Design and Modelling of An Active System for Control of Floor Vibrations

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Abstract

Typically, architectural elements, mass, and/or stiffness are considered potential solutions for floor vibration. Alternatives to these fixes include but are not limited to, adding frame members, erecting full-height partitions, and thickening the floor slab. These solutions are expensive to install in a new building, challenging to implement and uncomfortable for the residents of older structures. A solution like erecting full-height dividers also goes against the idea of open-plan offices that are common in tenant fit-outs. To address the treatment of vibrating floors, tuned mass dampers (TMDs) are frequently attached to the floor to provide reactive damping. TMDs are the most practical, affordable, and least disruptive floor vibration control option for both new and existing floor systems because of their little weight penalty, cheap cost, and ease of installation. It is important to include damping into a floor's design if you want it to be light, open, and free of vibrations while also adhering to the current serviceability standards. There are several kinds of floor vibrations that result in the structural deterioration over time. Some are human induced, either through the usage of machines the improvement in structural design that allows for more slender build, or simply walking at differing resonating frequencies; others are natural, such as earthquakes or strong winds which create the need for active control of vibrations. This paper investigates the implementation of different vibrational control methods into the flooring or walls of the building in order to gain stability in times the building is under stress. TMDs are merged with control systems to form AVCs. Several different methods are discussed such as using the Hybrid tuned mass dampers, partial floor loads as multiple tuned mass dampers, VIVDs, PID controllers, lightweight floor systems, etc. Hybrid TMDs have modeling algorithms that are futher studied. To achieve high optimization of any civil structure in order to have control over vibrations, the hybrid modelling technique uses both statistical analysis of energy (SEA) and finite element method (FEM) to foretell operation of the controller. There is a quick response to any predictions simulated, in structures that are targets of medium to high frequencies.

Most passive damping systems have drawbacks such as pre requirements of high mass of inertia and low efficiencies in transient waves, especially when there is a change in structure or mass. Active controlled tuned mass damper minimizes these drawbacks and increase efficiency of the damping system, even expanding to a larger range of frequencies located at the transient phase. Some major criteria for developing and designing AVCs that require a careful consideration are the sturdiness and operational specifications, the minimum instability of closed loops, and the highest stroke and overloading of actuators.

Keywords: floor vibrations; control systems; vibration control; damping; TMDs

1. INTRODUCTION

Building floor vibrations brought on by human activity as well as natural factors, such as earthquakes and winds, pose serious problems for structural engineers working in the current era. By increasing the bulk and rigidity of structural components through techniques like including frame members, building full-height walls, or increasing the thickness of the floor slabs has historically been the focus of strategies to lessen these vibrations. Even while these strategies work, they are frequently costly, challenging to execute, and disruptive, especially in open-plan office spaces that prioritize flexible layouts and preexisting structures.

One option that is becoming increasingly popular is Tuned Mass Dampers (TMDs). TMDs serve as a more affordable and useful method to absorb floor vibrations. Their working function includes a secondary load is attached directly to the building, adjusted to counteract vibrations produced at certain frequencies. In addition to lessening vibration amplitude, this technique preserves the architectural integrity of contemporary building designs. It maintains the architectural integrity of the building in addition to reducing the vibrational amplitude, further reiterating its benefits.

Although passive TMDs have many advantages, their effectiveness may be restricted by factors such as the large mass required to overcome inertial forces and its inefficiency in handling transient vibrations. This paper works to provide solutions for these drawbacks through the use of Active Vibration Control (AVC). In AVC systems, the use active control components, such actuators and sensors, in addition to the general working of TMDs, mitigate both periodic and non-periodic excitation. This hybrid technique improves the performance of TMDs through increased damping across a broader frequency range and an improvement in overall stability and comfort.

In order to precisely reduce floor vibrations using AVC, we look at the design and modeling of an active control system. The study focuses on modeling the control system using both frequency domain and temporal domain studies to minimize disturbances brought about by human presence. Many approaches are investigated, such as the use of PID controllers to provide accurate damping in real time, the addition of partial floor loads to increase the mass and therefore damping effect, and hybrid tuned mass dampers to highlight a multidisciplinary solution. The software which is used in the modelling includes MATLAB and SIMULINK. The simulations are beneficial in evaluating the system's stability as well as reactivity to various inputs, which provides insight into the proposed AVC system's capabilities.

2. LITERATURE REVIEW

Passive control techniques have been widely employed because of their simplicity and dependability, and active control is a logical progression from these techniques. Structural control may be divided into two categories: passive control, which does not require external energy, and active control, which employs active actuators and sensors

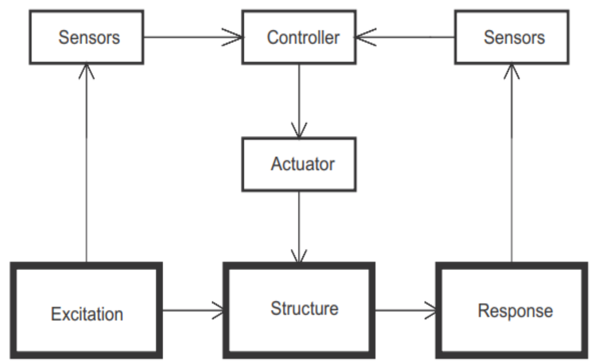


Fig. 1. Active Control. [1]

to regulate unwanted vibrations. There are several controls that are purpose-built for structural control applications. The most widely used mass-based drive—without a spring and a dash—may be the Active Mass Damper (AMD) [25]. First proposed in the 1950s, AVCs further development was hampered by an absence of the required equipment. In passive vibrational methods, PVCs, the vibrational sensitivity of each floor is enhanced by exerting a certain force as a reaction to any external movement. In AVCs the same phenomenon is achieved, except the reactionary force is produced with the aid of an outside source of energy. These AVCs are viewed as systems that provide force using real-time processing controllers and sensors placed at pre-set points inside the controlled structure. The sensors pick up on the movement and/or outside excitation of the building. As shown in Fig. 1 and Equation (1), the sensor's signals are placed into a specific algorithm in the controllers which analyse and produce a command in the output which is used to move the device providing force.

$$M\ddot{x}(t) + C\dot{x}(t) + Kx(t) = F(t) + U(t) \quad (1)$$

where M = mass, F = force, C = damping coefficient, K = spring coefficient.

U(t) is the force provided and controlled by AVC where:

$$U(t) = f(x(t), \dot{x}(t), F(t)) \quad (2)$$

This control law includes a velocity feedback scheme, presented in the equation:

$$U(t) = f\big(\dot{x}(t)\big) = -K_G\dot{x}(t) \quad (3)$$

KG represents constant gain. An improvement occurs by the AVC's real-time response: an increase in the effectiveness of response in control and the adaptability to the numerous risks in vibration reduction systems. Yet, since more energy is being added to the fundamentally stable system, it is conceivable that the system might become unstable [1].

This paper also suggests a hybrid system that consists of separate slabs resting on a curved base. Gravity is used to hold the slab in place while the curvature stiffens the connection between the slab and the frame. The application of bumpers between the slab and the frame serves to prevent damage to either part during excitation. The suggested system is distinctive in that it uses TMDs in conjunction with the idea of base isolation to achieve the desired performance. This design demonstrates how vibrations in structures subject to seismic loading can be reduced by isolating the slab's mass and employing it as a translational tuned mass damper. In contrast to conventional composite slab constructions, it demonstrates the ability to reduce displacement and inter-story drift by up to 45%. Besides the lowest stories, the suggested methodology also improves the acceleration of the slabs. This improvement is the result of the mass's high proportion acting as a damper. The design can be improved and made more flexible thanks to the higher mass ratio. The strain on the structure's frame is still considerably less without major energy loss. To show how the mechanism would respond to a specific seismic excitation, the range of efficacy should be assessed against a variety of earthquake inputs while keeping design concerns in mind. The design of the system can be simply modified to take wind loading into consideration. Future research into the multi-hazard nature of this system has the potential to be beneficial [2].

Tuned mass dampers (TMDs) are regarded to be the most popular control method for reducing vibrations in tall structures. They have a broad range of practical uses in high-rise buildings all over the world because of their convenience and effectiveness. This particular thesis outlines the theoretical underpinnings of a novel concept that involves using Multiple Tuned Mass Dampers (MTMDs) to handle a portion of the load from various floors. If the weight of the floor slab, floor finishes, and architectural walls is isolated using bearing mechanisms akin to those used for base isolation, some of the weight of these components can be employed, particularly in the case of steel deck floors [3].

This review's objective is to discuss every structural control-related topic. In contrast to earlier reviews, this literature thoroughly describes the mathematical modelling of actuators and the structure-actuator coupled system utilizing both linear and nonlinear techniques. The strategies for optimal device placement, system identification, and state estimate are also discussed in this study. It is also thought about how time delays in active control systems affect system stability. The study outlines several control tactics, including modern intelligent control methods Like Fuzzy Logic, Neural Networks (NN), and Genetic Algorithms (GA). The performance of structural control systems applied to actual buildings has also been examined. [4]

Knowing the behavior and effects of excitations on buildings, such as powerful wind and seismic forces, is crucial for developing a dynamic model of a building's structure. Fig. 2 depicts the force that the earthquake and wind excitation had on the building. Seismic waves are produced when there is a rapid discharge of energy in the Earth's crust. Because of the ground motion brought on by these seismic waves, the building structure oscillates, causing the floor masses to feel inertial force. The force is defined by the equation:

$$f = -m\ddot{x}_g \qquad (4)$$

where m is the mass and ẍ is the earthquake-induced ground acceleration.

