A Comparative Study on the Single Degree of Freedom System

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Abstract

This paper presents an investigation on innovative optimum design of single degree of freedom system with and without viscous fluid damper. This type of damper dissipates the buildings mechanical energy into heat energy. Most of the structures is subjected to load which varies with time hence the structure is under vibration. This vibration in structural system may result from a wide variety of sources such as wind, seismic waves. In the present study the effect of vibration on Single Degree of Freedom System (SDOF) is studied in simulation software as per codal provision

Keywords: *Single Degree of Freedom System (SDOF), Innovative optimum design, Viscous fluid damper, Buildings mechanical energy*

INTRODUCTION

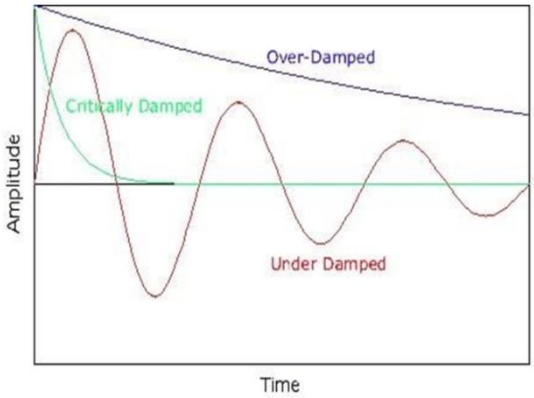
General

Earthquake is known to be one of the most destructive phenomena experienced on earth. It is caused due to a sudden release of energy in the earth's crust which results in seismic waves. When the seismic waves reach the foundation level of the structure, it experiences horizontal and vertical motion at ground surface level. Currently, there are several design philosophies in earthquake engineering, making use of experimental results, computer simulations and observations from past earthquakes to offer the required performance for the seismic threat at the site of interest. These range from appropriately sizing the structure to bestrongandductileenough to survive the shaking with an acceptable damage, to equipping it with base isolation or using structural vibration control technologies to minimize any forces and deformations. While the former is the method typically applied in most earthquake resistant structures, important facilities, landmarks and cultural heritage buildings use the more advanced (and expensive) techniques of isolation or control to survive strong shaking with minimal damage.

In 1960s accelerograms giving detailed information on the ground acceleration occurring in earthquakes were becoming more generally available. The advent of strength design philosophies, and development of sophisticated computer-based analytical procedures, facilitated a much closer examination of the seismic response of multi-degree-of-freedom structures. It quickly became apparent that in many cases, seismic design to existing lateral force levels specified in codes was inadequate to ensure that the structural strength provided was not exceeded by the demands of strong ground shaking. At the same time, observations of building responses in actual earthquakes indicated that this lack of strength did not always result in failure, or even necessarily in severe damage. Provided that the structural strength could be maintained without excessive degradation as inelastic deformations developed, the structures could survive the earthquake, and frequently could be repaired economically. However, when inelastic deformation resulted in severe reduction in strength, as, for example, often occurs in conjunction with shear failure of concrete or masonry elements, severe damage or collapse was common. With increased awareness that excessive strength is not essential or even necessarily desirable, the emphasis in design has shifted from the resistance of large seismic forces to the "evasion" of these forces. Inelastic structural response has emerged from the obscurity of hypotheses, and become an essential reality in the assessment of structural design for earthquake forces. The reality that all inelastic modes of deformation are not equally viable has become accepted. As noted above, some lead to failure and others provides ductility, which can be considered the essential attribute of maintaining strength while the structure is subjected to reversals of inelastic deformations under seismic response.

