is a complex system. So during dynamic analysis initially simplify this structure into single degree of freedom system. The present research work will be focused on parametric study of single degree of freedom systems with theoretical validation based on the principles of structural dynamics. Generally responses are easy to determine for periodic forcing function but are quite complicated and cumbersome if the forcing function become arbitrary. In such case numerical integration techniques are adopted. Duhamel integral method finds very useful application in this regard. The present work will be directed in determining the response of a single degree of freedom system under different types of arbitrary forcing functions. Models representing single degree of freedom systems with known characteristic and specifications will be tested using the shake table. Different periodic and aperiodic forcing functions will be fed into the controller and the response of the model to such excitation will be noted and plotted using the software available with the shake table. The theoretical responses will be developed using Duhamel integral method for aperiodic vibration. Comparisons of these results will be performed to validate the experimental work.

Keywords— Duhamel Integral, SDOF System, Shake Table, Structural Dynamics

I. Introduction

Earthquake response analysis is an art to simulate the behavior of a structure subjected to an earthquake ground motion based on dynamics and a mathematical model of the structure. The correct analysis will depend upon the proper modeling i.e. the behavior of materials, elements, connection and structure. Models may be classified mainly by essential difference in the degree-of-freedom. The model, or the number of degrees of freedom, should be selected carefully considering the objective of analysis. Sometimes sophistication or complicated models are not only useless but also create misunderstanding to interpret the results in practical problems. Therefore, it is important to select an appropriate and simple model to match the purpose of the analysis. Analytical models should also be based on physical observations and its behavior under dynamic load.

There are many situations in real life when a structure is subjected to vibration caused by dynamic loads due to machines, road traffic, rail traffic or air traffic, wind, earthquake, blast loading, sea waves or tsunami. The term dynamics load includes any loading which varies with time. The manner in which a structure responds to a given dynamic excitation depends upon the nature of dynamic characteristics of the structure and how it stores and dissipates energy. The energy is stored in from of potential energy and is dissipated in the form of kinematic energy through vibration. When a dynamic load is applied on a structure it produces a time dependent response in each element of a structure. The present research work will be focused on experimental analysis of single degree of freedom systems (with different length and mass) with theoretical validation based on the principles of structural dynamics. Structural dynamics mainly constitute the development of the equations of motion and solution thereof for determining the response quantities to evaluate the behavior of the structure under time depending forces. Generally responses are easy to determine for periodic forcing functions but are quite complicated and cumbersome if the forcing function became arbitrary [3]. In such case numerical integration technique are adopted. Duhamel integral method [4] finds very useful application in this regard.

This article is divided into five different sections including this introduction as Section I. In Section II, theoretical background and review of literature are presented. Methodology is discussed briefly in Section III. In Section

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IV experimental investigation and results are discussed. Section V is focused on the conclusions and the future scope of the work related to this article.

II. Related Work

Chen [1] performed experimental research on the consequence of SDOF and multi-degree-of-freedom (MDOF) modeling for seismic response of a multi-storey building. Investigations were performed by considering only the fundamental mode of the structure [1].
Trombetti [2] had performed a comparative study between the numerically predicted and experimentally observed (through shaking table tests) dynamic behaviors of two scaled models of steel frame buildings, in which one building was symmetric and another one asymmetric in plan.

III. Methodology

The development in the field of earthquake engineering requires experimental study. Laboratory testing of components and structures as physical models is an effective way to study the complex phenomena. A shake table can be used to test the model of the structure with suitable scale. In this study fundamentals of the structural dynamics are validated by using an electro dynamic shake table.

Objective of this present work is to investigate responses of a SDOF system under different dynamic loadings with the help of a shake table. A typical SDOF system is shown in Figure 1 and details of a typical SDOF model is given in Table 1. A typical triangular and trapezoidal impulse [6] is shown in Figure 2 and Figure 3 respectively.

