PARTICLE DAMPER MODELLING FOR VIBRATION CONTROL

A Thesis

Submitted by

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We do hereby recommend that the thesis prepared under my supervision by ***BISWAJYOTI GHOSH*** *(Roll no: 202110402011) entitled* ***"PARTICLE DAMPER MODELLING FOR VIBRATION CONTROL"*** *be accepted in partial fulfilment of the requirements for the Degree of Master of Civil Engineering with specialization in Structural Engineering from Jadavpur University, Kolkata-700032.*

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This thesis is hereby approved as a legitimate study into an engineering subject that was conducted and presented in a manner that allows its acceptance as a requirement for the degree for which it has been submitted. It is understood that by signing this approval, the undersigned do not endorse or support any assertion made, viewpoint expressed, or conclusion reached within it, but rather only approve the thesis for which it has been submitted.

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SYNOPSIS

Engineering has for a long time been confronted with the problem of structural vibrations which has the possibility of compromising the operations and safety of many systems and structures. A new class of passive vibration control systems known as particle dampers has emerged as a possible solution to these oscillations and enhance the structure. This thesis focuses on the particle damper modelling by employing the ANSYS computational tools and stresses on the comparable method that considers the balance between model precision and computational efficiency. The method of the research is based on the creation of the accurate particle damper models where the boundary conditions, geometrical representation and material characteristics are set to reproduce the behaviour observed in the real world. The behaviour of the particles and the structure is analysed dynamically through transient analysis and the interaction between the particles and the structure under various stress conditions is studied. Besides shedding light on previously unknown scenarios, in which particles violate boundary boundaries, the thesis reveals significant findings on the behaviour of particle dampers, especially under seismic forces. This result underlines the significance of accurate definition of boundary conditions and constraints for modelling. The finding has potential applications in a wide range of future studies in the areas of fluid-structure interactions, real-time control strategies, advanced particle dynamics modelling, and machine learning. The practical applications offer the possibility of developing more accurate and efficient structural vibration control systems in aerospace and architecture fields. In conclusion, this thesis is a significant step towards achieving the objective of understanding and mastering **ANSYS** particle damper modelling and has the potential to revolutionise the field of structural dynamics by enhancing the safety and force bearing capacity of structures.

This snapshot provides a clear and detailed idea about your thesis work, the techniques employed, the findings and future scope of multiple researches and practical implications in the field of modelling particle damper.

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LIST OF ABBREVIATIONS

1. PDM - Particle damper model
2. PTMD – Particle tuned mass damper
3. FEM – Finite element method
4. FEA – Finite element analysis
5. DEM- Discreate element method
6. SPH- Smoothed Particle Hydrodynamics

LIST OF SYMBOLS

1. m_s = Mass
2. k_s = Stiffness
3. c_s= Stuctural damping
4. ν_s = Displacement
5. F = Base shear
6. a_g = Acceleration time history
7. ω_s = Natural circular frequency
8. ξ_s = Damping ratio
9. f_s=Natural frequency
10. m= Total mass of PTMD
11. m1p = Mass of the single particle
12. ρ = Density of the particles
13. Dp = Diameter of the particles
14. D=Diameter of the single particle
15. Vspd =Volume of the particles in the PTMD
16. Vepd =Void volume of the PTMD
17. Vpd = Volume of the PTMD
18. Veid =Void volume of the single particle damper
19. N=Number of the particles
20. ρ_p= Packing density of the PTMD
21. g = Acceleration due to gravity
22. Δt = Time step
23. d = Clearance of the simplified single particle damper

CHAPTER 1

INTRODUCTION

It is well-known that the control of vibrations and oscillations of various systems is one of the key issues in structural dynamics and an engineering. These oscillations caused by external loading, internal instabilities or coupling mechanisms may degrade the working efficiency of the system, and generate damages or even lead to disastrous failure. As a response to this challenge, engineers and scholars have always sought for innovative methods for these vibrations' suppression to improve the reliability and durability of structures in general.

Particle dampers, also known as passive energy dissipation devices, are made up of energy transfer processes that take place in a restricted area of granular materials. Thus, for the goal of dampening vibrations, this notion also depends on friction, particle bed impacts, and energy conversion principles.

When it comes to frequency ranges, particle dampers are as special as they can get due to their considerable possible dampening behaviour across a wide range of frequencies and thus enabled various applications. From civil engineering structures such as bridges and buildings to aerospace systems and mechanical components, particle dampers have exhibited potential in reducing vibrational responses induced by earthquakes, wind loads, rotating equipment, etc.

Particle dampers are rather complicated systems, and if one wants to predict how they will behave in various scenarios, a proper modelling this thesis stage is required. Several factors, including particle size and material properties, confinement, and applied excitation, affect the dynamics of particle dampers. An in-depth knowledge of these factors is therefore needed to develop sound predictive models which can guide the design and use of particle dampers for actual applications.

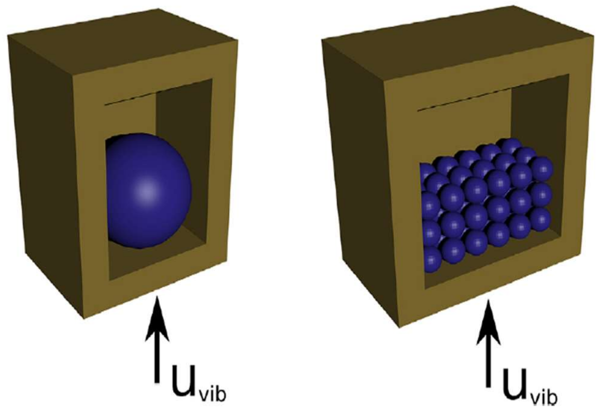


Fig. 1. a) Equivalent particle system (left), b) Multi particles system (right) [1]

The goal of the thesis is to explore the implementation of the particle damper modelling strategy using equivalent particle method. The equivalent particle method, is a compromise between cost and fidelity for predicting particle damper behaviour. This method replaces the internal granular material in the damper with a single equivalent spherical mass considering particle interactions, friction, and energy loss [11]. This abstracts the complexity involved in granular dynamics and allows for a tractable analysis capturing important features of particle damper behaviour.

Due to its convenience and capacity to deliver quick insights into the possible performance of particle dampers, the equivalent particle approach is particularly intriguing for engineering applications. This thesis investigates the intricacies of the equivalent particle approach, examining its accuracy, constraints, and usefulness in a variety of situations through ANSYS-based simulations. The study goes into the complexities of the approach using the computational power of ANSYS, investigating how several aspects, such as particle size, material qualities, and system excitation, affect the precision of the predictions.

The main goal of this thesis is to contribute to the field of particle damper modelling by offering a thorough assessment of the performance of the equivalent particle approach. The research intends to establish the validity and applicability of the equivalent particle approach for forecasting particle damper behaviour by comparing simulation findings with experimental data and more sophisticated models. The study also aims to provide insights into improving the accuracy and applicability of the technique for a variety of engineering applications.

In conclusion, this thesis represents an investigation into particle damper modelling with a focus on the equivalent particle approach. The work attempts to improve our comprehension of particle damper behaviour and its practical application using ANSYS simulations. Through this research, we hope to make significant concept in the field of vibration control, ultimately promoting more durable and safe engineering solutions in a range of sectors.

CHAPTER 2

2.1 LITERATURE REVIEW

Particle damper modelling (PDM) has been researched by numerous academics up to this point. These publications covered a range of PDM-related topic, such as experimental research, numerical analyses, and optimization methods.
A summary of past works on PDM is provided here:

Masri & IbrAahim (1971) investigated the effect of stationary random stimulation with a Gaussian probability distribution and a white-power spectral density on a single-degree-of-freedom system coupled to an impact damper. Electronic-analog techniques and digital computer techniques were used to independently determine the time average statistics of the system's reaction. The ratios of an impact damper system's mean-squared displacement and velocity response to the corresponding response level of the primary system without the damper show a clear minimum at values of $0.2<e<0.8$.

