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A Review on Clutching Inerter Damper for Vibration control of Multi-Degree of Freedom System

Prachi P. Maru[1], Vishal B. Patel[2], Atul N. Desai[3]

P.G. Scholar, Structural Engineering Department, Birla Vishvakarma Mahavidyalaya, Vallabh Vidyanagar - 388120, Gujarat, India[1]

Asst. Professor, Structural Engineering Department, Birla Vishvakarma Mahavidyalaya, Vallabh Vidyanagar - 388120, Gujarat, India[2]

Head of the Department, Structural Engineering Department, Birla Vishvakarma Mahavidyalaya, Vallabh Vidyanagar - 388120, Gujarat, India[3]

Abstract*:* The world's population is rapidly growing and as a result, there is a scarcity of available land for development. In order to accommodate more people in a compact space, there is now a need for vertical development and architecture, which involves constructing structures that are taller and slenderer. Taller structures create a challenge since they must be more stable and resistant to seismic and wind effects, which are more dominant on them. A passive control device system called Clutching Inerter Damper (C.I.D.) is a unique device that can reduce these vibrations and are used as a vibration-controlling tool to safeguard tall buildings during earthquakes. The tool can control motion since it is made up of a clutch mechanism and a rotary inerter. This paper offers a thorough analysis of this unique device's operation and its operating principles and provides a full assessment of the prior research done on it. The study concludes with a comparison of the responses obtained using this device and those obtained using prior studies when applied to a multi-degree of freedom (MDOF) system under seismic excitation. Response reduction in terms of % has been established to provide the effectiveness of the C.I.D. According to the study's findings, the C.I.D. system improves the seismic stability of the building and exhibits special benefits in moderating the resonant response because of the C.I.D.'s mass magnification effect generated by inertance.

Keywords*:* Clutching inerter damper, vibration control, seismic, resonant response, tall buildings, multi-degree of freedom.

I. INTRODUCTION

Recent land limitations have necessitated the construction of vertical buildings, which entails creating taller, leaner structures in order to accommodate more people in a smaller area. Greater structural stability and resistance are required for taller structures because they are more susceptible to larger wind and earthquake stresses. Numerous structural vibration-control strategies have been developed and put to use to reduce and absorb vibration in order to solve this issue. Civil engineers, especially those working in the structural engineering sector, are essential to assure the stability and safety of very large structures. One strategy is to make the structure more rigid, which can help it withstand the forces produced by earthquakes and wind. This strategy, meanwhile, might make the structure rigid and stress out the joints which can possibly lead to failure. To address this issue engineers have created a variety of structural vibration-control techniques that can suppress and absorb vibration.

Overall, these structural vibration-control techniques must be used to guarantee the stability and safety of tall structures in high-risk environments. Transferring the main structural system's vibrations to an additional oscillatory system is one of the core principles of structural control systems. The fundamental load-bearing elements of the building, such as the columns, beams, and walls, make up the main structural system. In the second system, called the auxiliary oscillatory system, the energy from the dynamic stresses is intended to be absorbed and dissipated. Common components of this system include base isolators, dampers and inerters. Base isolators are made to isolate the building from its base so that it can move independently in the event of an earthquake. While dampers function by dissipating energy through various materials, including viscous fluids or friction pads, inerters use a combination of mass and force to dampen vibrations. These devices are inserted inside the structure.

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A. Inerter

An inerter is a 2-terminal mechanical device that is used to control vibrations in a structural system. It was very first used in automobile industry by Smith in Formula-one race car to absorb the vibrations and to provide comfortability to the user. By understanding its concept this principle was introduced in civil engineering and was implemented in buildings keeping in mind the safety and security of the residents and also to maintain the functionality of building at the times of earthquake.

The main principle of inerter is energy storage. When the building experiences an earthquake-induced vibration, the inerter responds by resisting the motion of the building and storing energy in the device. This stored energy can then be released back into the system which can be further used to counteract the motion of the building and reduce the amplitude of vibrations. It stores and releases kinetic energy in response to changes in the acceleration of a mechanical system. Thus, it can be said that the force produced by the inerter is proportional to the acceleration of the building, and can be given by the equation $F=m*a$, where F is the force, m is the mass of the building, and a is the acceleration. By using an inerter in a building's structural system, it is possible to reduce the impact of earthquake-induced vibrations and improve the safety and stability of the building.

B. Inerter Mass Damper (IMD)

The Inerter mass damper (I.M.D.) is a type of device used to control vibrations in different types of structures. The rotational motion of the flywheel causes an inertial force to be developed which is equal and opposite to the external force applied to the structure. This helps to reduce the amplitude of the vibrations of the structure. The damper in the system helps to dissipate the energy that is generated during the oscillation of the inertial mass, thus providing additional damping to the system. The I.M.D. system is particularly effective in controlling high-frequency vibrations that may be generated due to wind loads or seismic activities.

The gear and flywheel-based I.M.D. system is an innovative approach that has been developed to enhance the performance of traditional I.M.D. systems. This system is designed to be compact, cost-effective, and easy to install. It can be used in a variety of different structures, including buildings, bridges, and towers. The clutching inerter damper (C.I.D.) system that is being studied is an extension of this concept, which further improves the effectiveness of the I.M.D. system by incorporating a clutch mechanism.