Figure 1. Typical Diagram of SDOF Model

Table 1: Details of a Typical SDOF Model

Description	Specification
Material Type	Mild Steel
Mass at Top(gm)	256
Height of the Model from Base(mm)	150
Base Plate Size(mm)	150 X 150
Pole Weight(gm)	117
Weight of the Base Plate(kg)	1.047

Similar types of models are made with different pole hight and top mass to evalute the responses of these models under triangular and trapezoidal impluse loading as shown below.

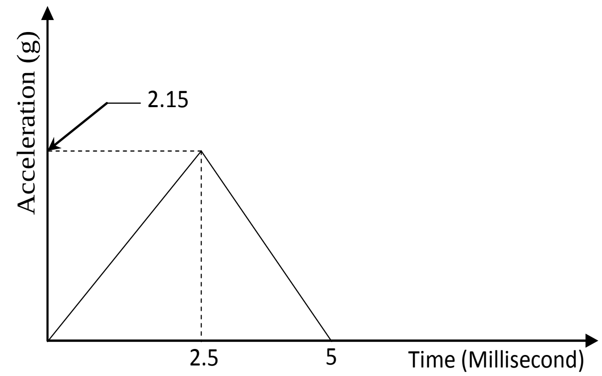

Figure 2. Graphical Representation of Classical Triangular Shock

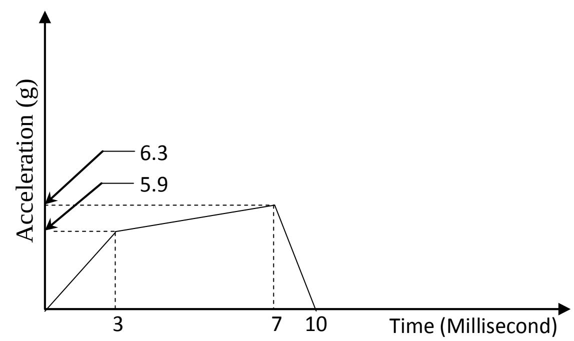

Figure 3. Graphical Representation of Classical Trapezoidal Shock

A. Experimentation with SDOF Models

A number SDOF models with known characteristics and specification have been tested using the shake table as shown in Figure 4. Different arbitrary forcing functions have been fed in to the controller and the response of the model to such excitation was noted and plotted using the software available with the shake table. This constituted the experimental analysis part for these arbitrary forcing functions. The motions of the base and the model have been monitored by accelerometers. In this article only force vibration has been considered to identify the response of the models.

B. Theoretical Validation

A numerical simulation can be performed along with the experimentation, to compare the actual and predicted response of the model. This simulation computes the response of a single degree of freedom (SDOF) [3] model, subjected to a known base acceleration, using the software available with the shake table. The recorded shake table acceleration is used as an input to get responses based on the theoretical concepts of structural dynamics. A computer program has been developed in Microsoft Excel solver to compute the model responses (acceleration, velocity & displacement) by Duhamel Integral [4] with experimentally obtained values of damping ratio and natural frequency.

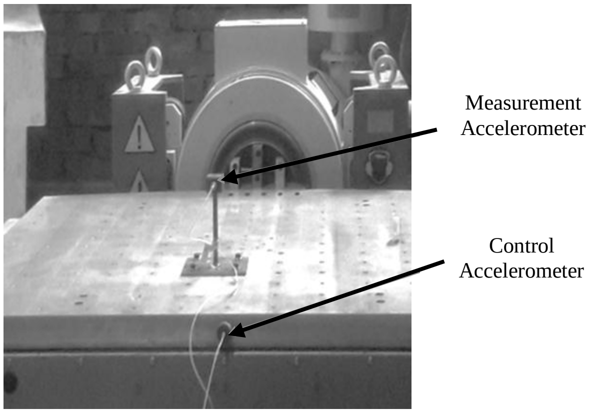

Figure 4. SDOF Model during Testing

IV. Results and Discussion

From Figure 5, it is observed that the peak acceleration is 2.15g and duration of the shock is 0.005 seconds. The controller cannot apply the shock abruptly, so the controller needs some pre-adjustment on the table to perform the shock, because of this table has some acceleration before and after the application of the shock impulse. An accelerometer cannot measure velocity directly, although the resulting signal can be integrated to obtain velocity. Also an accelerometer cannot measure displacement directly, although the velocity can be integrated to obtain displacement. In order to limit the number of pages of the article only one typical graphical representation of triangular and trapezoidal shock testing in Shake Table is shown below.