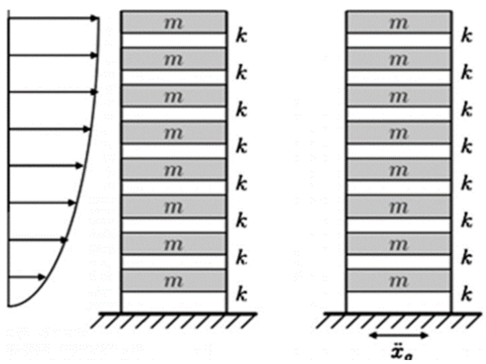


Fig. 2. a) wind excitation b) earthquake excitation [4]

The ground motion's amplitude and other characteristics, the structure's dynamic attributes, the materials the structure is made of, and its foundation are only a few of the variables that affect how the structure moves (soil–structure interaction).

Depending on the number of degrees of freedom (DOF) it has, a civil structure will have a number of natural frequencies. Resonance develops when the ground's vibration frequency is similar to the building's natural frequency. Due to resonance, the floors may thus move erratically in various directions, resulting in inter-story drift, or the relative translational displacement between two succeeding floors.

The building suffers serious damage if the drift value or deformation surpasses its critical threshold. High-frequency waves are more pronounced in small buildings, while low-frequency waves are more pronounced in massive structures or high-rise buildings. It's crucial to prevent the building from vibrating at its low order natural frequencies, where a large portion of the building's elastic energy is stored [4].

The use of an electric circuit to analyze a variable inertance and variable damping (VIVD) system as a vibration control investigates the single-degree of freedom (DOF) in accordance to the variable inerter theory. A VD device is placed in series with an inerter to create a VI device. This VI devise is used to change the corresponding inertance by regulating the damping characteristic in the VD device. The results are obtained by analyzing the frequency domain of a system with single degree of freedom that also has VI and VD abilities. The VIVD semi-active system is proven to have much better control over vibrations than the regular VD system. To overcome complications with respect to the mechanical networks, the mechanical energy is converted into electrical energy using a damper powered by electromagnetism using mechanical-electrical analogies. This permits the design of an electric circuit which replicates a VIVD device. Due to satisfactory findings from evaluations in frequency and time domains, the VIVD vibration control system would considerably develop the execution of a semi-active system [5].

When there are many potential places for actuators, the system used methods which were foundational in natural gradients. These methods can be very costly. The number of sites of test, sensors and actuators taken into consideration in this scenario is constrained by the calculation time required to get a local solution, which may be enormous and unaffordable. This study suggests an alternate strategy based on the Coral Reefs Optimization (CRO) algorithm, a newly developed meta-heuristic. In more context, the Coral Reefs Optimization with Substrate Layer is taken into consideration as an improved form of the CRO (CRO-SL). With the competitive revolutionary algorithm CRO-SL, various exploration techniques are collaboratively developed inside a single pool of possible solutions to the problem. In order to address challenging optimization issues, the suggested algorithm can encourage competition among various search techniques. With regard to structural design, this research represents a significant stride towards enhancing the operation of active vibration control systems to complicated, real structures - those that have several points of testing or/and variety of vibration modes - by solving designs which fit optimization at the global level with acceptable time to compute them[6].

This study examines the integration of semi-active variable damping TMD (SAVDTMD) with piezoelectric friction dampers as an alternative to the techniques now in use to reduce floor vibrations, particularly vibrations brought on by walking. The utilization of an MDOF floor model during the investigation sheds some light on the impact of modes that the design of the controller did not specifically target. The analytical models included an ideal semi-active control law that was initially created for car suspension control. Two floor system examples that are typical of those with a floor vibration issue are assessed, and it is demonstrated that the SAVDTMD can successfully regulate both the targeted and untargeted modes. Problems with the control force spilling over to unintended modes were investigated and found to be stable. [7]

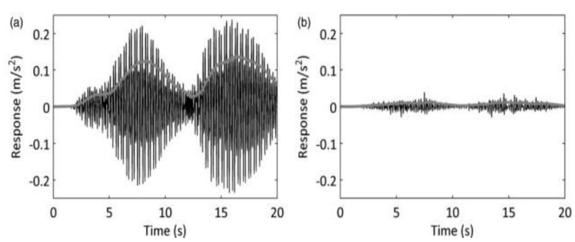
Long-span, light-weight floors are typically susceptible to structural vibrations due to their low resonance frequency and natural damping. Since they can be quickly triggered by persons walking or jogging, they present a serviceability problem for those who live or work in these buildings. Tuned mass dampers can be used to improve the dynamic behavior of such structures. These passive damping systems' poor transient damping performance and high inertial damper mass requirements are a drawback.

The damping efficiency dramatically decreases, particularly for systems with resonance frequencies that change over time (as a result of an increase in mass, a modification to the structure, or temperature-dependent events).

For a wide range of frequencies in transient phase, an active controlled tuned mass damper can be employed to decrease inertial mass and increase damping efficiency. When building a controller for an active vibration control device, a number of limitations, such as the stability in closed loop, robustness and performance standards, as well as the maximum stroke and saturation of the actuator, must be taken into account. This study examines various control strategies, simulating them with a second and fourth order system to weigh their benefits and cons [8].

This study also demonstrates how to employ an observer-based pole-placement controller and a proportional-integral (PI) controller to lower vibration in a walkway bridge structure with a single actuator and sensor pair. Results of the experimental modal analysis are used to find reduced-order models of the walkway. They are used in both the construction of a PI controller and the state estimation methods needed to build reduced-order observer controllers. The variety of ordering of the latter depends on the number of plant modes selected for their designs. To obtain gains in plant and observer feedback, they are made by articulating desired floor closed-loop eigenvalues and observer eigenvalues.

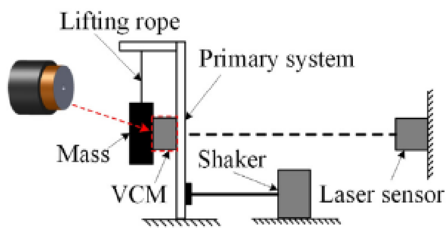
In contrast to the PI controller, which automatically chooses one solution, observer-based controller design processes allow for a wide range of possibilities. As shown in the analytical and practical investigations given, (Fig. 3) the flexibility of observer-based controllers for greater controller orders above a purely single-input single-output controller system also allows for the separation and control of target vibration modes. Additionally, the observer-based controller design method in this work has only used one plant mode. The optimal solution is then determined using a multi-objective evolutionary algorithm optimization strategy while abiding by a predetermined set of constraint restrictions. The best vibration mitigation performance among the available solutions in this situation is the ideal option [9].



(a) (b)

Fig. 3. Typical (a) uncontrolled and (b) controlled walking time histories. [9]

In another study, transient vibrations are adjusted. They are introduced by the stimulation of impulse. The study into active dynamic vibration absorbers (ADVAs) provides a non-linear convergence technique.



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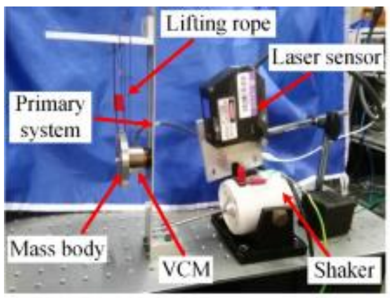
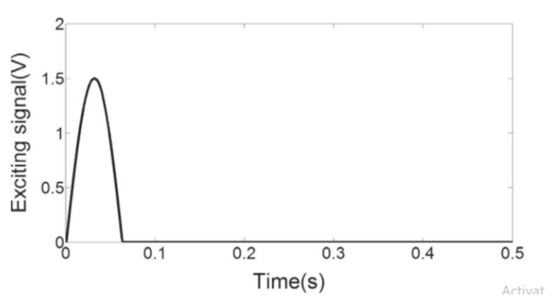


(b)

Fig. 4. The experimental setup (a) Schematic diagram of the experimental set-up (b) Photograph of the experimental set-up [10]

The main system's exciting signal as well as experimental transient response are shown in Figure 5. Starting at more than 200 µm, the vibrational amplitude steadily diminishes. The main system's natural frequency eventually also determines the frequency of the transient response.



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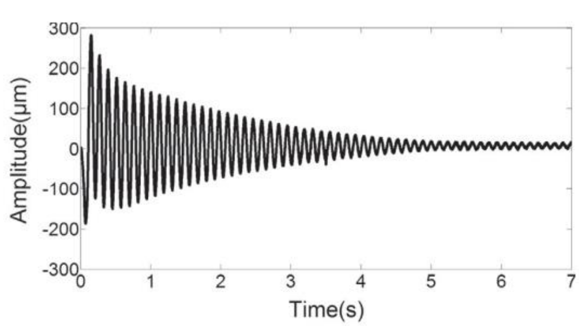

(b)

Fig. 5. (a) Exciting signal of the shaker (b) Transient response of the primary system [10]

A voice coil motor (VCM) is added and its function is to continuously dampen the transient reaction of the prime system, also serving as a magnetic muffler (Fig. 4a). The results of the studies show that the nonlinear ADVA can reduce the convergence time by 70% compared to the linear ADVA (Fig. 4b) 95% of the uncontrolled transient vibration at 1.5 s is eliminated thanks to the cooperation between the nonlinear ADVA and VCM magnetic damper [10].