Papa Lou & Masri (1995) examined the behavior of granular material dampers using tungsten powder as an impacting mass under wide-band random excitation both experimentally and analytically. A tiny building model with base excitation is used to examine the effects of some of the key system characteristics, such as the total auxiliary mass ratio, container size, and excitation intensity. Based on the idea of an analogous single-unit impact damper, an approximative analytical solution is proposed. Under random stimulation, the effectiveness of a particle damper utilized to regulate forced vibrations of buildings, using tungsten powder as an impactor, was examined. The impact of the important system variables—such as the total auxiliary mass ratio, container dimensions, and excitation intensity—on the particle damper's behavior is taken into consideration.

Hisao- Hayakawa (1999) examined the useful (or streamlined) macroscopic model of the discrete element technique (DEM) for granular friction. The main emphasis is on the stick-slip motion in a sheared granular friction process, which is consistent with an experiment by Nasu no et al. (Phys. Rev. E 58 (1998), 2161). In this study, he investigated the use of the discrete element method (DEM) for the effective (or streamlined) macroscopic model of granular friction. From the simulations of the DEM model and the effective model, he obtained several excellent results.

Friend & Kinra (1999) proposed the goal of this research is to quantify non-linear particle impact damping in the setting of unrestrained vertical beam vibration. The different mathematical parameters, including the reduced mass of the beam, the reduced rigidity of the beam, and the lowered damping coefficient, are explained in this work. The velocity of particles at any moment t can then be determined for various instances. After that, we learn about the specific damping capacity and the energy lost during a particle hit.

J. O'Rourke a, Snider (2000) et. al. examined a unified model for the collisional mass, momentum, and energy transfer between bed particles in a fluidized bed of gas, liquid, and solid. By adding collision variables to the right-hand side of the transport equation for the single-particle distribution function for the bed particles, the mathematical model expands the equations of the multiphase particle-in-cell (MP-PIC) approach. In fluidized beds, a novel model has been created for the numerical calculation of the collisional transfer of mass, momentum, and energy between bed particles. In this article, we go into detail about the method's equations, how the collision terms are numerically solved, and some characteristics of the new collision terms.

Zhang (2017) et.al. investigated damping behaviors of granular particles in a quasi-two-dimensional (Q-2D) closed container subjected to vertical vibration are modelled using the discrete element method (DEM). In the amplitude-frequency plane of external excitation, a phase diagram and damping contour of vibrated granular particles are obtained. The key finding is that the proposed approach works best in environments with relatively high vibration, where granular particles are more frequently found in suspended states. The calibration of the contact parameters in the DEM simulation is the key to this methodology.

Mao &Chen (2004) et.al. investigated the 3D DEM for computer simulation and characterization of particle damping. This study is an endeavor to give a thorough technique for particle damping analysis and design by fostering a deeper understanding of the phenomenon. It is demonstrated that the particle damping can attain a very high specific damping capacity, with a maximum instantaneous value of 50%. We discover that the damping is profoundly nonlinear.

Pugnaloni(2013) et.al. investigated when different-shaped grains are considered, the response of a PD that has been remains valid. Simulations with triangular, square, and hexagonal grains as well as those with various dissipative qualities have been run. Furthermore, we demonstrate that particle fragmentation, which is likely while working in challenging settings, does not affect the system's reaction. According to the data we have shown for PDs with grains of various forms, the particle geometry has little effect on damping effectiveness. If the ideal enclosure height is adopted, using a lot of particles in a PD ensures that a universal frequency response function will be obtained.

Marhadi & Kinra (2004) examined that a cantilevered beam with a particle-filled container attached to its free end is dampened using the Particle Impact Dampening (PID) principle. Lead spheres, steel spheres, glass spheres, tungsten carbide pellets, lead dust, steel dust, and sand are among the many particle materials whose PID is assessed. PID has been researched in relation to the effects of particle mass ratio, number, material, and form. The experimental results show that a more sophisticated PID model must eliminate the restriction of all particles moving as a single particle and include the size and number of particles as additional independent factors.

Chen (2009) et.al. proposed that the tuned particle damper is established, and its ability to control vibration is examined using several theory evaluations and numerical simulations. In comparison to the traditional dynamic vibration observer, the tuned particle damper's damping action has a greater impact. The tuned particle damper's dampening process is very nonlinear, and the effect is dependent on the rate of vibration. With an increase in particle damping, which merely dissipates the mass block's vibrational energy, the tuned particle damper will not collapse.

Shan & Li (2009) et.al. suggested coupling simulation algorithm uses both the discrete element method and the finite element method. The accuracy of the modelling of the response of a cantilever plate with a particle damper is demonstrated by a comparison of the analytical and experimental data. It is demonstrated that the mass-fill ratio and particle density of the particle damper affect the cantilever plate's reaction. Additionally, the results show that the relationship between particle densities and mass-fill ratios is what determines how well the damping works. For the same particle densities, the maximum value of the primary plate amplitude is always smaller for the mass-fill ratio of 70% than for the mass-fill ratios of 50% and 30%.

Pugnani a (2009) et.al. examined the behavior of a mechanical system with one degree of freedom made up of a primary mass, M, a linear spring, a viscous damper, and a particle damper. We discover friction, shear damping force, and normal contact force. From the various plots, we can then determine the effective mass and the ratio of effective damping to viscous damping.

Suhr & Six (2016) examined a stress dependency of the bulk friction coefficient is also seen in the measurements of several granular materials under minor normal loads. Both in the experiments and the simulations, the bulk friction coefficient decreases as the applied normal stress increases. It is concluded that one way to incorporate the bulk friction coefficient's dependence on normal stress in a DEM simulation is by adopting the proposed model.

Kitayama &Takasaki (2015) et.al. investigated that an impact damper which consists of multiple vibrators installed on a main structure and dissipates the vibrational energy by collisions between the vibrators. States the optimization method of differential evolution (DE) and attempted to determine the masses and spring constants of the vibrators that maximize the damping effect. And carried out experiments to verify the damping effect of the proposed impact damper with three vibrators. And investigated the effects of the coefficient of restitution, mass, and number of vibrators on the damping performance. The vibrations of a main structure following an impact can be quickly damped by using the collisions between multiple vibrators. The amplitude of the vibration is proportional to the magnitude of the impact. DE can be used to optimize the vibrator parameters for the maximum damping effect.

Chaouki (2013) et.al. examined normal contact force model that discusses the flaws. To accurately forecast particle/particle and particle/wall interactions, the model parameters are changed. To determine the normal impact of spherical particles formed of various materials on a flat metal plate, numerous experiments were conducted. The most popular contact force models are reviewed and their drawbacks are explored in this research. We learn about the microscopic (local) and macroscopic (global) quantities that can result from a particle collision from this work. A thorough account of the contact between the two colliding particles is necessary to calculate microscopic parameters like force, overlap, and particle velocity. Evaluation of macro-amounts like the COR is simple.

Abbaspour-Fard (2004) provided some idea that the contact model and method of force transformation for a multi-sphere particle have been applied accurately, along with the notion that the multi-sphere model was properly constructed. Additionally, a simulation example has been given to show how the MSM can simulate issues with agricultural processing. We learned about different simulation findings from this work, such as the position of a particle at any moment t. next, the particle-to-particle friction coefficient. We can immediately determine the coefficient of friction from the sphere's intensity. If we know the direction of the particles, the damping coefficient, and the actual weight of the particle, we may also find deformations and contact force.