Passive fluid viscous damping systems are generally well suited to vibration control of civil structures subjected to seismic excitation. In particular, fluid viscous dampers that operate on the principle of fluid orificing exhibit extraordinarily high levels of energy dissipation density. The dynamic behavior of a fluid orificing damper is examined through steady-state cyclic data. Mathematical models of the damper are derived from the cyclic test data and subsequently used in obtaining analytical predictions of the seismic response of a scale-model building structure subjected to earthquake ground acceleration. The discussion on fluid orificing dampers is expanded by considering a generalized mathematical model for describing both linear and nonlinear fluid viscous damper behavior. The energy dissipation characteristics of generalized fluid viscous dampers are then examined with reference to the performance of an idealized single-story structure.Vibration theory was initiated by Pythagoras in the Fifth century B. C. By establishing a rational method of measuring sound frequencies, Pythagoras quantified the theory of acoustics. He proved with his hammer experiments that natural frequencies are system properties and they do not depend on the magnitude of excitation. Galileo also experimented with pendulum in the Seventh century. He observed that the relationship between sound and vibration of mechanical system was understood for a long time, but Galileo first to prove that pitch is determine from the frequency of vibration. Vibrations have made rapid strides in last few decades that the advent of computer has brought in a revolution in this area like many others. Due to vibrating of any structure there may be a possibility of change in the position and orientation of structure with respect to initial position. Thus, the easiest way to describe a vibratory system is a degree of freedom (DOF). The number of independent coordinates necessary to specify the configuration or position of a system at any time is referred as the number of degrees of freedom. Also represents minimum number of independent coordinate of systems required to denote the position of the mass at any instant of time. A system which requires only one coordinate to describe its position at any instant of time is known as single degree of freedom system (SDOF). System with more than one degree of freedom is called multi degree of freedom system (MDOF).

Another important aspect in earthquake resistant design is damping characteristics of structures. Damping is a phenomenon that makes any vibrating structure to decay in amplitude of motion gradually by means of energy dissipation through various mechanisms. The damping is classified based on damping ratio(ξ) such as, if $\xi =1$, Critically damping condition, if $\xi<1$, Under damping condition, if ξ>1, Over damping condition. Generally, the buildings are designed with under damping condition, where the system oscillates at reduced frequency with amplitude gradually decreasing to Zero.



IMPORTANCE

To study the behavior of structure by the installation of damper and to know the responses of single degree of freedom structure.

LITERATURE REVIEW

General

The passive energy dissipation systems for Civil Engineering structure with use of fluid viscous dampers are carried out. The following research work was identified prior to setting or objectives for the present invention.

Murat Dicleli et al.,1 has presented a paper on Seismic performance of chevron braced frames with and without viscous fluid dampers as a function of ground motion and damper characteristics. This paper deals with comparative study on steel buildings of chevron braced frame (CBF) with and without viscous fluid damper (VFD).

The VFD dissipates the structural base shear as well as deflection. The VFD reduces the story drift by 30-70% as well as story shear force of 40-70%. Also, it prevents the compression failure due to the axial loads. As the damping ratio increases there will be the reduction in the deformation of frame. The practical implication of using VFD shows that the maximum deformation of 4 story CBF without VFD produces 30% damping and with VFD 50% damping so there will be the dissipation of energy occurs.

Hernan Garrido et al.,[2] presented a paper on Improvement of tuned mass damper by using rotational inertia through tuned viscous mass damper. The study involved on the rotational inertia double tuned mass damper (RIDTMD) for an S.D.O.F. system. The RIDTMD is a combination of rotational inertia viscous damper (RIVD) and tuned viscous mass damper (TVMD) both which will dissipate the displacement of motion into rotational motion. So, on applying the De-Alembert's principle the damping parameters are to determined such as natural frequency and mode shape. In order to determine the response of RIDTMD three main parameters are to be considered such as tuned mass damper, structural displacement and mass. To represent the structural response in frequency domain dynamic magnification factor (DMF) is used. The D.M.F. provided with frequency ratio ranging from 0.5-1.5 for RIDTMD and TMD has given. It is to be noted that the structure provided with RIDTMD has smaller DMF then the TMD due to flatter in frequency response curve.

Himanshu Mevada et al.,[3] has presented a paper on Experimental determination of structural damping of different material. It deals with the experimental method to investigate the behavior of structural component due to harmonic vibration. It has been conducted in determining the natural frequency of beam and its damping ratio by the use of dynamic analysis. In dynamic analysis, vibration is more important than the deflection control in designing buildings. It essentially requires two sets of calculation such as natural frequency of beam and peak acceleration due to dynamic loading is approximated by estimating the effective mass of the system and then calculating the peak acceleration. By the experimental setup beams are fixed at one end and due to the external force, the beam will oscillate and it is sensed by the accelerometer. In this case beam is made up of aluminium, brass, steel and the obtained result is validated with lab view software.

Chaitra HN et al.,[4] has carried a paper on a Study on performance of regular and vertically irregular structures with damper, shear wall, and infill wall. The project deals with study on regular and irregular buildings with seismic effect. By the installation of damper, shear wall, and infill wall the modal is analyzed by equivalent static analysis and time history analysis. The storey displacement of modal provided with infill wall is lesser than the shear wall and damper. As well as the stiffness of infill wall building is higher than the shear wall and damper.