In the case of Active Mass Dampers (AMDs) accelerometers are used as sensors to measure vibrations, and additional components include AC servomotors and an unfixed mass that is attached to the motor through a ball-screw mechanism. The Negative Acceleration Feedback (NAF) control method is utilised, which takes the acceleration signal directly and provides the appropriate displacement for the active material. This occurs while taking into account the capabilities of the AC servo motor that is able to follow the ideal displacement effectively. A system with a single degree of freedom was used to theoretically demonstrate the effectiveness of the NAF control (SDOF). It was discovered that the intended natural mode can have its damping efficiently increased with the NAF control while avoiding instability in the low frequency range. The MultiModal NAF (MMNAF) control is presented to stifle the numerous inherent ways of Multi Degree of Freedom (MDOF) systems utilising a single AMD according to the theoretical conclusions of the SDOF system. The ability of the MMNAF control to reduce MDOF system vibrations has been demonstrated in theory and practical experiments. [11].

Since controlling vibration and displacement in structures subjected to seismic stimulation is quite challenging, there has been a lot of interest in developing a structural control system to ward off disruptions. The application of the bees algorithm to change gains of a traditional PID controller for active vibration management of a building-like structure with two stories under Northridge Earthquake stimulation is the main emphasis of this study. The Bees algorithm is a versatile strategy that ensures a successful result for controller optimization when employing traditional trial-and-error design techniques. The main goal of this work is to improve the PID controller by optimizing KP, KI, and KD gains utilizing the bees technique in order to lessen floor vibrations during earthquake excitation. The PID controller is offline tuned using the mathematical model of the system after the system and its algorithm have been defined. The performance of a system-implemented genetic algorithm (GA), an established optimization method, will also be contrasted with that of the BA. The article uses the experimental findings from the structural system to illustrate how well the tuned PID controller works. The functioning and effectiveness of the tuned PID controller are thus studied and empirically verified. Much less movement and acceleration occurs on the flooring and in the cart. The experimental responses of the system are displayed graphically [12].

In the following study, skyhook dampers are used to actively regulate high-frequency vibration. For active vibration control to be implemented successfully, the selection of the damper gain and its ideal location are essential. Certain sensor/actuator placements are preferred in vibration control to lessen structural vibration with the least amount of control effort. A strong modelling technique to forecast the performance of the controller is required in order to optimize a general built-up structure to manage vibration. For effective response predictions at medium to high frequencies, the current work uses a hybrid modelling approach that combines the finite element method (FEM) and statistical energy analysis (SEA). Here, the hybrid method is used to explore a number of generic control design problems for a broad network of plates connected by springs. The best positions and gains for the skyhook dampers are obtained by combining the hybrid technique with numerical optimization utilizing a genetic algorithm. Results from a deterministic modelling method are contrasted with those from the hybrid method's optimal controller gain and location findings. The results from the two methods show good agreement, but the results from the hybrid method are obtained in a vastly shorter period of time [13].

In order to suppress vibrations of a device that are low-frequency while the device is fitted on pant-tilt platform, active control methods with visual feedback are developed where the vibrations are caused by disturbances to the support. In the principal axes of rotational control, the yaw and pitch handled are by placing the pan/tilt platforms in a robot's head, an antenna, surveillance system for vision, etc. However, in a moving system- turbulences -caused by the road or sea waves- could potentially significantly compromise the alignment control of the piece of equipment installed at the top of the tilt platform as a result of its inherent low-frequency vibration in the base.

For the attenuation of vibration, the adaptive sliding control (ASC) technique is developed. In some finite linear combinations of the orthogonal basis, the unknown disturbance is represented using a function approximation technique.

Thus, the pan/tilt system dynamics are demonstrated as steady first-order filter propelled by the errors of a function's estimates. Additionally, the theory of Lyapunov stability is used to derive the adaptive updating law. Second, the effectiveness of vibration suppression will be evaluated using the often-applied feedback active vibration control (AVC) with filtered-x LMS algorithm and compared to that of adaptive sliding control. For independent single axis excitation, experimental testing of the control algorithms reveals that the ASC and feedback AVC, correspondingly, have yielded average single-frequency disturbance attenuations of roughly 25.14 and 23 dB. The vibration attenuations caused by the two approaches for dual-frequency excitation are approximately 20.77 and 12.73 dB, respectively. ASC and feedback AVC provide corresponding 17.57 and 15.18 dB reduced vibration under single-frequency disruptions for simultaneous two axes excitations. Thus, the two active control approaches for reducing low-frequency vibration of the device on the pan/tilt platform are proven to be legitimate and effective [14].

In order to lessen the influence of the equipment's self-excitation on the automobile body, a parallel connection of a negative stiffness unit is connected in a parallel connection to a positive linear stiffness spring which results in developing a high static stiffness as well as on the other end it also forms a low dynamic stiffness - written in short form as HSLDS -

vibration isolator. Since the stiffness is not linear therefore it satisfies the parameter required to design such as of the curve of any target stiffness. The acceleration produced by the under-chassis parts is tested using a vibration test. A stiff yet bendable dynamic model with several parts of a high-speed train is created based on the test findings and incorporates both the self-excitation of the under-chassis machinery and the elastic vibration of the car body. Various connection methods for the under-chassis equipment are used, and the end results on the vehicle body with reference to the quality of ride (transience) and vibration are examined. These methods include rigid hanging, vibration isolation theory (VIT) hanging, dynamic vibration absorber (DVA) hanging, and HSLDS hanging. The simulation outcomes demonstrate the effectiveness of the proposed HSLDS vibration isolator. [15]

There is now more interest in designing and erecting extremely tall structures as a result of the population development in big cities and towns, as well as building regulations. Demands for tightness rather than power often influence the structural appearance of constructions. Super-tall buildings now have more flexibility and insufficient natural damping due to advancements in construction technology, procedures, and material quality. When there is a lot of wind, the major worry for buildings is occupant discomfort. Extreme vibrations brought on by wind gusts are a key problem in the design and building of supertall buildings. This method consists of an inner or basic structure made up of two top and reduced components, as well as a structural outer tubular framework. Within the top component, the exterior and essential structures are kept apart. In this part, damping devices are used to restrict the relative bending movement involving the outside and core framework and to get a grip on the wind-induced movements of the building by dissipating the vitality that is vibrational. This functional system's control performance is contrasted with that of a structure controlled by a tuned mass damper (TMD). The outcomes reveal that the self-acting system that is structural effectively reduces wind-induced vibration in super-tall buildings and enhances occupant comfort under strong wind excitation This method, which combines an exterior tube with a core structure, is composed of two lower and higher halves. By restricting the overall movement of the outer and core framework and absorbing vibrational energy, the damping products utilized in this area regulate the wind-induced vibration of the building [16].

A floor design may regularly change for functional structural reasons, lengthening the calculating process. For structural engineers working under time constraints, an effective yet precise approach of immediately forecasting maximum flooring reaction is critically needed. A particularly useful technique for predicting the structure's maximum reaction to heavy loads is the response range approach. For the specified load, it is a plot of the maximum reaction that reflects the inherent abundance of several single-example linear oscillators. The reaction spectrum has a well-known application in measuring the top response of structures to earthquakes. It is really used to anticipate floor reactions caused by passenger bouncing. In order to find the correct acceleration reaction spectrum, experiments on single-step loads produce recordings that are later applied to a single level of freedom system with a range of frequencies and damping ratios. These data are statistically analyzed to provide a representative range, which is then used to establish a spectrum analytical design bent [17].

The simulation results demonstrate the ideal installation places for an inertial drive that operates regularly. Effective control of time-varying excitations of vibration machines on a floating watercraft is made possible through the use of a control that is automatically centered on real-time dimension associated with cost function and searches automatically for the inertial actuator's most effective mounting position. To the best of our knowledge, this is the moment when an automated control system is used first to quickly go to an actuator and manage a time-varying excitation. This work proposes a linear shaft motor, a DSP system, two tachometers, four-speed sensors, an inertial actuator placed on an accelerometer, a moving vibration that is an active system, and a regional feedback cycle. The ideal mounting location for the inertial actuator is sought after using an algorithm that is in line with real-time measurement and the expense function. The smallest force transmission from the vibrating goods to your adaptable foundation within the drifting motorboat will be the requirement for the best installation place.

It is confirmed that there are considerable differences between the shows for the inertial drive in various mounting tasks. For a drive that is inertial on a regular basis, mounting jobs work best. For the inertial actuator installed permanently in situ, the inertial actuator commonly obtains the vibration control performance that is superior in a very constrained regularity range. To achieve broadband performance, a linear shaft motor enables you to move an actuator that is inertially possessing a time-varying excitation [18].

Base isolation technologies are a widely established and reliable method to reduce unwanted and dangerous vibrations in a variety of purposes and to protect bridges, buildings, and other essential pieces of civil infrastructure from destruction that would result from activity of seismic waves. Conventional base isolations, however, cannot adjust to environmental changes or vibration sources since they are essentially passive, which reduces their efficacy and longevity and, in certain situations, has unwanted impacts. Based on the structure's alleged characteristics as well as the size and frequency of expected earthquakes, an effective foundation is a compromise design. This research describes the stiffness-softening performance of a magnetorheological elastomer (MRE) in a scaled-down building that is three stories, with the goal of protecting building structures from unpredictable events like earthquakes; however, the stability of the structure and usage is still upheld. The results of the modeling and experiments show that the MRE stiffness-softening isolator should be able to sufficiently damp vibrations if controlled through fuzzy logic [19].