Ai, Chen (2010) et.al. examined the most popular models for rolling friction and suggests a more inclusive approach. A four-category classification of these models is made based on their essential traits. These models' reliability in simulating rolling resistance effects resulting from various physical circumstances was evaluated utilizing several benchmarking studies. We learn about a few findings from this research, including the rolling resistance coefficient, the relative rolling motion, and the rolling radius of the particles. Additionally, we learn about rolling stiffness from a variety of theories and contact torque from a variety of models.

Kiwanuka's d (2010) et.al. studied the filling and discharge of pea grains from a 3D flat-bottomed bin using both experimental and DEM studies. In order to analyse their effects on the macroscale indicators, such as the wall pressure, discharge velocities, and material outflow parameters, such as contact torques, normal contact forces, rolling torques, etc., fixed mean values of the experimentally determined single particle data, such as the particle density, Young's modulus, Poisson's ratio, as well as the sliding and rolling friction coefficients, were incorporated. Based on the experimentally determined single particle rolling friction coefficient, the impact of rolling friction was investigated.

Kiwanuka's d (2011) et.al analysed the filling and discharge processes of granular material in a 3D flat-bottomed bin using the discrete element technique (DEM). Some mathematical concepts, such as contact forces between a particle and another particle or a wall, contact torques, and coefficient of friction, are explained in this essay. Additionally, we learn about the viscous damping coefficient and other things from experimental research.

Stevens & **Hiranya (2005**) suggested that in order to reduce the likelihood of permanent deformations after impact, pendulum experiments be carried out to simultaneously measure the restitution coefficient and collision duration of two spheres making a normal impact. This data would then be used to compare current force laws for similar impacts. This approach is straightforward because it only considers typical impacts between two particles. The application of these findings to the more complicated issue of oblique collisions and collisions involving more than two particles has not been fully explored, especially the ability of models to forecast collision duration.

Bajer (2014) et.al. performed an experimental examination of the characteristics of a multilayer beam that had been partially dampened by a material-based damping device. The key finding is that the suggested approach for regulating the mechanical properties of a vacuum granular structure is an intriguing substitute for conventional damping systems based on pricey smart materials and composites due to its conceptual simplicity, efficacy, and low cost.

Masri2(2011) et.al. analysed the performance of multi-unit particle dampers using an MDOF system using experimental and analytical/computational methods. We discover normal and tangential contact forces, crucial time step equations, and matrix forms of every component in the equation of movements from the analytical results.

Masri b (2011) et.al. analyzed a study that included experimental, analytical, and computational results to see how well an MDOF system performed with multi-unit particle dampers. We discover normal and tangential contact forces, crucial time step equations, and matrix forms of every component in the equation of movements from the analytical results.

Ron gong (2020) et.al. investigated the amplitude dependent behavior in particle dampers under low amplitude excitation, it was explored if the equivalent material model might be applied. The features of particle dampers are expressed as properties of an effective medium in this paper using a novel modeling technique. The equivalent bulk modulus, equivalent juvenile modulus of elasticity, equivalent Poisson's ratio, and other mathematical expressions are found in this text.

Ghosal b (2016) et.al. investigated modeling of a cantilever beam made of a hexagonal honeycomb structure with particle-filled honeycomb cells. Several mathematical expressions, including the impact force of a particle, the particle's equation of motion, the coulomb friction force, and the particle's relative velocity, can be found in this work.

Park & Palumbo (2018) discussed how granular treatments' capacity to dampen vibration is currently being investigation. The lightweight polyimide particles were used to fill cavities in sandwich beams constructed of aluminium. The complex stiffness of structures before and after damping treatment was measured for the investigation of vibration damping. In the damping treatments, particles of various sizes, weights, and polymer compositions were utilized. Depending on the types of particles, significant, frequency-dependent changes in the structural loss factor were seen. The Rayleigh-Ritz technique predicted this behaviour. Investigated was the method by which structural vibration energy is lost in light-weight granular material. The vibration damping seems to have been increased by the acoustic-structure interaction between the structure and the frame of the light particles, according to a comparison of measured and predicted values.

Horabik & Molenda (2016) Studied physical models suitable for DEM modelling of agricultural granular materials processes. Moreover, to compile and display the published data on the physical characteristics of biologically derived materials, such as grains, oilseeds, and fruits, that is necessary for DEM simulations. The technique of continuum mechanics does not allow for the description of events on the grain scale, but DEM based on the approximate solution of equations of motion for each grain in an assembly does. To ensure effective simulations and accurate output data, contact models and material properties are essential input data. Both research fields are still in the process of evolving, and the most often used nonlinear viscoelastic contact models are shear and rolling friction.

Masri (2013) et.al. Investigated a modified DEM-based approach that incorporates the governing equations of motion for a particle damper attached to an MDOF system, then introduced the DEM method's scheme, which includes a contact force model, a contact detection algorithm, and an implementation procedure, before validating the method in both specialized computational tests and experimental tests. A series of shaking table tests are devised and carried out to evaluate the improved DEM-based simulation method of particle damper systems, particularly for the case of particle dampers linked to an MDOF system under dynamic loads. The validation findings demonstrate that the method produces estimates of the shaking table test results that are not only reasonably accurate but also very well agree with the results of specific computational tests.

Hastie (2018) explored the COR utilizing high-speed video in a three-dimensional setting to record the erratic behavior of irregularly shaped polyethylene pellets. Coefficient of restitution is referred to as COR. We can find different results about COR, such as how, on average, the COR for impacts with conveyor belts was lower than for impacts with stainless steel.

O1son (2000) et.al. investigated the efficiency and predictability of particle damping. A lot of work has gone into describing and forecasting how a variety of potential particle materials, shapes, and sizes would behave in a laboratory setting and at high temperatures. Intriguing test findings serve as illustrations of the methodologies utilized to produce data and extract the properties of the nonlinear damping phenomenon. For a cantilevered beam system that incorporates particle damping, preliminary experimental damping measurements have been made. The testing's results highlight some of the difficulties in foretelling the highly nonlinear behavior of particle dampers, as factors like friction and excitation amplitude can have a big impact on the behavior.

2.2 OBJECTIVE AND SCOPE OF WORK

OBJECTIVE:

The main objective of this thesis is to investigate, simulate and evaluate the effectiveness of particle dampers as a seismic control strategy using the Equivalent particle method. The study will concentrate on using El Centro earthquake data to accomplish the following objectives:

Model Development: to develop rigorous and validated computational model for particle dampers by applying the Equivalent particle method. This model considered the particle size, density and how the particle do interact in a structural system.

Performance Evaluation: Investigated the effectiveness of particle dampers in reducing structural vibrations and seismic forces for selected El Centro earthquake data and Japan 311 earthquake time history. Simulations, as well as comparison studies has been performed.

Parametric Studies: To learn how specific factors, such as the particle's properties and the dampers' placement, affect the dampers' performance. To perform parametric research to improve damper design for various structural configurations.

Validation: Checking the results of simulation with empirical data, experimental data, or other well established analytical tools to verify the model generated.

Practical Application: Evaluating potential of actual implementation of particle dampers in real-life structural engineering projects to minimize seismic exposure.

SCOPE:

The following significant issues with particle damper modelling and earthquake mitigation are covered in this thesis:

By focusing on these goals and staying within this scope, our research will advance knowledge of particle dampers and their use in earthquake engineering, ultimately improving the resilience of buildings in earthquake-prone areas.

Computational Modelling: Creation of an elaborate mathematical model for particle dampers that includes equations for motion, energy loss, and interactions between particles and structures.

Computational Simulation: Using data from the El Centro and Japan 311 earthquakes, the created model is integrated in ANSYS for numerical simulations and particle damper performance analysis. We can use other earthquake time history data as well for the analysis.

Data Integration: The collection and integration of ground motion recordings and other El Centro & Japan earthquake data for use in comparisons and simulations.