Abdollah Javidialesaadi et al.,[5] has presented a paper on Energy transfer and passive control of single degree of freedom structure using one directional inertia viscous damper. In this paper, it is proposed to control the structural vibration by means of one directional rotational inertia viscous damper (ODRIVD). Since the traditional method of controlling the structural motion into the rotational vibration is known as rotational inertia viscous damper (RIVD). RIVD is one of inerter based device with large inertial mass for passive control device. Due to the inertial mass, there may be a possibility of reduction in the natural frequency of system as well as the position and orientation of structure may differ. Therefore, a new technique of RIVD is developed is known as the ODRIVD. In this case the maximum dissipation of energy takes place and the amplitude of vibration reduces.

Qinhua Wang et al.,[6] carried out a study on Inerter based tuned liquid column damper for seismic vibration control of a single degree of freedom system (SDOF). This paper deals with the optimal installation of tuned liquid column damper inerter (TLCDI) for the SDOF Structure to control the base excitation of structure by reducing the response of structure. Also, the effectiveness of TLCDI have been investigated with respect to the varying frequency ratio. The behavior of the TLCDI is carried out for 44 actual induced earthquakes and which reduces 77-81% of displacement of the structure.

Motivation towards Proposed Work

Design of SDOF system with damper to minimize the amplitude of vibration.

OBJECTIVES

1. To measure the damping factor for designed damper.
2. To compare the response SDOF system with damper and validate same using finite element software.

METHODOLOGY

Design of SDOF model

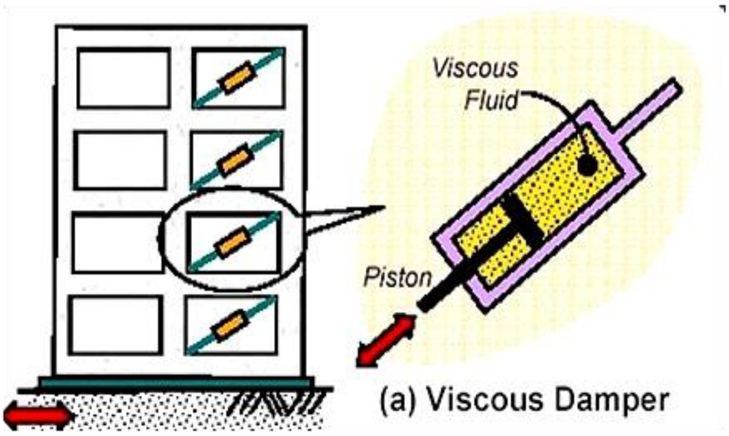
Model is constructed using standard metals. The geometry of the model is being selected based on the literature review. The selected model is designed as single degree of freedom (SDOF) system by considering the entire mass of the structure can be lumped into single point that is at slab level and the slab is considered to be 100 percent rigid. Columns and beams are rigidly connected to the system with stiffness value of 4EI/L. The material selected for SDOF system are, base plate is made up of wood having dimensions (30*15) cm and thickness is about 1.25cm, column is made up of aluminum and dimensions (2.5*15) cm and height (40cm), slab is also made up of aluminum and dimensions (30*15) and thickness is about 1.25cm. Young's modules of aluminum is 69GPa.

Frame structure details

The earthquake response of building frames that are asymmetric in plan is characterized by coupling between translation and torsional degrees of freedom. Here the asymmetry could arise due to unsymmetrical distribution of mass, stiffness, damping and strength characteristic. Such structure, when subjected to horizontal support motions, display not only bending oscillations, bit also, undergo torsional vibrations. The structure under study is a model for single story building frames that consist of a relatively rigid rectangular aluminum supported at the corners four aluminum columns. Apart from the distribution of stiffness, the mass and damping characteristics offered by aluminum columns would also contribute to the planar asymmetry of the structure. Since the slab is much stiffer than the columns, under the action of dynamic base motions, it is reasonable to assume that the slab would display in its own plane. In the experimental setup the frame is mounted on table that is driven by electric motor.

Design of dampers

Viscous fluid dampers are installed to the system which dissipates the mechanical energy into heat energy. These dampers are placed diagonally in between the columns in the direction opposite to the vibration.