In fact, advances in design and building techniques have produced floor constructions that are more susceptible to vibration because they are thin and light. The current trend toward creating more open architecture makes this worse. In addition to other structures, samples of considerable vibration brought on by human-induced excitation have been discovered in footbridges and open floors. It has been demonstrated that Active Vibration Control (AVC) using inertial mass actuators significantly lowers response levels and enables otherwise excessively live constructions to comply with vibration serviceability requirements open-plan flooring systems and light-weight footbridges are examples of civil constructions that can respond to high levels of vibration caused by human activity. Utilizing inertial mass actuators and accelerometers to execute direct velocity in practice, this concept involves minimizing the performance index that includes all key practical issues [20].

Due to possible architectural limitations, it is usually not possible to use non-structural features to improve damping and tightness, such as full-height walls. As a passively adjusted mass damper, the PTMD is used. The equations of motion for the linked PTMD-floor system are derived using a single degree of freedom that is created to be equal to the PTMD. An optimization approach is used to identify the PTMD that is the best design. Investigated are the effects of PTMD tuning on its reaction caused by variations in floor mass. Additionally, PTMD may or may not be able to function well in terms of the number of dynamic interactions that are human structure when it is placed through tuning due to changes in flooring real-time lots [21].

The wind generating system's productivity is impacted by vibration, which lowers efficiency. While a system's vibration might not be harmed, it can be paid off or converted into electricity by using procedures that are acceptable. A vibration control system enhances the responsiveness of the turbines' structure and dependability, which has a direct impact on the component lifespan. Lowering the system's vibration amplitude will result in reduced noise, ensure user and operator comfort, and continue to maintain excellent production efficiency. These will help the machine increase the lifespan of a piece of industrial machinery. It offers applications for vibration control that is passive, active, and semi-active for structures, particularly for wind turbines. Damping devices have already been implemented extensively in wind generators for increasing their effectiveness by mitigating vibration [22].

Traditional vibration dampers, such as a traditional tuned mass damper, might not be successful in controlling the seismic reaction in high-rise structures at the same time. The Multi-Tuned Liquid Column Damper-Inerter (MTLCDI), a novel passive vibration control device, is developed in this work to manage the seismic response of nearby high-rise structures. To examine the seismic performance of MTLCDI, two distinct designs with this system—inter-story MTLCDI (IS-MTLCDI) and inter-building MTLCDI (IB-MTLCDI)—have been designed. Both ISMTLCDI and IB-MTLCDwe outperform individual TLCDIs between buildings as well as other vibration dampers for the management of seismic vibration of absolute acceleration and displacement that is inter-story whenever two structures have different normal frequencies. IS-MTLCDI reduces reactions more than IB-MTLCDI at the typical frequency at which it operates. However, using IB-MTLCDI may be better if there are considerable discrepancies when taking into account the natural frequencies of nearby structures because of its positive effects that may be mitigated and the convenience of installation [23].

The study use a brand-new rocker system with liquid viscous dampers to reduce vibration. Three parts make up this control system: viscous fluid dampers, struts, and rockers (FVD). The reinforcing components are solely subjected to tensile force in this manner. This makes the strut buckling issue insignificant. This advantage is beneficial for metal bars used as reinforcing parts. Long steel bars can be used for bracing between movable members and tiny framework connections in numerous stories by launching prestress into the bars. The suggested method has the advantage of allowing the employment of lengthy steel bars as stiffeners between swing system users and moment framework connections above selected levels. This research presented a novel vibration system that takes into account a rocker mechanism with fluid viscous dampers. Brace, Seesaw, and Fluid Viscous Damper make up the proposed Energy Swing Dissipation (SEDS) system (FVD). Long steel bars may be used as bracing and can be installed in numerous stories by including prestressing into the bars [24].

Industrial applications of the methods include proportional-derivative (PD) and proportional-integral-derivative (PID) controllers. Industrial applications trust PID control. PID control could be the controller that is most immediately beneficial in real-time applications without model understanding. The fact that PID controls are straightforward and truly have physical implications that are obvious sets them apart from other types of control. Although theoretical PID control algorithm research is widely known, it has not yet perhaps advanced enough in the field of structural vibration control. a straightforward control that is proportionally applied to reduce wind-induced building drift. To reduce structural motion brought on by earthquakes, an integral is utilized as the proportional controller with AMD. These control solutions are insufficient, nevertheless, because it is challenging to adjust the PID gains to provide desirable results for phenomena like rising time, overshoot, settling time, and steady-state error. The lyapunov theory is used to demonstrate the stability of AMD PD/PID control for building structures, and stability that is enough for tweaking PD/PID gains is determined. Fact that stability analysis is the technological advancement behind the PID systematic tuning technique [25].

Seismic vibrations increase the structure's anxiety, thus the vibrations they produce aren't seen to be healthy for the structure's health. As a result, there is a reliance on technological techniques to reduce vibrations. Structural inspection is one of the most often used inspection techniques. By employing external control devices such as passive, active, hybrid, or semi-active in the control associated with the structure, the seismic vibrations are decreased by applying a sufficient counterforce established by the control law. The constant recurrence of events causes harm to buildings. Undoubtedly, one strategy that is well-liked for this injury is structural examination. The main goal of structural control is to constantly offer a sufficient counterforce. An effective control algorithm determines the necessary counterforce. To provide a sufficient counterforce, this optimized and adaptive control system modifies the quasi-bang-bang control algorithm. Particle Swarm Optimization is used to optimize the constant output loads used in the modified quasi-bang-bang controller for the optimum performance under dynamic loads such as earthquakes (PSO). After that, the regulator is used on a three-story fixed MR damper form. A variety of seismic performance assessments were performed on this architecture. The most efficient trimmed optimum linear quadratic Gaussian (LQG) controller, a quasi-bang-bang, and a modified controller that is quasi-bang-bang contrast the results so produced. The findings show that the PSO-modified controller reduces structural responses, such as relative displacement, inter-story displacement, and absolute accelerations, more effectively than the other controller. The voltage comparison also reveals that the controller that is suggested to attain greater performance uses less power [26].

Modern super-tall buildings are particularly susceptible to wind-induced vibrations because of their innately high flexibility and little damping. An aerodynamic alteration that reduces wind-induced vibrations is to taper a structure's cross-section. Another control method to reduce structural vibrations is tuned mass (TMD). In exceptionally tall structures, the effects of using the tapering method and TMD system on wind-induced vibration are being researched. Utilizing frequency domain analysis, the along-wind and reactions to crosswinds are assessed for various taper and TMD mass ratio values. The findings show that for tapered constructions, as the taper ratio rises, the natural frequency of the residence increases. The tapering method is unable to successfully lower the acceleration response because the acceleration is proportional to the square of the natural regularity. When compared to displacement, TMD offers better acceleration control performance. The acceleration and displacement reactions can be successfully managed by combining the two control systems, which will also help meet the convenience and security needs of the occupants of extremely tall structures. The fact that the TMD system offers better acceleration control performance than displacement response is without a doubt one of the key benefits of employing it. Tapered tall structures have higher normal regularity than non-tapered tall structures because they have a smaller effective modal mass and more stiffness. Due to their lower effective modal mass and increased stiffness, tapered tall buildings exhibit higher normal regularity than non-tapered tall structures. As a result, it is challenging to effectively reduce the acceleration reaction when it is proportional to the square of the natural tapering frequency. In the wind-induced vibration of extremely tall buildings, the combined effect of these two control techniques, namely the tapered cross-section and TMD system, is investigated. This type of control is effective in decreasing building drift caused by the wind, but it is less effective in reducing the overall magnitude of the acceleration reaction. This kind of control works well to reduce wind-driven building drift, but it works less well to reduce the overall size of the acceleration reaction [27].

The TMD solution incorporates additional mass with an operational spring, damping elements, and other elements for damping of the main building. The detuning effect and the excessively long TMD stroke constitute two basic problems in the current TMD systems, despite the fact that conventional linear TMD is well known. The two primary issues with TMD systems are the detuning effect and excessive TMD lift. Variable Stiffness TMD (RVS-TMD), a brand-new semi-active TMD, is utilised to boost TMD systems' performance. An undamped TMD plus a changable stiffness device, that can have varied stiffnesses, make up the RVS-TMD (RVSD). By manipulating the changeable element, the RVSD hysteretic loops may reach all parts in the graphs of the force-deformation diagram, increasing energy dissipation [28].

In recent decades, numerous significant incidents and breakdowns in the marine and offshore industries have been attributed to vibration, which poses a safety concern to offshore maritime facilities and impairs their structural serviceability. It is difficult to manage vibration in coastal marine structures generated by self-excited nonlinear forces, hydrodynamic huge deformations, and very nonlinear responses. Traditional vibration control techniques can be divided into passive, active, semi-active, or hybrid categories. An excellent example of the structural addition of (usually) viscoelastic damping layers is the passive approach, which involves a hysteresis loop of cyclic stress and deformation of the layer that is damping vibrational power. Active methods forces, which need sensors and a feedback loop, can create the structural actuators used to minimize vibration. Hybrid systems include active and passive damping, whereas semi-active control methods modify or regulate the mechanical characteristics of the element damping the vibration control unit [29].

Vibration is a significant problem affecting the accuracy and surface quality of workpieces during ultra-precision machining. Direct payload interference and ground vibration interference were challenging to eliminate concurrently with traditional negative-stiffness active damping techniques. The efficacy of traditional anti-vibration technologies to avoid direct payload disruptions is degraded, and low-frequency residual vibrations severely restrict further advancements in machining precision. Use is made of a novel absolute displacement feedback active vibration control method that combines infinite and zero stiffness. The equivalent stiffness is between the isolated payload and the reference point, and between the isolated payload and the reference point between, which tends to infinity and zero, respectively. This stiffness is determined by connecting the positive and negative stiffness in series and parallel. While successfully suppressing direct payload disturbances and low-frequency (2Hz) ground vibrations, it provides smooth and tight blending control. Finally, using an array of infinite and zero stiffness, we experimentally validate the efficacy of the active damping approach. The accuracy and surface quality of workpieces made with extreme precision may be produced in a manner that is both reliable and outstanding. The active vibration management approach suggested in this article offers a practical means of enhancing the functionality of ultra-precision machine tools [30].