Parametric Studies: Investigation of the effects of damper placement, density, and particle size variations on the dampening effectiveness of particle dampers.

Comparative Analysis: The effectiveness of particle dampers evaluation of compare their performance to that of other damping techniques or retrofitting processes.

Validation: To Confirm simulation results by contrasting them with empirical data or experimental findings from particle damper tests.

Practical Recommendations: Supplying useful suggestions and recommendations for the use of particle dampers in seismic retrofitting and structural construction.

Our research will improve our understanding of particle dampers and their use in earthquake engineering by focusing on these objectives and adhering to these constraints, which will ultimately increase the longevity of structures in seismically active regions.

CHAPTER 3

MATHEMATICAL FORMULATIONS

The theoretical framework for analysing the behaviour of the frame and the particle damper is provided by the mathematical formulation. Understanding how the two components interact and operate depends on the laws of motion guiding their dynamics.

3.1 STRUCTURAL DYNAMICS MODEL

EQUATION OF MOTION:

The governing equations for the entire system of the additional particle damper are expressed as in equation.

$$m_s\ddot{v}_s + c_s\dot{v}_s + k_s v_s = -m_s a_g + F \quad \ldots\ldots\ldots\ldots\ldots (1)$$

where m_s, k_s and c_s stand for the structure's mass, stiffness, and damping respectively. Additionally, 'v_s' stands for the structure's displacement with respect to the ground, 'F' represents force generated at the base of the PD and the ground acceleration time history, denoted by 'a_g.' And the following equation is represented as when it is normalized in relation to the structural mass.

$$\ddot{v}_s + 2\xi_s\omega_s\dot{v}_s + \omega_S^2 v_s = -a_g + \frac{F}{m_s} \quad \ldots\ldots\ldots\ldots\ldots (2)$$

Where '$\omega_s = 2\pi f_s$' and ξ_s are the structure's natural circular frequency and damping ratio, respectively and f_s denotes natural frequency.

EQUIVALENT PRINCIPLE:

Based on the following equivalent principles, the particle group in the PTMD is replaced by a single particle:

(1) The void volume of the PTMD (Vepd*)* equals that of the single-particle damper (Veid*)*.

(2) The total mass of the particles in the PTMD (m) equals that of the single particle(m1p).

(3) The particles in both the PTMD and single-particle damper are spheres, and their densities are kept constant as ρ.

(4) The container of the PTMD is a cuboid with a height that equals the diameter of the particles (Dp), whereas the container of the single-particle damper is a cylinder and its bottom diameter equals the diameter of a single particle (D).
The following equations are used to define the parameters of the equivalent principle:

The volume of the particles in the PTMD Vspd is given by Eq.

$$Vspd = 1/6N\pi D^3 \ldots\ldots\ldots\ldots\ldots (3)$$

where *N* is the number of particles, N = m/m1p, and m1p is the mass of a single particle in the PTMD.

The void volume of the PTMD is given by Eq.:

$$Vepd = Vpd - Vspd = (1/\rho_p - 1)\ Vspd \ldots. (4)$$

where Vpd is the volume of the PTMD and ρ_p= Vspd/Vpd is the packing density of the PTMD.

The void volume of the single-particle damper Veid is:

$$Veid = \pi/12D^3 + \pi/4D^2d \ldots\ldots\ldots\ldots (5)$$

where d is the clearance of the simplified single-particle damper

Based on the equivalent principle, the clearance of the simplified single-particle damper can be obtained from Eq.:

$$(1/\rho_p - 1)\ m/\rho = m^{3/2}\rho + \pi/4(6m3/\pi\rho)^{2/3}d \ldots\ldots\ldots (6)$$

The study of Hales shows that the volume ratio of balls with the same radium cannot exceed 0.74 when densely stuffed, i.e., ρp ≤ 0.74. According to the equivalent principle, m = m3. The expression of the length of particles freely moving in the equivalent single-particle damper is established.

CHAPTER 4

METHODOLOGY

Finding out if a particle damper can effectively reduce the structural vibrations of a computational three-story frame model is the primary goal of this study. The challenge stems from the need to improve the structure's resistance to dynamic forces that could jeopardize both the structure and the comfort of its occupants, such as wind and seismic vibration. Developing efficient vibration control techniques is becoming more and more crucial, especially as the number of tall structures increases.

Finite Element Method (FEM) modelling is another computational technique where the structures and systems of interests are divided into a series of interconnected elements. This network of elements enables the engineers to predict responses such as stress, strain, and deformation by feeding in values such as material properties, load, and support conditions. This versatility makes it possible for FEM to solve problems in shapes, behaviour and load distribution of materials involved in structures in dramatically varying manners; hence, FEM becomes an indispensable tool in civil, mechanical, and Aerospace engineering. Hence, FEM modelling simplifies complex problems by availing systematic details of the system which makes the real-world practice of designs more accurate and safer.

The Discrete Element Method (DEM) is a mathematical tool for forecasting the interaction of systems containing discrete separate particles or elements. The DEM model considers the particles as contact points with interaction forces and displacements to model types of gravel flows, cracks, and particles. DEM is also particularly useful when studying flow of particles, their impact, collision or compaction the motion of each element is tracked thus making it ideal for; Material Science, mining and civil engineering where the behaviour of the particle is essential.

4.1 ANSYS FRAME MODEL CREATION

Here in this study the computational square shape building model is drawn in Ansys Space Claim. The total height of the frame is 3000 mm having beams of line length 1000 mm and cross-sectional area is 100 mm^2. The perimeter of slabs is 4000 mm with 1000000 mm^2 surface area. Thickness of the slab is 45 mm. The floor-to-floor height is taken as 1000 mm.

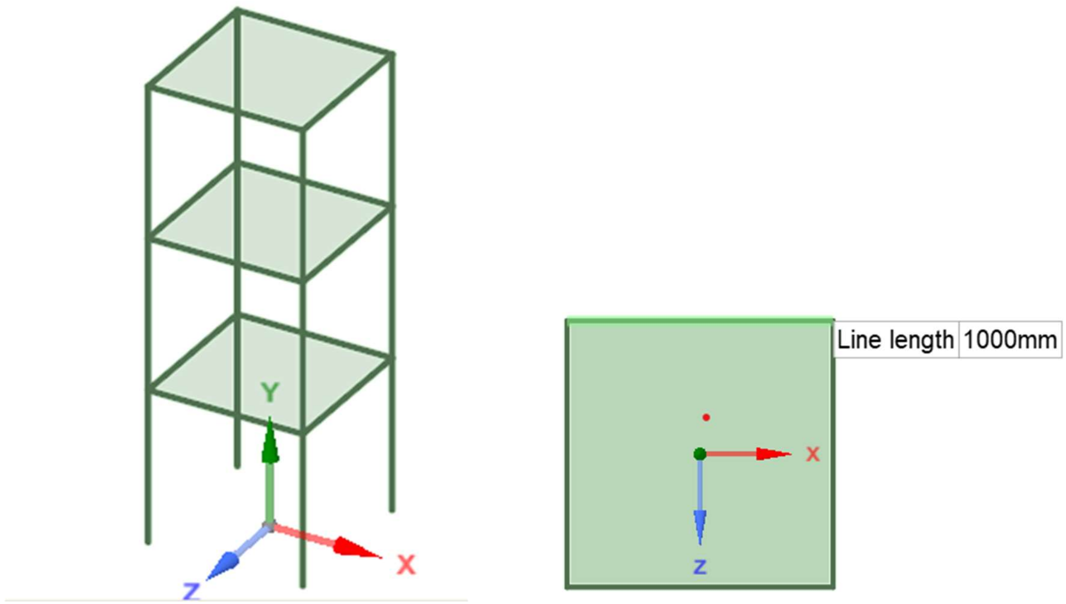


Figure 4.1 –a) 3-D Ansys model of the frame, b) Structural plan

Here steel is taken as default solid material as available in Engineering Data option. Material data considered for the steel are; density 7850 kg/m^3, Young's modulus 2×10^{11} Pa, Poisson's ratio 0.3. Material damping is taken as 5 % as per Indian Standard.