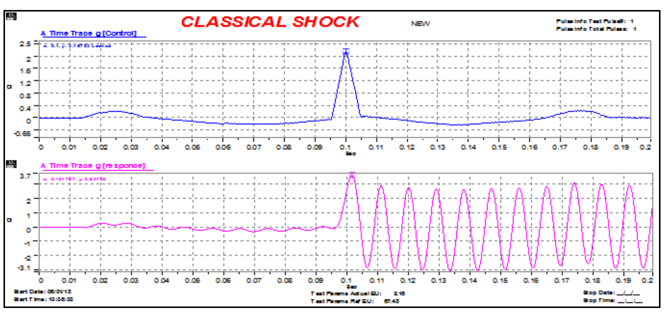

Figure 5. Time Vs Acceleration Plot for Triangular Shock

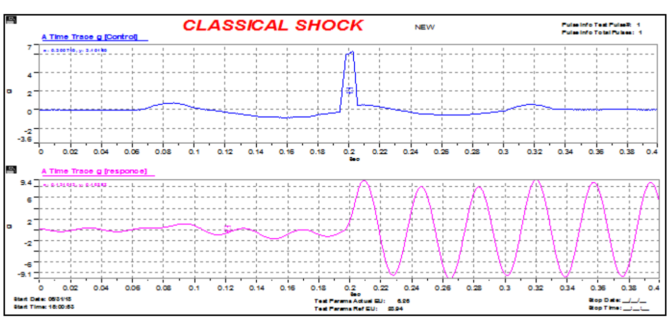

Figure 6. Time Vs Acceleration Plot for Trapezoidal Shock

From Figure 5 and Figure 6, maximum responses of the typical SDOF model for triangular and trapezoidal shock obtained from Shake Table experrimentation, are summerised in Table 2.

Table 2 Summary of Output Results from Experimental Study

Shock Definition	**Input Parameter**		**Maximum Output Response**		
	Acceleration in m/sec^2	**Total Stay Time in sec**	**Acceleration in m/sec^2**	**Velocity in m/sec**	**Displacement in mm**
Triangular	2.15g	0.005	3.64055g	0.09401	1.46
Trapezoidal	6.00g	0.010	10.7611g	0.34644	7.60

Maximum responses of the typical SDOF model for triangular and trapezoidal shock obtained from theory of structural dynamic (by Duhamel Integral) are tabulised in Table 3.

Table 3 Summary of Output Results from Theory of Structural Dynamics

Shock Definition	**Input Parameter**		**Maximum Output Response**		
	Acceleration in m/sec^2	**Total Stay Time in sec**	**Acceleration in m/sec^2**	**Velocity in m/sec**	**Displacement in mm**
Triangular	2.15g	0.005	3.3167g	0.07277	1.36
Trapezoidal	6.00g	0.010	10.0023g	0.2900	6.96

V. Conclusion and Future Scope

After comparing theoretical and experimental values following observations can be made. Damping ratio of the SDOF model as determined by using half power band width is 0.00124 and it is within the prescribed range (0.001 to 0.002) for mild steel bared type structures. Variation in the values of time period of the SDOF systems obtained by experimentation is within 10% of theoretical calculation. The Excel file developed for calculation of the responses using Duhamel's Integral have exhibited excellent one to one correlation with the results obtained from the Shake Table. Acceleration from shake table experimentation is about 9 to 10% more than the theoretical response. It is very useful to the structural designer to get the values of maximum responses for any ground motion directly from this study.

In this present Duhamel integral has been used. Other type of numerical integration technics may be applied in similar type

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of study. Mild steel models have been used in the present study. Similarly other materials can be used. Cross section of the stick model was square, similar study can be carried out by using circular cross section of the stick model.

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