3. MODELING AND SIMULATION

A mass damper system is essentially how a floor's vibration control is accomplished. The control system modelling to reduce disruptions brought on by human presence is presented in the research. Both frequency domain and temporal domain modelling were carried out. The outcomes of testing the final transfer function with additional inputs and discussing them were discussed. According to stability criteria, plots have been judged on how well they adhere to the input instruction.

The control system is very important because there is a growing demand for the design and construction of extremely tall structures as a result of the population development of big cities and the availability of restricted building space. High-rise building structural design is frequently dictated by stiffness needs rather than strength requirements. Super-tall structures are more flexible and lack natural damping as a result of advancements in construction technology, procedures, and material quality. These structures' major worries during strong wind occurrences are the discomfort of the occupants, such as physical motion sickness symptoms or emotional reactions like worry. Supertall skyscraper design and construction are very concerned about excessive vibrations brought on by wind loads.

The block diagram of the system is presented below:

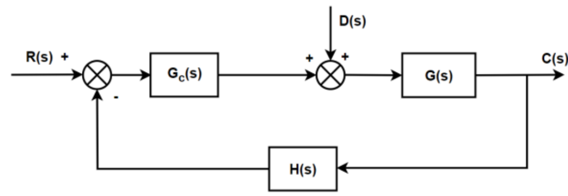

Fig. 6. The block diagram used to find the system characteristics.

The terminologies used in this paper are:

Table 1. Terminologies

k: Spring constant
fv: Damper coefficient
M: Mass
$x(t)$: Position of the mass in the time domain
$f(t)$: Force input in time domain
X(s): Position of the mass in the Laplace domain
$F(s)$: Force input in Laplace domain
Gc(s): Controller transfer function
R(s): Input variable of T(s) (Command)
C(s): Output variable of T(s) (Position of the manipulator)
T(s): Equivalent transfer function
G(s): Plant transfer function
s: Laplace variable

Fig. 7 shows the dynamics of a floor vibration control system, which is a damper and a spring grounded from one side

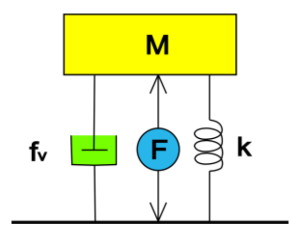

Fig. 7. Schematic diagram of floor vibration controller.

Using governing equations,

$$\sum F = ma \tag{5}$$

$$f(t) - f_v\, v(t) - kx(t) = ma(t) \tag{6}$$

Take $F = Cu(t)$

$$Cu(t) = m\ddot{x}(t) + f_v\dot{x}(t) + kx(t) \quad (7)$$

Converting to Laplace domain,

$$CF(s) = (Ms^2 + F_v s + K)X(s) \quad (8)$$

Rearranging:

$$\frac{X(s)}{F(s)} = \frac{C}{Ms^2+F_v s+K} \quad (9)$$

The transfer function becomes:

$$G(s) = \frac{C}{Ms^2+F_v s+K} \quad (10)$$

By assumption of some values as: C = 5, M = 1, Fv = 11.31 and K = 5 (these values are assumed as such, that they will give us a stable transfer function), we get

$$G(s) = \frac{5}{s^2+11.31s+5} \quad (11)$$

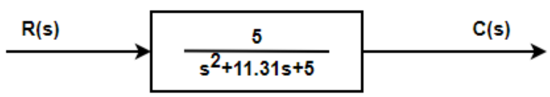

Fig. 8. Open loop block diagram.

Now, for the modeling in time domain

$$\frac{C(s)}{R(s)} = \frac{5}{s^2+11.31s+5} \quad (12)$$

$$s^2C(s) + 11.31sC(s) + 5C(s) = 5R(s)$$

Taking Laplace, we get

$$\ddot{c} + 11.31\dot{c} + 5c = 5r \quad (13)$$

Let $x_1 = c$, $x_2 = \dot{c}$ so, $\dot{x}_1 = x_2$

$$\dot{x}_2 = -5x_1 - 11.31x_2 + 5r \quad (14)$$

And the output is position, so

$$y = x_1 \quad (15)$$

In vector-matrix form:

$$\begin{bmatrix}\dot{x_1}\\ \dot{x_2}\end{bmatrix} = \begin{bmatrix}0 & 1\\ -5 & -11.31\end{bmatrix}\begin{bmatrix}x_1\\ x_2\end{bmatrix} + \begin{bmatrix}0\\ 1\end{bmatrix}r \quad (16.1)$$

$$y = \begin{bmatrix}1 & 0\end{bmatrix}\begin{bmatrix}x_1\\ x_2\end{bmatrix} \quad (16.2)$$

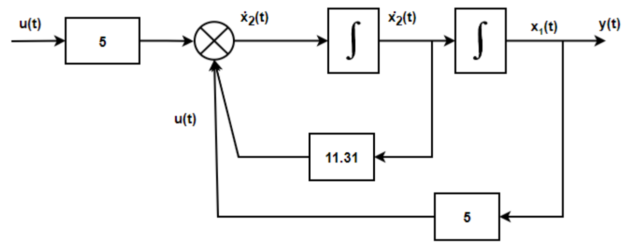

Fig. 9. Gain/ Signal attenuation diagram.

Adding the feedback and converting open-loop into closed-loop transfer function.

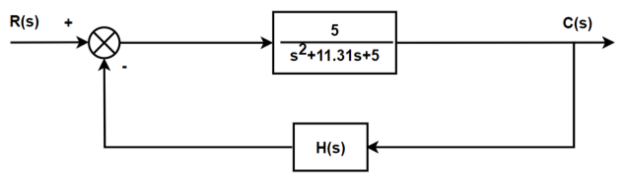

Fig. 10. Unity feedback block diagram.

With a unity feedback, the equivalent transfer function becomes:

$$T(s) = \frac{G(s)}{1+G(s)} \quad (17.1)$$

$$T(s) = \frac{\frac{5}{s^2+11.31s+5}}{1+\frac{5}{s^2+11.31s+5}} \quad (17.2)$$

$$T(s) = \frac{5}{s^2+11.31s+10} \quad (17.3)$$

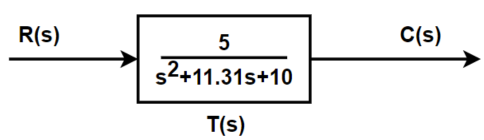

Fig. 11. Equivalent Transfer function block diagram

I. IMPLEMENTATION

For the modeling, designing, and characteristics of our system, we have used software like MATLAB and SIMULINK.

A. Time Response of the System

$$G(s) = \frac{C(s)}{R(s)} = \frac{5}{s^2+11.31s+5} \quad (18)$$

For a step input, $R(s) = \frac{1}{s}$

We get,

$$C(s) = \frac{5}{s(s^2+11.31s+5)} \quad (19)$$

Using partial fractions:

$$C(s) = \frac{A}{s} + \frac{B}{s^2+0.461} + \frac{C}{s+10.85} \quad (20)$$

Calculating values of constant

$$C(s) = \frac{1}{s} + \frac{-1.044}{s+0.461} + \frac{0.044}{s+10.85} \quad (21)$$

After Laplace inverse, it can be written as:

$$c(t) = 1 - 1.044e^{-0.461t} + 0.044e^{-10.85t} \quad (22)$$

We know that the transfer function for a second order system can be written in form of natural frequency, ωn and damping ratio, ζ as:

$$G(s) = \frac{{\omega_n}^2}{s^2+2\zeta\omega_n s+{\omega_n}^2} \quad (23)$$

By comparing with our transfer function, we get

$$\omega_n = \sqrt{5} = 2.236 \quad (24)$$

And,

$$2\zeta\omega_n = 11.31, \zeta = \frac{11.31}{2\sqrt{5}}$$

$$\zeta = 2.528 \quad (25)$$

Since $\zeta>1$, the system is overdamped.

Using MATLAB step input:

Table 2. Performance parameters

Rise Time	4.7710
Settling Time	8.5828
Settling Min	0.9003
Settling Max	0.9993
Peak	0.9993
Peak Time	15.3880

4. RESULTS

Now, the system is tested against multiple inputs. All the responses will be plotted and for each response, will be discussed the pros and cons.

1) Step Input:

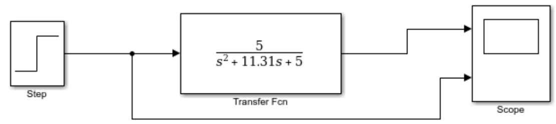

Fig. 12 SIMULINK block diagram for Step input.

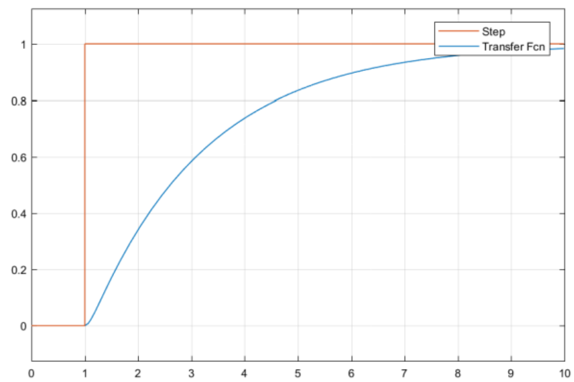

Fig. 13 Response plot of Step input.