Measurement of Vibration

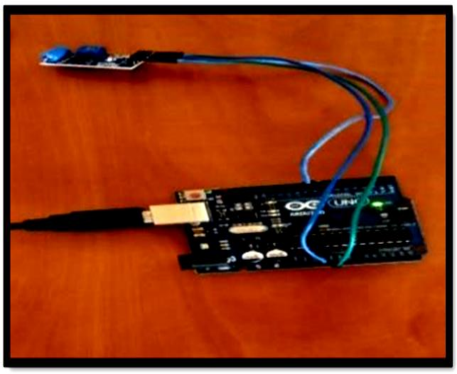
For that system the excitation force will be applied by using D.C motor. This excitation force will be measured by using "Tilt sensor". A Tilt sensor measures the tilting position with reference to gravity and enables the easy detection of orientation and vibration. Amplitude will be measured for the applied excitation force to the SDOF structure in presence and absence of damper. The successive amplitudes are determined by logarithmic decrement, which is used to find the damping ratio of an under damped system in the time domain. The measured amplitude of SDOF structure will be validated using any one of the finite element's software such as ETABS, SAP. Finally, the result will be interpreted.

Shake Table

Shake table is an essential tool for assessing the behavior of structural components, the whole system works similar to those induced in real earthquake. Shake table is used to study the dynamic effects on the performance of specimens. The horizontal shake table is used for horizontal vibration so that the table is able to generate harmonic motions of different amplitude. By varying the speed of the motor, the frequency content of the base motion can be varied.

Tilt sensor

A tilt sensor is an instrument that is used for measuring the tilt in multiple axes of a reference plane. Tilt sensors measure the tilting position which reference to gravity and are used in numerous applications. They enable the easy detection of orientation or inclination. This sensor is responds to some type of the input from the environment such as heat, light, motion, temperature, pressure and moisture. Sensors are used to switch currents and voltages. Every sensor as three terminals: Vcc, GND and output. Vcc is used to power up the sensor; to provide a fixed negative reference, ground is used, and the output of the sensors.



Tilt sensor working principle

These sensors consist of a rolling ball with a conductive plate beneath them. When the sensor gets power, the rolling ball falls to the bottom of the sensor to form an electrical connection. When the sensor is tilted, the rolling ball doesn't fall to the bottom so that the current cannot flow the two end terminals of the sensor.

MODELLING AND ANALYSIS

SDOF System without Damper

The analysis of SDOF system is carried by following assumptions such as:

1. The entire mass is concentrated at the slab level.
2. Beams and slab are 100% rigid. Flexibility and stiffness are taken by column.
3. Joints between the column and beam and beam and slab are rigid.

The selection of the geometry and the material properties of the S.D.O.F. system is carried out by the reference of Indian Institute of Science Bangalore (IISC). The S.D.O.F. system mainly consist of base plate, column, and slab portion. Also, the modelling of S.D.O.F. system is completed by the help of ETABS.

1. BASE PLATE

Material – Steel

Dimension – (300*150*10) mm

2. COLUMN

Material - Steel

Dimension – (300*25*3) mm

3. SLAB

Material - Steel

Dimension – (300*25*3) mm

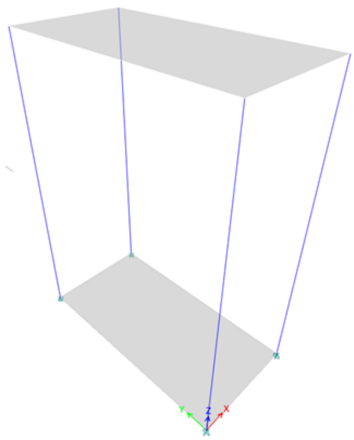


Figure 1.0 SDOF system without damper

Table 1 – Modal Periods and Frequencies

Case	Mode	Period sec	Frequency Cyc/sec	Circ Freq rad/sec	Eigen value rad2/sec2
Modal	1	0.146	6.862	43.1132	1858.7471