Meshing and Load application is done in Transient structural. Element size of 0.125 m is taken and the mesh is created. In case of load application, standard earth gravity (g = 9.81 m/s^2), El Centro earthquake data of 30 seconds with 0.02 seconds time step and Japan 311 earthquake data of 30 seconds with 0.02 seconds time step also are applied in x direction. Fixed support is assigned to the bottom face of four columns.

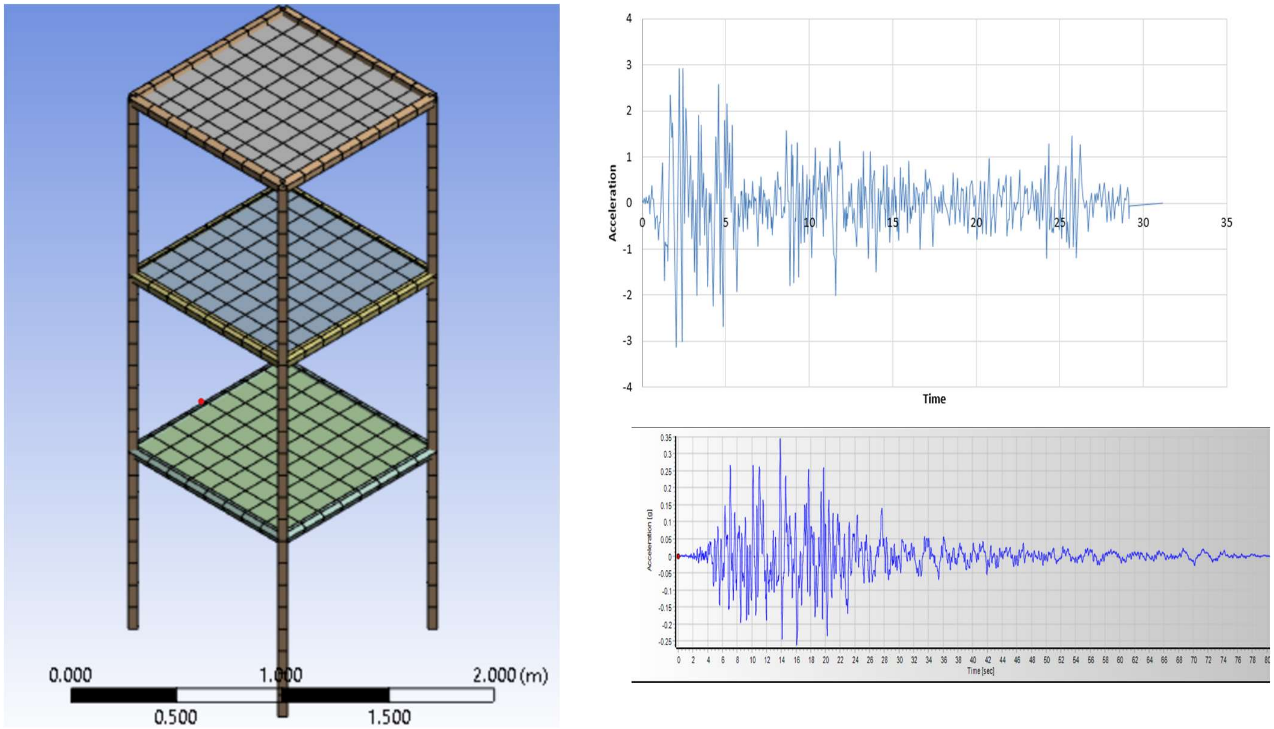


Figure 4.2.- a) Meshing of the frame,

b) El Centro earthquake acceleration in m/s^2 time history graph (N-S component)

c) Japan 311 earthquake time acceleration in m/s^2 history graph (N-S component)

4.2 PARTICLE DAMPER MODELLING

The rectangular container carrying a particle; i.e., equivalent particle working as particle damper has same material properties as the frame model. A rectangular container is fixed on the top of the structure. Here we used a simplified model to analysis, here we took an equivalent ball which mass is equivalent to the mass of n number of small balls.

The frame size we already mentioned above. The size of the container is (600×530) mm^2 which is on the top of the frame. The height of the container is 625 mm. In the box there is an equivalent ball in the centre of the box. The diameter of the ball is 440 mm. Friction coefficient is taken as 0.42.

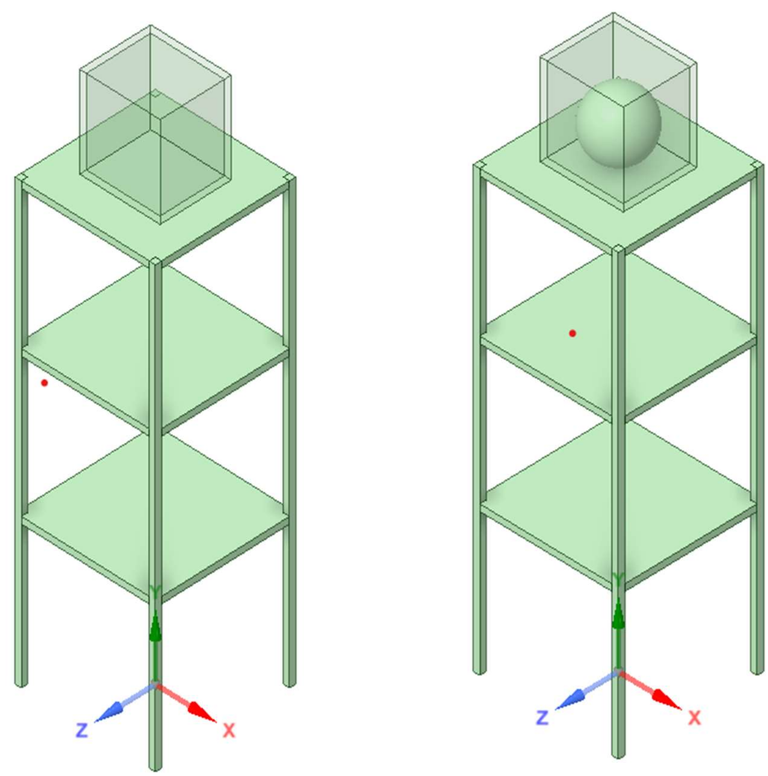


Figure 4.3.- a) Container without ball, b) Container with ball

CHAPTER 5

RESULTS AND DISCUSSIONS

This section discusses the findings of the application of particle damper to the field of structural vibration control. The dynamic behaviour of the equivalent particle damper configurations and their significant influence on the decrease of acceleration and top-floor deformation are shown through rigorous analysis and modelling. Here, the structure's response is studied both with and without taking the effect of particle damper into account.

5.1 VALIDATION OF PROPOSED METHOD

To validate the equivalent particle damper model, a comparison was made with the experimental results presented by **Zheng, Masri,** and **Lu** in their book **"Particle Damping Technology: Based on Structural Control."** A structural frame identical to the experimental setup was modelled in ANSYS. The natural frequency and top floor peak acceleration obtained from the numerical simulations were found to be in good agreement with the experimental results, thereby validating the accuracy of the proposed equivalent particle damper model.