The system's response is very stable and follows the step input very precisely yet, has some steady state error.

2) Ramp Input:

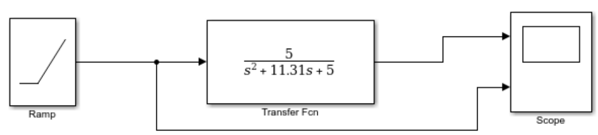

Fig. 14 SIMULINK block diagram for Ramp input.

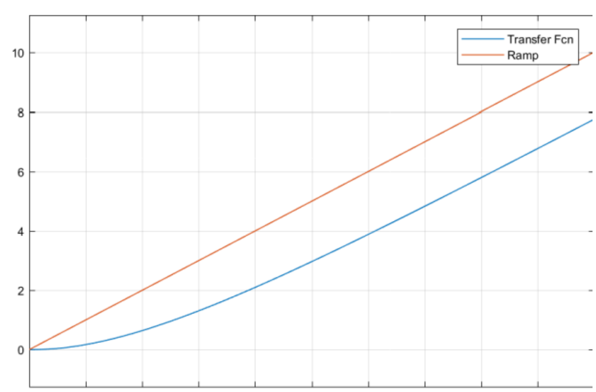

Fig. 15. Response plot of Ramp input.

The system's response is very stable and follows the ramp input but takes a long time and has some steady state error.

3) Parabolic Input:

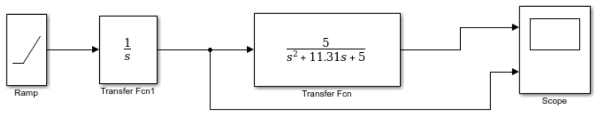

Fig. 16. SIMULINK block diagram for Parabolic input.

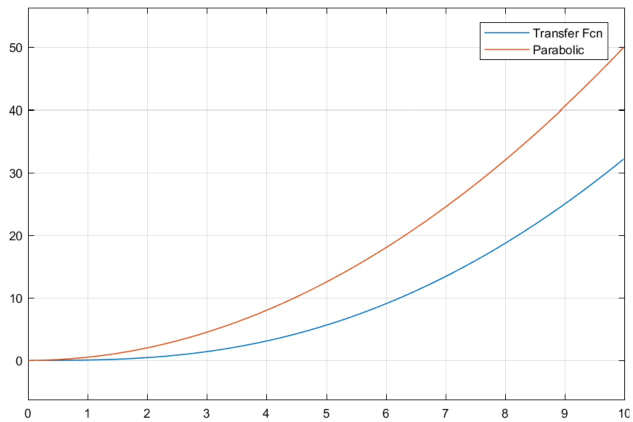

Fig. 17 Response plot of Parabolic input.

The system's response is very stable and follows the ramp input but takes a long time and has some steady state error.

B. Stability of the System

From all the above plots, we concluded that our system is stable and only a few alternations are required (which will be done by implementing either of the P, PD or PID controller) to make it suitable for our application.

The open loop transfer function with P controller gain K and the unity feedback system, in a block diagram is:

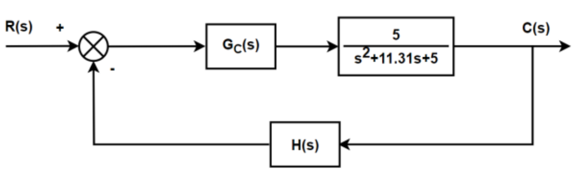

Fig 18. P controller in unity feedback general block diagram.

For the intended system, a P-controller is implemented with a unity feedback system.

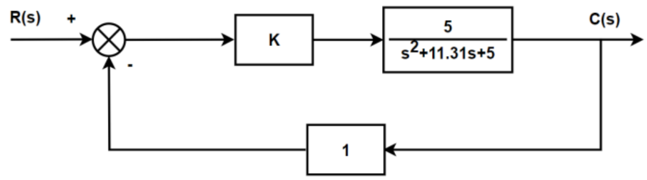

Fig 19. P controller in unity feedback in system block diagram.

The following system can be reduced to get equivalent transfer function T(s).

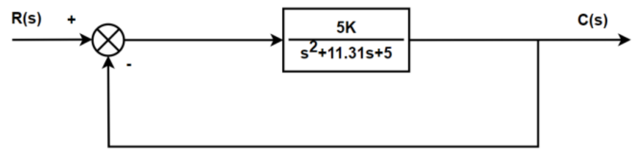

Fig 20. Equivalent transfer function block diagram.

Using:

$$T(s) = \frac{G(s)Gc(s)}{1 + G(s)Gc(s)}$$

$$T(s) = \frac{5K}{s^2+11.31s+(5+5K)} \qquad (26)$$

With the help of Routh Hurwitz technique, we can determine the stability of the system and the range of the P-controller gain K for which the system is stable.

Table 3. Routh Hurwitz Table:

s2 s1 s0	1 11.31 $\dfrac{-\begin{vmatrix} 1 & 5+5K \\ 11.31 & 0 \end{vmatrix}}{11.31}$ 5+5K	5+5K 0 0

For a stable system, there should be no sign changes in the first column. So, the term 5+5K must be greater than zero, $5 + 5K > 0$.

The limit for the gain is $K > -1$.

II. Error Analysis of the System

A. Steady State Error

The steady state error for the system against multiple inputs is be tested and the results are discussed below:

$$G(s) = \frac{5}{s^2+11.31s+5} \qquad (27)$$

1) Step Input:
Using the simplified form of final value theorem:

$$e_{step}(\infty) = \frac{1}{1+\lim_{s\to 0} G(s)} \quad (28)$$

$$e_{step}(\infty) = 0.5 \quad (29)$$

Where,

$\lim_{s\to 0} G(s)$ is the Position constant K_p.

2) Ramp Input:
Using the simplified form of final value theorem:

$$e_{ramp}(\infty) = \frac{1}{s\lim_{s\to 0} G(s)} \quad (30)$$

$$e_{ramp}(\infty) = \frac{1}{0} \quad (31)$$

$$e_{ramp}(\infty) = \infty \quad (32)$$

Where,

$\lim_{s\to 0} G(s)$ is the Velocity constant Kv.

3) Parabolic Input:
Using the simplified form of final value theorem:

$$e_{para}(\infty) = \frac{1}{s^2\lim_{s\to 0} G(s)} \quad (33)$$

$$e_{para}(\infty) = \frac{1}{0} \quad (34)$$

$$e_{para}(\infty) = \infty \quad (35)$$

Where,

$\lim_{s\to 0} G(s)$ is the Acceleration constant K_a.

Since the system was a Type 0 system, as expected, for ramp and parabolic input the steady state error is infinite. And for the step input, the error is 1.

Finally plotting the root locus using MATLAB. Root Locus is a powerful method of analysis and design for stability and transient response.

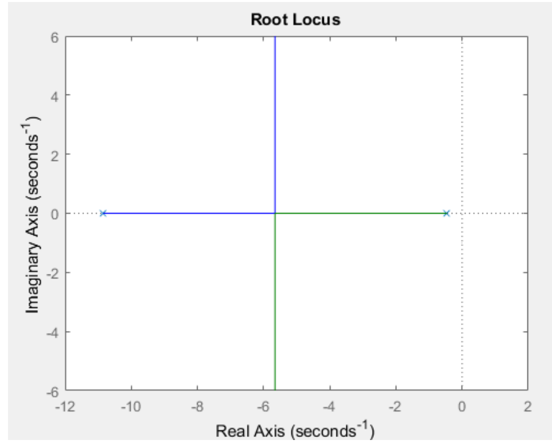

Fig 21. Root Locus.

From the plot, we conclude that root locus starts at the poles of the system and ends at infinity. Note: This is the plot of the system itself with no controller.

A PI controller was implemented:

Table 4. Controller Parameters

	Tuned
K_p	6.6491
K_i	3.6631
K_d	n/a
T_f	n/a

The block diagram of the controller is presented below:

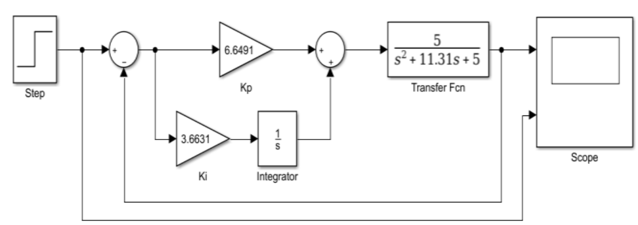

Fig 22. Block diagram of controlled system

This gave us the following response:

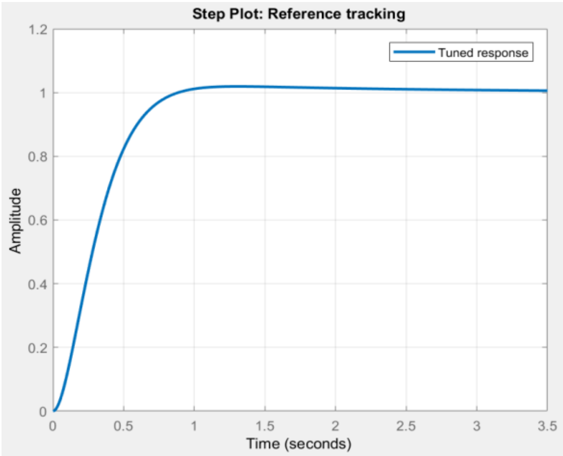

Fig 23. Step Plot diagram of Amplitude against Time

We can see that the steady state error had been minimized and the settling time has been reduced.