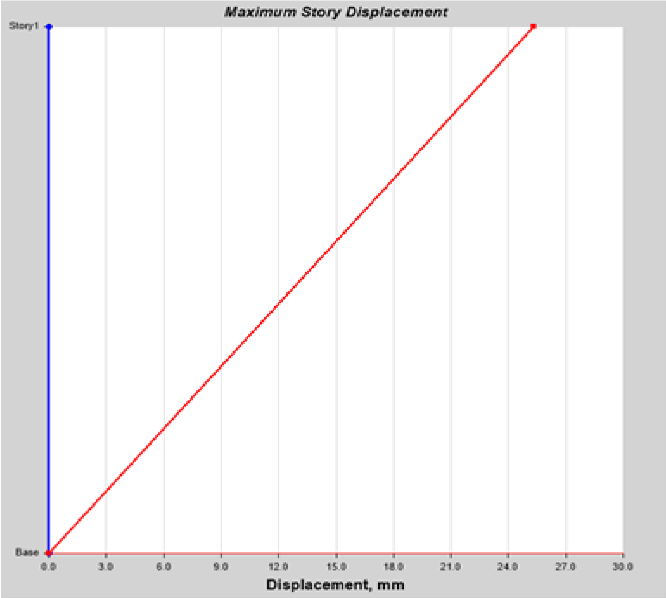


Figure 2.0 Story response Vs Story displacement

Table 2 - Modal Periods and Frequencies

Case	Mode	Period sec	Frequency Cyc/sec	Circ Freq rad/sec	Eigen value rad2/sec2
Modal	1	0.898	1.113	6.9949	48.9287

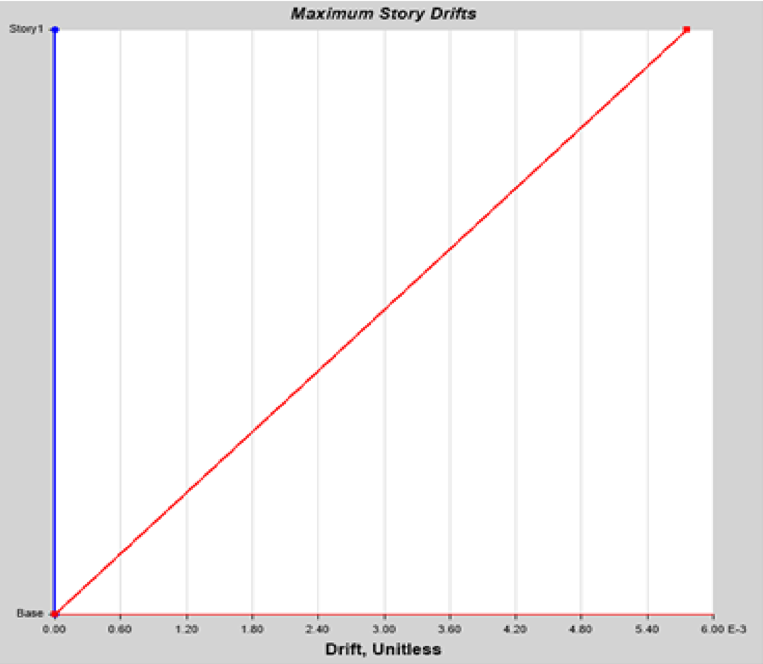


Figure 3.0 Story response Vs Story drift

SDOF SYSTEM WITH DAMPER

A SDOF system with viscous fluid damper is used which works under the principle of dissipation of energy by this the amplitude of vibration is minimized and deformation of the structure is nullified.