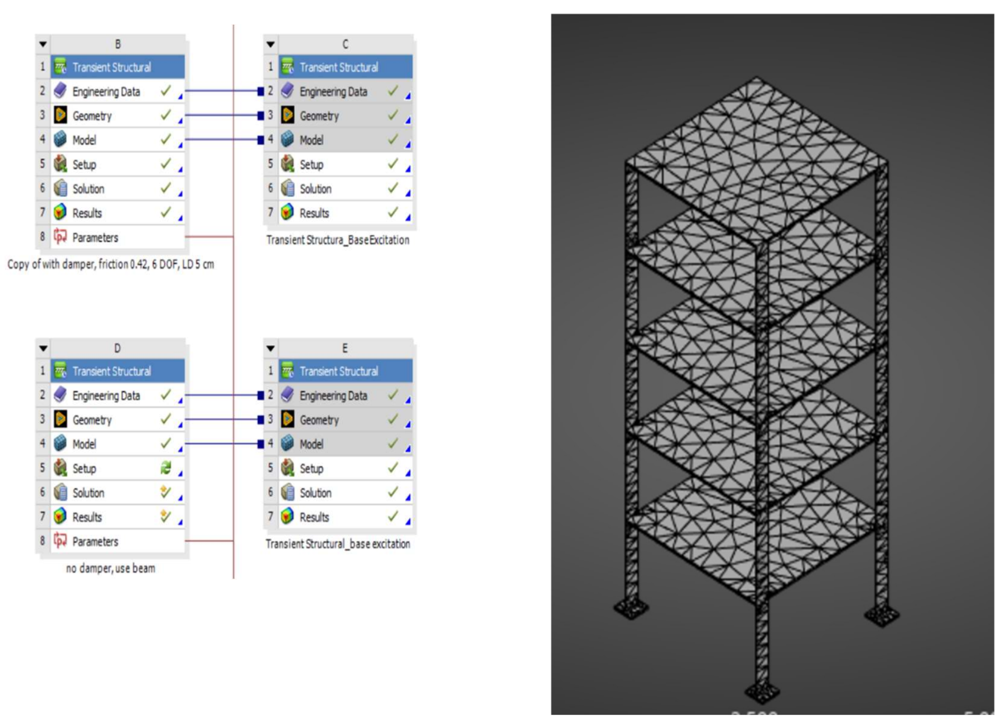


Figure 5.1.- a) Flow chart of transient structural procedure in Ansys, b) Frame Structure

5.1.1 MODE SHAPES

To validate the accuracy of the ANSYS model, a comparison between the mode shapes and modal frequencies from both the experimental model and the analytical simulation is conducted. These parameters are fundamental in characterizing a structure's dynamic response, and close alignment between experimental and analytical results indicates a reliable model. The following sections present these results side by side to highlight any differences and assess the model's capability in accurately representing the structural behaviour.

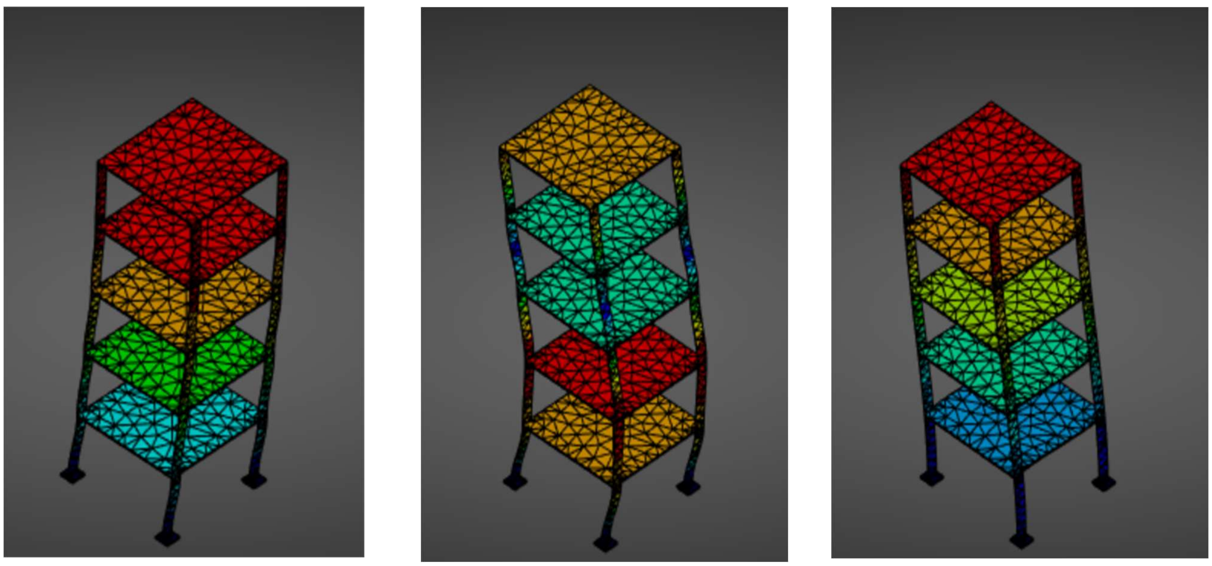


Figure 5.2.- Mode shapes of three different modes

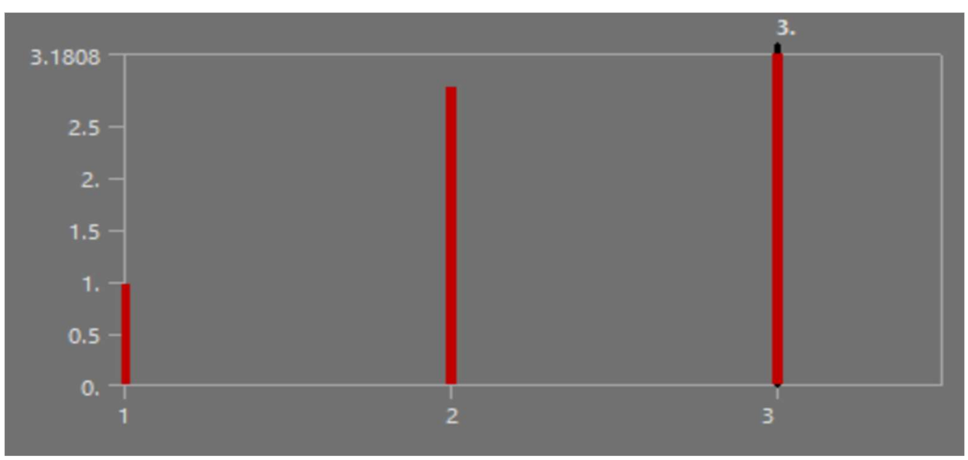


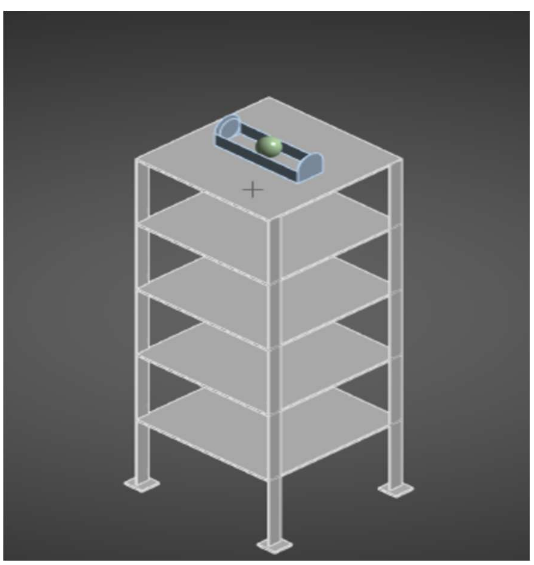
Figure 5.3.- Natural Frequency plot of three modes

SL NO.	NATURAL FREQUENCY	EXPERIMENTAL MODEL(Hz)	ANALYTICAL MODEL(Hz)
1.	Frist Mode	1	0.96015
2.	Second Mode	3	2.8551
3.	Third Mode	5	3.1808

Table 1.- Comparison of natural frequencies of experimental model with analytical model

5.1.2 TOP FLOOR ACCELERATION

To evaluate the accuracy and reliability of the developed ANSYS model, a comparative analysis is conducted between the top floor acceleration data obtained from an experimental model and the corresponding analytical results from the ANSYS simulation. This comparison serves as a critical validation step, ensuring that the analytical model accurately replicates the dynamic behaviour observed in physical testing. By aligning the peak accelerations and response patterns from both the experimental and simulated models, this study seeks to verify the effectiveness of the ANSYS model in predicting structural responses under dynamic conditions. Here I have analysed in 0.1g for both the earthquake data which incorporated in ANSYS as the input accordingly.