5. CONCLUSIONS

In the following article we have modelled an active system for control of floor vibrations and designed a PI controller for it. After which the transfer function was tested with different inputs and the responses were plotted. The system's response showed long settling time and steady state error. A PI controller was implemented to improve the conditions. Different values of Kp and Ki were used until the conditions were corrected. We also made a root locus which showed two poles on real axis and the asymptotes were lying on vertical axis showing the upper value of K as infinite. To provide reactive damping, tuned mass dampers (TMDs) are commonly mounted to the floor. Because of its low weight penalty, low cost, and ease of installation, TMDs are the most practical, economical, and least disruptive floor vibration control alternative for both new and existing floor systems. It is critical to incorporate damping into the design of a floor if you want it to be light, open, and vibration-free while also meeting current serviceability standards. There are several types of floor vibrations that cause structural damage over time. In structures that are targets of medium to high frequencies, there is a speedy reaction to any predicted predictions. Most passive damping systems have limitations such as large mass of inertia requirements and low efficiency in transient waves, particularly when there is a change in structure or mass. The active controlled tuned mass damper reduces and increases the effectiveness of the damping system, while expanding over a wider spectrum of transient phase frequencies. The sturdiness and operating standards, the smallest instability of closed loops, and the greatest stroke and overloading of actuators are some significant criteria for creating and building AVCs that must be carefully considered.

REFERENCES

[1] M. J. Hudson and P. Reynolds, "Implementation considerations for active vibration control in the design of floor structures," Eng. Struct., vol. 44, pp. 334-358, 2012 2012.

[2] T. Engle, H. Mahmoud, and A. Chulahwat, "Hybrid tuned mass damper and isolation floor slab system optimized for vibration control," J. Earthq. Eng., vol. 19, no. 8, pp. 1197-1221, 2015 2015.

[3] T. A. Sakr, "Vibration control of buildings by using partial floor loads as multiple tuned mass dampers," HBRC j., vol. 13, no. 2, pp. 133-144, 2017 2017.

[4] S. Thenozhi and W. Yu, "Advances in modeling and vibration control of building structures," Annu. Rev. Control, vol. 37, no. 2, pp. 346-364, 2013 2013.

[5] D. Ning, Z. Jia, H. Du, W. Li, and N. Zhang, "A variable inertance and variable damping vibration control system with electric circuit," presented at the 2019 14th IEEE Conference on Industrial Electronics and Applications (ICIEA), 2019, 2019.

[6] C. Camacho-Gómez, X. Wang, E. Pereira, I. M. Díaz, and S. Salcedo-Sanz, "Active vibration control design using the Coral Reefs Optimization with Substrate Layer algorithm," Eng. Struct., vol. 157, pp. 14-26, 2018 2018.

[7] G. Jiang and L. M. Hanagan, "Semi-active TMD with piezoelectric friction dampers in floor vibration control," presented at the Smart Structures and Materials 2006: Damping and Isolation, 2006, 2006.

[8] J. Baader and M. Fontana, "Active vibration control of lightweight floor systems," Procedia Eng., vol. 199, pp. 2772-2777, 2017 2017.

[9] D. S. Nyawako and P. Reynolds, "Observer-based controller for floor vibration control with optimization algorithms," J. Vib. Control, vol. 23, no. 3, pp. 345-360, 2017 2017.

[10] X. Wang and B. Yang, "Transient vibration control using nonlinear convergence active vibration absorber for impulse excitation," Mech. Syst. Signal Process., vol. 117, pp. 425-436, 2019 2019.

[11] D.-H. Yang, J.-H. Shin, H. Lee, S.-K. Kim, and M. K. Kwak, "Active vibration control of structure by Active Mass Damper and Multi-Modal Negative Acceleration Feedback control algorithm," J. Sound Vib., vol. 392, pp. 18-30, 2017 2017.

[12] M. Arif Şen, M. Tinkir, and M. Kalyoncu, "Optimisation of a PID controller for a two-floor structure under earthquake excitation based on the bees algorithm," Low Freq. Noise Vibr., vol. 37, no. 1, pp. 107-127, 2018 2018.

[13] A. G. A. Muthalif and R. S. Langley, "Active control of high-frequency vibration: Optimisation using the hybrid modelling method," J. Sound Vib., vol. 331, no. 13, pp. 2969-2983, 2012 2012.

[14] C. Chang and J. Shaw, "Low-frequency vibration control of a pan/tilt platform with vision feedback," J. Sound Vib., vol. 302, no. 4-5, pp. 716-727, 2007 2007.

[15] Y. Sun, J. Zhou, D. Gong, W. Sun, and Z. Xia, "Vibration control of high-speed trains self-excitation under-chassis equipment by HSLDS vibration isolators," J. Mech. Sci. Technol., vol. 33, no. 1, pp. 65-76, 2019 2019.

[16] H. E. Kalehsar and N. Khodaie, "Wind-induced vibration control of super-tall buildings using a new combined structural system," J. Wind Eng. Ind. Aerodyn., vol. 172, pp. 256-266, 2018 2018.

[17] M. Setareh, J. K. Ritchey, A. J. Baxter, and T. M. Murray, "Pendulum tuned mass dampers for floor vibration control," J. Perform. Constr. Facil., vol. 20, no. 1, pp. 64-73, 2006 2006.

[18] J. Chen, G. Li, V. Racic, H. E. Kalehsar, Khodaie, and N. R, "Seismic performance of optimal Multi-Tuned Liquid Column Damper-Inerter (MTLCDI) applied to adjacent high-rise buildings," Proc. Inst. Civ. Eng. Transp, vol. 112, no. 5, pp. 233-244, 2013 2013.

[19] J.-D. Kang and H. Tagawa, "Seismic performance of steel structures with seesaw energy dissipation system using fluid viscous dampers," Eng. Struct., vol. 56, pp. 431-442, 2013 2013.

[20] E. Pereira, I. M. Díaz, E. J. Hudson, and P. Reynolds, "Optimal control-based methodology for active vibration control of pedestrian structures," Eng. Struct., vol. 80, pp. 153-162, 2014 2014.

[21] S. Thenozhi and W. Yu, "Stability analysis of active vibration control of building structures using PD/PID control," Eng. Struct., vol. 81, pp. 208-218, 2014 2014.

[22] J. Chen, G. Li, and V. Racic, "Acceleration response spectrum for predicting floor vibration due to occupants jumping," Eng. Struct., vol. 112, pp. 71-80, 2016 2016.

[23] R. Kandasamy et al., "A review of vibration control methods for marine offshore structures," Ocean Eng., vol. 127, pp. 279-297, 2016 2016.

[24] J. Yang et al., "Development of a novel multi-layer MRE isolator for suppression of building vibrations under seismic events," Mech. Syst. Signal Process., vol. 70-71, pp. 811-820, 2016 2016.

[25] G. Kumar, A. Kumar, and R. S. Jakka, "The particle swarm modified quasi bang-bang controller for seismic vibration control," Ocean Eng., vol. 166, pp. 105-116, 2018 2018.

[26] Z. Wang and C. M. Mak, "Application of a movable active vibration control system on a floating raft," J. Sound Vib., vol. 414, pp. 233-244, 2018 2018.

[27] L. Wang, J. Li, Y. Yang, J. Wang, and J. Yuan, "Active control of low-frequency vibrations in ultra-precision machining with blended infinite and zero stiffness," Int. J. Mach. Tools Manuf., vol. 139, pp. 64-74, 2019 2019.

[28] N. J. J. o. W. E. Khodaie and I. Aerodynamics, "Vibration control of super-tall buildings using combination of tapering method and TMD system," vol. 196, p. 104031, 2020.

[29] Q. Wang, H. Qiao, D. De Domenico, Z. Zhu, and Y. Tang, "Seismic performance of optimal Multi-Tuned Liquid Column Damper-Inerter (MTLCDI) applied to adjacent high-rise buildings," Soil Dyn. Earthq. Eng., vol. 143, no. 106653, p. 106653, 2021 2021.

[30] J. Byzyka, M. Rahman, D. A. Chamberlain, and M. Malieva, "Performance enhancement of asphalt patch repair with innovative heating strategy," Proc. Inst. Civ. Eng. Transp., vol. 175, no. 5, pp. 300-309, 2022 2022.