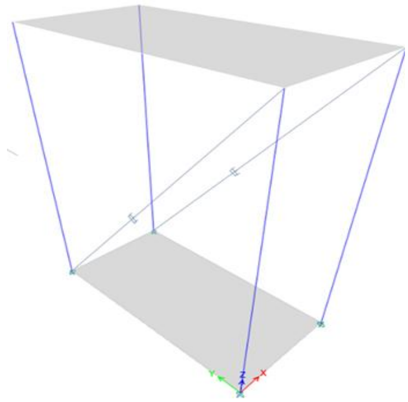


Figure 4.0 SDOF system with damper

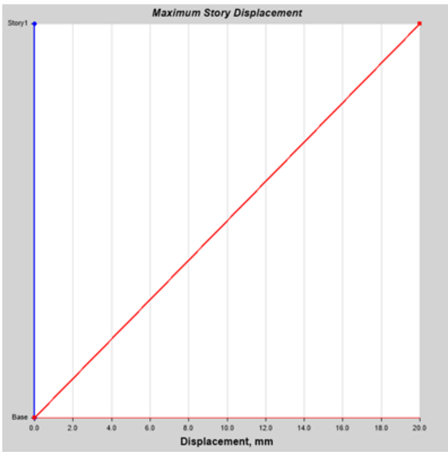


Figure 5.0 Story response Vs Displacement

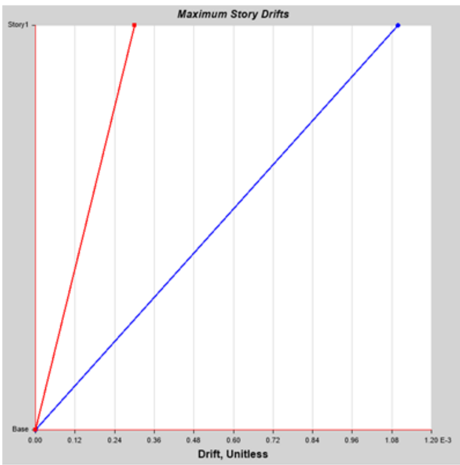


Figure 6.0 Story response Vs Drift

STORY DISPLACEMENT AND DRIFT

It can be observed from figure 2,3,5, and 6 shows that the displacement and drift is maximum with the absence of viscous fluid damper (VFD). The models provided with the VFD helped in reducing the amplitude of vibration to a maximum extent due to the application of external force by this the deformation of SDOF system is minimized.

ANALYSIS

The analysis of SDOF system is determined by the help of Response Spectrum Analysis (RSA). It is the representation of maximum of damped SDOF system of different natural period but having same damping under the application of earthquake ground motion at their base.

Table 3 - Load Case Definitions

Name	Type
Dead	Linear Static
Live	Linear Static
Modal	Modal - Eigen
RP-X	Response Spectrum
RP-Y	Response Spectrum

Table 4 - Response Spectrum - IS1893 2016

Name	T sec	Value	Seismic Zone	I	Soil Type	R	Damping Ratio
IS 1893-2016H	0	0.036	V	1	II	5	0.1
IS 1893-2016H	0.1	0.09					
IS 1893-2016H	0.55	0.09					
IS 1893-2016H	0.8	0.061					
IS 1893-2016H	1	0.048					
IS 1893-2016H	1.2	0.040					
IS 1893-2016H	1.4	0.034					
IS 1893-2016H	1.6	0.030					
IS 1893-2016H	1.8	0.027					
IS 1893-2016H	2	0.024					
IS 1893-2016H	2.5	0.019					
IS 1893-2016H	3	0.016					
IS 1893-2016H	3.5	0.013					
IS 1893-2016H	4	0.012					
IS 1893-2016H	4.5	0.012					
IS 1893-2016H	5	0.012					

Name	T sec	Value	Seismic Zone	I	Soil Type	R	Damping Ratio
IS 1893-2016H	5.5	0.012					
IS 1893-2016H	6	0.012					
IS 1893-2016H	6.5	0.012					
IS 1893-2016H	7	0.012					
IS 1893-2016H	7.5	0.012					
IS 1893-2016H	8	0.012					
IS 1893-2016H	8.5	0.012					
IS 1893-2016H	9	0.012					
IS 1893-2016H	9.5	0.012					
IS 1893-2016H	10	0.012					

Table 5 - Modal Participating Mass Ratios with Damper

Case	Mode	Period sec	UX	UY	UZ	Sum UX	Sum UY	Sum UZ	RX	RY	RZ	Sum RX
Mode	1	0.898	0	0.5	0	0	0.51	0	0.51	0	0.10	0.51

Table 6 - Modal Participating Mass Ratios without damper

Case	Mode	Period sec	UX	UY	UZ	Sum UX	Sum UY	Sum UZ	RX	RY	RZ	Sum RX
Mode	1	0.146	0	1	0	0	1	0	0.62	0	0	0.625

Table 7 - Modal Load Participation Ratios with damper

Case	Item Type	Item	Static %	Dynamic %
Modal	Acceleration	UX	0	0
Modal	Acceleration	UY	51.6	51.6
Modal	Acceleration	UZ	0	0

Table 8 - Modal Load Participation Ratios without damper

Case	Item Type	Item	Static %	Dynamic %
Modal	Acceleration	UX	0	0
Modal	Acceleration	UY	100	100
Modal	Acceleration	UZ	0	0

CONCLUSION

This study explains the behavior of SDOF system under the performance of dynamic load with and without viscous fluid damper based on that following conclusion can be made.

1. The analysis shows that the time period of structure increases when VFD are mounted because of this frequency of the structure decreases and the dynamic effect on building also reduces.
2. The amplitude of vibration is obtained from the mode shape of a SDOF system.

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