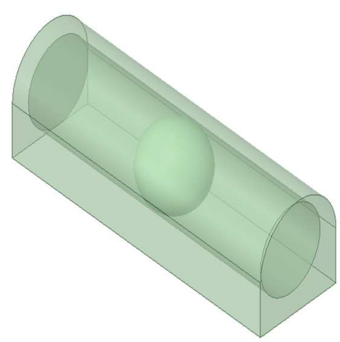
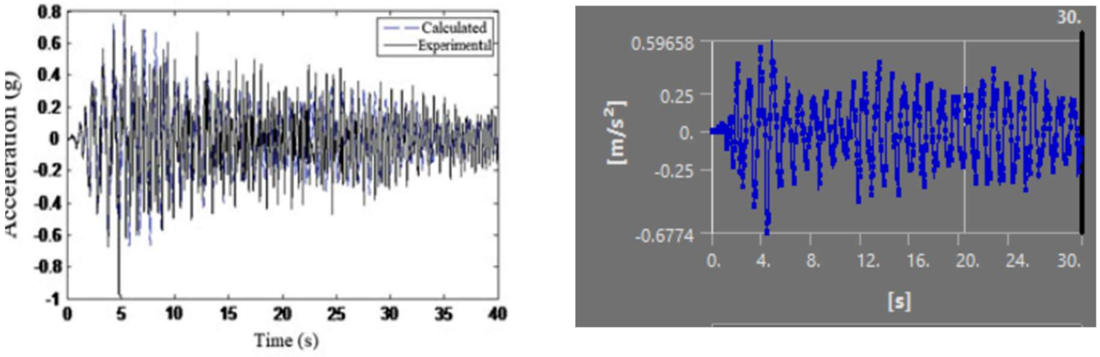


Figure 5.4.- Structural frame with the container & equivalent ball



Note: I have analysed 0 to 30 second earthquake data (El Centro 0.1g)

Figure 5.5.- Comparison of the top floor acceleration plot of experimental model & calculated model with the analytical model (EL-Centro wave-0.1g)

INPUT	Calculation(literature)	Experimental(literature)	Analytical
El Centro	0.4899	0.4796	0.5965

Table 2a- Comparison of top floor acceleration of calculation & experimental model with analytical model

The validation results demonstrate a close alignment between the experimental and simulated top floor acceleration values using EL-Centro wave (0.1 g), confirming the ANSYS model's accuracy in replicating the structural response. The experimental data recorded peak accelerations ranging from -1 m/s^2 to 0.8 m/s^2, while the ANSYS model yielded accelerations between -0.6774 m/s^2 and 0.6 m/s^2. Although the simulated values are slightly lower, they fall within a comparable range, suggesting that the equivalent modelling approach effectively captures the primary dynamic characteristics observed in the physical experiment. This consistency supports the reliability of the ANSYS model as a predictive tool for analysing vibration and structural performance under similar conditions.

Comparison of the calculated and experimental results for the peak acceleration (m/s^2) with the analytical result for the peak acceleration (m/s^2) on top of the test structure with the PTMD using Japan 311 earthquake data(0.1g) :

INPUT	Calculation(literature)	Experimental(literature)	Analytical
JAPAN 311	0.2548	0.2682	0.3174

Table 2b- Comparison of top floor acceleration of calculation & experimental model with analytical model (JAPAN 311 -0.1g)

The validation results after using the Japan 311 earthquake simulation data (0.1g) shows good agreements among analytical, calculated, and experimental models, thereby confirming the reliability of ANSYS simulation. Values of 0.3147 m/s² from the analytical model, 0.2548 m/s² from calculated data, and 0.2682 m/s² from experimental data are all closely aligned at the peak accelerations of the top floor. This agreement demonstrates that the ANSYS model could effectively mimic real-life structural responses under dynamic loading. Hence, this explains the model's reliability in predicting future findings and enhances the credibility of the equivalent method in investigating particle dampers.

5.1.3 TOP FLOOR PEAK DEFORMATION

Comparison of the calculated and experimental results for the peak displacement (mm) with the analytical result for the peak displacement (mm) on top of the test structure with the PTMD

INPUT	Calculation(literature)	Experimental(literature)	Analytical
JAPAN 311	12.7873	13.5102	10.736
EL- Centro	80.9500	79.0030	76.092

Table 3.- Comparison of top floor deformation of calculation & experimental model with analytical model

The validation results after using the Japan 311 earthquake simulation data and El-Centro simulation data show good agreements among analytical, calculated, and experimental models, thereby confirming the reliability of ANSYS simulation. This agreement demonstrates that the ANSYS model could effectively mimic real-life structural responses under dynamic loading. Hence, this explains the model's reliability in predicting future findings and enhances the credibility of the equivalent method in investigating particle dampers.

5.2. EQUIVALENT PARTICLE DAMPER

The study covers particle damper dynamics intricately, utilizing ANSYS as the modelling platform in exploring their capacity as a new alternative solution toward minimizing the adverse effects posed by vibrations and increasing structural resilience. The goal of the work was to evaluate the ability of particle dampers to reduce structural deformations under dynamic loading situations employed using the equivalent principle. The observed trend from the preliminary study was quite interesting: it has been found that upon activation of these dampers, levels of deformation in the structure dramatically decrease, especially at the topmost floors. In effect, it significantly brought down the deformation value at peak acceleration to 0.617 mm after applying EL-Centro earthquake data from 1.18 mm and 0.26 mm after Japan 311 earthquake data from 0.505 mm, considering installation of the particle damper. This result underscores the very heavy influence that particle dampers can exert on structural integrity and safety—the details of these findings shall be advanced later on in the following sections to have a thorough knowledge of the mechanisms through which particle dampers, in the context of the equivalent approach, achieve this remarkable decrease of deformation. This becomes yet another pointer towards the fact that particle dampers do play a very significant role as a necessary approach towards bettering structural integrity and resilience against external forces.

Relying on what is revealed through these findings, particle dampers can already be described as integral parts in advanced structural design mainly in high-seismic zones or other areas subjected to frequent dynamic loading. Also, the flexibility and durability of particle dampers make them workable solutions in long-term applications where conventional means of damping may completely fail or necessitate tough maintenance. The phenomena behind this advantage, to be described later, lie in the collisions of particles, interactions with the boundaries, and the optimum parameter choices for energy absorption. Hence, in justifying its use, this study underlines the position of the introduction of particle dampers as desirable and highly efficient ways of enhancing the safety and durability of structures; thereby opening a window for future research and development on it. Here are the following results which show the effect of particle damper into the structure:

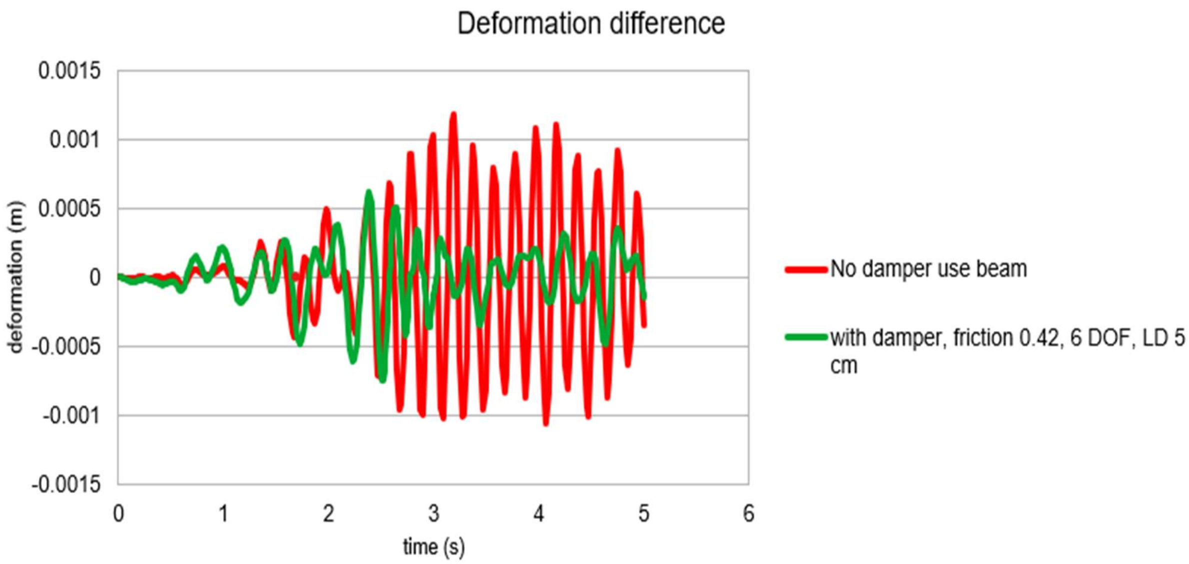


Figure 5.6- Comparison plot of top floor deformation with and without damper (EL-Centro wave)

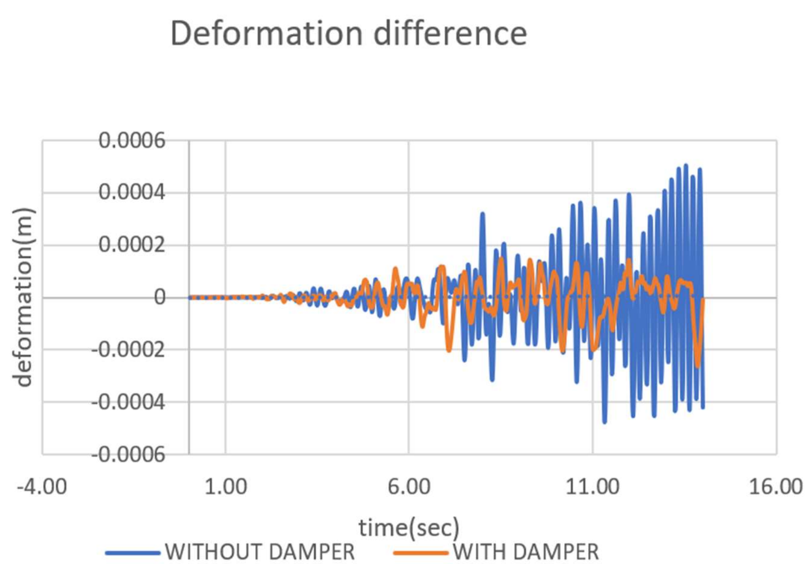


Figure 5.7- Comparison plot of top floor deformation with and without damper (Japan 311 wave)

The RMS displacement response after installation of the damper is reduced by **42.69** percent for El Centro earthquake data and reduced by **44.71** percent for Japan 311 earth quake data.

CHAPTER 6

CONCLUSIONS AND SUGGESTION FOR FUTURE SCOPE OF WORK

6.1 CONCLUSIONS

The study described here undertook the thorough modelling of particle dampers using ANSYS with the goal of reducing structural vibrations and improving the performance of engineering systems. By using an equivalent methodology, this study attempted to make a significant contribution to our knowledge of and experience with particle dampers, providing light on how well they work as passive vibration control mechanisms.

During this study, a modelling methodology was carefully developed to model particle damper behaviour in the ANSYS environment. The requirements of the study questions and objectives led the choice of modelling technique, whether it was the single particle approach, Discrete Element Method (DEM), or Smoothed Particle Hydrodynamics (SPH). It is important to emphasize that the method we have selected works well for capturing the fundamental dynamics of particle dampers at a computationally feasible level.

This work used a methodology that included geometric representation, material attributes, boundary conditions, and loading scenarios in the construction of particle damper models. These models were used to investigate the complex interactions between particles and structures under vibrational stresses through a range of dynamic investigations, including transient simulations. Because of ANSYS's flexibility and adaptability as a simulation platform, a range of characteristics and scenarios have been examined, providing insight into the aspects that affect particle damper performance.

Gaining knowledge about how particle dampers behave under seismic loads was one of the main results of this study. The simulation findings showed that particle dampers could display surprising behaviours in some cases. This emphasizes how important it is to define boundary conditions and limitations precisely. This study helps improve modelling methods in ANSYS for improved accuracy and dependability in seismic simulations by tackling these issues.

The results are further supported by the models' validation and verification, when appropriate, through comparison with experimental data. It is crucial to recognize that even though the equivalent approach produces priceless insights, it does so through assumptions and simplifications. Therefore, more sophisticated modelling approaches that take into consideration more complex particle dynamics, such as fluid-structure interactions and particle-particle interactions, may be explored in future research projects.

To sum up, the analysis of particle dampers using two separate seismic data sets Japan 311 and El Centro shows how well particle dampers work to decrease structure deformation under dynamic stress. The particle damper effectively reduced peak deformations during both seismic occurrences, demonstrating its ability to effectively disperse vibrational energy and improve structural stability. These notable decreases in deformation demonstrate particle dampers' promise as a dependable and creative way to lessen structural stress brought on by earthquakes. By demonstrating particle dampers' versatility and durability in actual seismic applications, this study reaffirms the importance of particle dampers in structural design and lays the groundwork for further research into their application in other structural contexts.

6.2 FUTURE SCOPE OF THE WORK

Without a doubt, the following are some prospective directions for further study or the future range of your thesis work on particle damper modelling in ANSYS with a comparable methodology**:**

- **Advanced Particle Dynamic Modelling:** Examine and create more sophisticated modelling approaches to model complex particle-particle interactions, such as dynamic packing effects and granular flows.
- **Fluid – Structure Interaction (FSI) Modelling:** Examine how to include fluid-structure interaction in simulations of particle dampers to examine the effects of coupled dynamics in the presence of viscous fluids in the damper.
- **Parametric Studies:** To learn how changes in particle characteristics, geometry, and operating circumstances affect particle dampers' damping effectiveness, conduct in-depth parametric studies.
- **Multi-Physics Simulation**: To address a wider range of damper applications, extend the modelling approach to consider numerous physical phenomena, such as heat transmission, material deterioration, and structural deformation.
- **Machine Learning Integration:** Examine how combining machine learning methods can improve particle damper designs and forecast how they would behave in various scenarios.

- **Applications in Industry**: Use the developed modelling techniques to address real-world engineering issues in a variety of industries, including automotive, aerospace, and civil engineering.

- **Seismic Performance Assessment**: Increase the research's attention to seismic performance assessment, considering how particle dampers behave in areas that are vulnerable to earthquakes.

- **Collaborative Research:** Investigate transdisciplinary uses of particle dampers in industries like architecture, renewable energy, and transportation by working with academics from many sectors.

- **Software Development:** To make particle damper modelling and analysis more efficient, we need more specific software tools or plugins.

These future scope points indicate possible avenues for additional study and advancement, using the work from your thesis as a starting point to advance our knowledge of and use for particle dampers in structural vibration control.

CHAPTER 7

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