TABLE 2. Literature Review Summary

Ref No	Authors, Paper Title	Year	Techniques Used	Findings
[1]	M. J. Hudson and P. Reynolds, "Implementation considerations for active vibration control in the design of floor structures."	2012	• DOFB controllers	Moderation of Vibration in floors produced by human activity
[2]	T. Engle, H. Mahmoud, and A. Chulahwat, "Hybrid tuned mass damper and isolation floor slab system optimized for vibration control."	2015	• separating the masses and using as a translational tuned mass damper • on a curved support	Buildings with seismic loads have reduced vibrations. Proves that it is possible to cut the movement and multi level drift by up to 45% compared to constructions made of normal slabs made from composite materials.
[3]	T. A. Sakr, "Vibration control of buildings by using partial floor loads as multiple tuned mass dampers."	2017	• using a few TMDs at the highest story of building to apply sinusoidal dynamic loads at various frequencies,	Decreases all structures drift, acceleration, and force response The use of extra storeys improves the response of structures to earthquakes.
[4]	S. Thenozhi and W. Yu, "Advances in modeling and vibration control of building structures."	2013	• technical aspects of structural controlsystems and building modeling	The most often utilised control mechanism is mr dampers. Stability is a crucial consideration in the design of controls. A central computational unit, which typically implements structural control, may malfunction at the behest of an earthquake. The most accurate data used for seismic events are acceleration signals.
[5]	D. Ning, Z. Jia, H. Du, W. Li, and N. Zhang,	2019	• VI device • VD device	Vivd suspension has A better vibration control performance than the conventional

Ref No	Authors, Paper Title	Year	Techniques Used	Findings
	"A variable inertance and variable damping vibration control system with electric circuit."			Vd suspension. Proposed vivd device has the same mechanical structure as the conventional electromagnetic vd device and different electric circuits
[6]	C. Camacho-Gómez, X. Wang, E. Pereira, I. M. Díaz, and S. Salcedo-Sanz, "Active vibration control design using the Coral Reefs Optimization with Substrate Layer algorithm."	2018	• algorithm with reference to coral reefs	Compared to a siso avc for the given application example, which is a truly complicated floor structure, significantly increases the vibration reduction.
[7]	G. Jiang and L. M. Hanagan, "Semi-active TMD with piezoelectric friction dampers in floor vibration control."	2006	• MDOF floor models • SAVTMD controlled floors	Control annoying floor Vibrations at fundamental mode Aided by spillover of the control force
[8]	J. Baader and M. Fontana, "Active vibration control of lightweight floor systems."	2017	• TMD, velocity or acceleration feedback and the disturbance estimation	Good damping efficiency Mitigate even varying resonance frequencies
[9]	D. S. Nyawako and P. Reynolds, "Observer-based controller for floor vibration control with optimization algorithms."	2017	• compared the vibration mitigation performances of two sets of controller schemes implemented in a single-input single-output (SISO) set-up: • (1) a PI controller	The best solution here is regarded as one that offers the greatest vibration mitigation performance amongst the solutions identified

Ref No	Authors, Paper Title	Year	Techniques Used	Findings
			• (2) a series of reduced-order-observer controller	
[10]	X. Wang and B. Yang, "Transient vibration control using nonlinear convergence active vibration absorber for impulse excitation."	2019	• nonlinear convergence ADVA to control the transient vibration	Can help shorten the convergence time of transient vibration suppressing and achieve faster decrements for transient oscillation attenuation.
[11]	D.-H. Yang, J.-H. Shin, H. Lee, S.-K. Kim, and M. K. Kwak, “Active vibration control of structure by Active Mass Damper and Multi-Modal Negative Acceleration Feedback control algorithm.”	2017	• MMNAF control generates the proper position for the active mass using the acceleration signal	Instability in the low frequency region Can successfully suppress multi natural modes of structures.
[12]	M. Arif Şen, M. Tinkir, and M. Kalyoncu, “Optimisation of a PID controller for a two-floor structure under earthquake excitation based on the bees algorithm.”	2018	• PID controller • Bees algorithm	The bees algorithm parameters, together with the goal function and the optimisation range, may all be altered to optimise pid controller performance. To enhance controller performance for structural systems under the influence of various genuine earthquakes, several types of intelligent, adaptive controllers will be developed in future research.
[13]	A. G. A. Muthalif and R. S. Langley, “Active control of high-frequency vibration: Optimisation using	2012	• hybrid modelling method	Skyhook damper gain and location is found with excellent accuracy in just a fraction of time compared to the traditional deterministic modelling techniques

Ref No	Authors, Paper Title	Year	Techniques Used	Findings
	the hybrid modelling method.”			
[14]	Y.-C. Chang and J. Shaw, “Low-frequency vibration control of a pan/tilt platform with vision feedback.”	2007	• feedback pan/tilt platform • feedback AVC method	Obtain good vibration attenuation Transient response Is poor as compared to that by the adaptive sliding control.
[15]	Y. Sun, J. Zhou, D. Gong, W. Sun, and Z. Xia, "Vibration control of high-speed trains self-excitation under-chassis equipment by HSLDS vibration isolators."	2019	• HSLDS vibration isolator based on target • stiffness curve is proposed	Hslds hanging, the time domain amplitudes of vertical and lateral vibration accelerations of carbody and the Psd are the minimum among all four hanging modes involved.
[16]	H. E. Kalehsar and N. Khodaie, "Wind-induced vibration control of super-tall buildings using a new combined structural system."		• Combines an exterior tube with a core structure • Is composed of two lower and higher halves. • By restricting the overall movement of the outer and core framework and absorbing vibrational energy, the damping products utilised in this area regulate the wind-induced vibration of the building	The outcomes reveal that the self-acting system that is structural effectively reduces wind-induced vibration in super-tall buildings and enhances occupant comfort under strong wind excitation
[17]	M. Setareh, J. K. Ritchey, A. J. Baxter, and T. M. Murray, "Pendulum tuned mass dampers for floor vibration control."		• PTMDs	The intesities of floor vibrations can be greatly reduced when ptmds are correctly tuned. The intesities of floor vibrations can be greatly reduced when ptmds are correctly tuned. The ptmd

Ref No	Authors, Paper Title	Year	Techniques Used	Findings
				might or might not be out of tune if human activity is the cause of extra live load. The floor reaction may be reduced if a human-structure interaction phenomenon is present.
[18]	J. Chen, G. Li, V. Racic, H. E. Kalehsar, Khodaie, and N.R, "Seismic performance of optimal Multi-Tuned Liquid Column Damper-Inerter (MTLCDI) applied to adjacent high-rise buildings."		• MTLCDI	In terms of seismic vibration management of absolute acceleration and inter-story drift ratios, the results show that when the two buildings have separate natural frequencies, both is-mtlcdi and ib-mtlcdi outperform inter-building single tlcdi as well as other vibration absorbers.
[19]	J.-D. Kang and H. Tagawa, "Seismic performance of steel structures with seesawenergy dissipation system using fluid viscous dampers."		• Seesaw energy dissipation	Reduces the reaction to a seismic event
[20]	E. Pereira, I. M. Díaz, E. J. Hudson, and P. Reynolds, "Optimal control-based methodology for active vibration control of pedestrian structures."		• Control system	The suggested methodology's feasibility is confirmed by experimental findings acquired on an in-service indoor walkway.
[21]	S. Thenozhi and W. Yu, "Stability analysis of active vibration control of building		• PD/PID	Numerical simulations and a two-story building prototype are used to validate the theory's results. These findings validate our theoretical analysis.

Ref No	Authors, Paper Title	Year	Techniques Used	Findings
	structures using PD/PID control."			
[22]	J. Chen, G. Li, and V. Racic, "Acceleration response spectrum for predicting floor vibration due to occupants jumping."		• design-oriented acceleration response spectrum	Vibration response found at the highest state while people jump Test floor and thene a real floor were used
[23]	R. Kandasamy *et al.*, "A review of vibration control methods for marine offshore structures."		• Semi-active control • methods	Control as well provide modications in the damping methods of structures located at offshore marines
[24]	J. Yang *et al.*, "Development of a novel multi-layer MRE isolator for suppression of building vibrations under seismic events."		• Multi layer MRE	Fuzzy logic is the best method to implement mre
[16]	H. E. Kalehsar and N. Khodaie, "Wind-induced vibration control of super-tall buildings using a new combined structural system."		• Wind-induced controller	Provide an Appropriate flexibility in the architectural and structural design of supertall Buildings based on the proposed structural system
[25]	G. Kumar, A. Kumar, and R. S. Jakka, "The particle swarm modified quasi bang-bang controller for seismic vibration control,"		• Quasi bang controller	The findings show that the pso modified quasi bang-bang controller outperforms the other controller in terms of minimizing structural reactions such as relative displacement, inter storey drift, and absolute accelerations.
[26]	Z. Wang and C. M. Mak, "Application of		• movable active vibration control	Excitation resulting from an actuator with a shaft that can be

Ref No	Authors, Paper Title	Year	Techniques Used	Findings
	a movable active vibration control system on a floating raft,"		system consists of a linear motor with a shaft, a DSP system, • two tachometers, four velocity sensors, and an inertial actuator connected to an accelerometer by	used to provide broadband perfomance
[27]	L. Wang, J. Li, Y. Yang, J. Wang, and J. Yuan, "Active control of low-frequency vibrations in ultra-precision machining with blended infinite and zero stiffness,"		• Ultra precision machining	This research proposes an active vibration control strategy for improving the performance of ultra-precision machine tools.
[28]	N. J. J. o. W. E. Khodaie and I. Aerodynamics, "Vibration control of super-tall buildings using combination of tapering method and TMD system."		• Tampering • TMDS	To reach desired transient state the crosswind and structural design needs to be improved by providing control to change inherent characteristics.
[29]	Q. Wang, H. Qiao, D. De Domenico, Z. Zhu, and Y. Tang, "Seismic performance of optimal Multi-Tuned Liquid Column Damper-Inerter (MTLCDI) applied to adjacent high-rise buildings."		• Multi tunes liquid colum damper	In terms of seismic vibration management of absolute acceleration and inter-story drift ratios, the results show that when the two buildings have separate natural frequencies, both is-mtlcdi and ib-mtlcdi outperform inter-building single tlcdi as well as other vibration absorbers.
[30]	J. Byzyka, M. Rahman, D. A. Chamberlain, and M. Malieva,		• Asphalt • heating	It is determined that preheating a pothole excavation with infrared heat before to filling and compaction enhances the

Ref No	Authors, Paper Title	Year	Techniques Used	Findings
	"Performance enhancement of asphalt patch repair with innovative heating strategy."			bonding strength and endurance of the repair interface.