C. Clutching Inerter Damper (CID)

A clutching inerter damper, also known as a CID, is a type of vibration control device used in automotive and industrial applications. It consists of three main components: a clutch, an inerter, and a damper. The clutch is used to engage or disengage the CID from the system, while the inerter is responsible for storing and releasing kinetic energy in response to changes in the system's motion. The damper is used to dissipate energy and reduce vibrations. In present study the clutch is presented by a ratchet and pawl mechanism. The clutching mechanism is formed between pinion and flywheel. The device works by providing both energy storage and energy dissipation, which helps to reduce the amplitude of vibrations and protect the building's structural integrity.

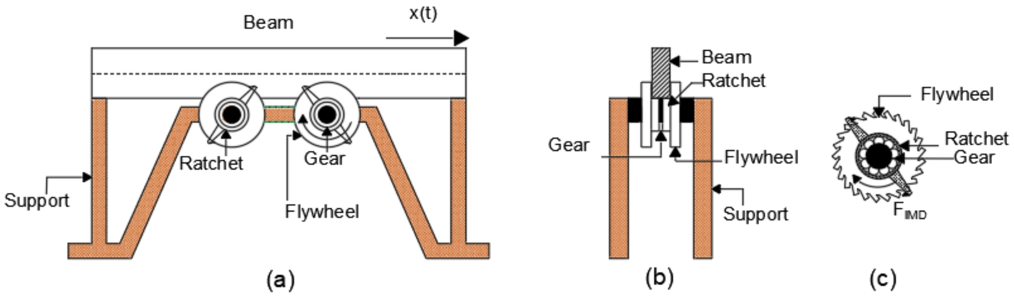

Fig. 1 A S.D.O.F. system with a C.I.D. (a) Front view (b) Side view (c) Detailed view of flywheel, ratchet and gear

Fig. 1 shows the SDOF system with an CID. Here it is assumed that the lateral force coming from left towards right is taken as positive. When the system is subjected to +ve lateral load, beam moves towards right and due to its translational motion, it drives the gear to rotate clockwise. As the gear and ratchet wheel is attached with pawl, the pawl generates the rotational force to the flywheel and thus the flywheel gets rotated clockwise.

When the lateral load is reversed, the right ratchet wheel becomes idle and thus no rotational force is generated in the flywheel by pawl. But now the opposite i.e., left flywheel undergoes the same motion, but in anticlockwise direction. Due to this reason instead of 1, 2 flywheels have been taken into the study as the ratchet-pawl clutch allows the rotary

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motion in only single directions. The system can work only when the acceleration and velocity is in same direction and will stop if the direction is reversed. Therefore 2 flywheels are provided that can work one by one. The arrangement of the flywheel is opposite to one another.

II. LITERATURE REVIEW

Garrido et al., [4] (2013) introduced a new vibration control device called a rotational inertia double-tuned mass damper (RIDTMD) which is more effective than a traditional tuned mass damper (TMD) in suppressing vibrations at excitation frequencies near resonance. The device consists of a TMD in which the typical viscous damper is replaced with a tuned viscous mass damper. The study had derived the equations of motion and transfer function of the considered model. The performance of the new device was compared with that of a traditional TMD in terms of frequency response and strokes of auxiliary masses. The results of the paper shows that the proposed RIDTMD is more effective than a TMD at the same mass ratio, particularly at excitation frequencies near resonance. The RIDTMD also has a wider suppression band, and the moving block stroke is nearly identical for both devices. The optimum design parameters of the system subjected to harmonic load are obtained using a numeric technique. The paper demonstrates that the RIDTMD can be used as an effective vibration control device for S.D.O.F. structures subjected to harmonic loads.

Hu and Chen, [7] (2015) had replaced traditional dynamic vibration absorber (T.D.V.A.) with inerter based mechanical network. $H_{infinity}$ and H_2 optimization had been carried out for inerter based dynamic vibration absorbers (I.D.V.A.) Here T.D.V.A. was added with inerter and spring and 4 combinations of I.D.V.A. have been studied in the work because just adding the single inerter either in series or parallel shows no improvement in $H_{infinity}$ and H_2 performance. But by opting inerter with spring significant improvements were obtained in both the performances. 20% improvement was achieved in $H_{infinity}$ when compared with TDVA and effective enlargement of frequency band was observed while 10% of improvement was seen in H_2 performance.

Hwang et al., [8] (2007) investigates a new mechanical damper called the rotational inertia damper, which provides effective mass to the structure and enhances the efficiency of the damper by connecting it to a toggle bracing to magnify the relative displacement. The paper also shows that the performance of the rotational inertia damper is further improved with the addition of a viscous or friction damping mechanism, and the vibration control effect of the rotational inertia damper increases significantly as the lead of the ball-screw decreases. The paper concludes that the efficiency of a toggle bracing depends heavily on the relative stiffness of the damper and the brace, and the displacement-magnification effect is maximized when the stiffness ratio of the damper/brace is less than 1/10,000. The rotational inertia damper combined with various energy-dissipating mechanisms turned out to be effective in reducing structural vibration. The efficiency of the damper depended heavily on the length of the ball screw lead; as the lead decreased, the effective mass, effective damping, and consequently the effectiveness of the damper increased significantly. The device can be used effectively even in structures with small drift.

Javidialesaadi and Wierschem [12] (2019) have studied the effectiveness and behaviour of S.D.O.F. system with One-directional rotational inerter viscous damper (O.D.R.I.V.D.) The proposed device consists of one directional ball screw and flywheel which converts relative motion to rotation of flywheel. This works for a single direction only and transfers primary structure's energy to flywheel in one direction and is unaffected by relative motion of other direction and thus does not allow energy to be transferred back to the primary structure. Therefore, it differs from the traditional damper which works in both the direction. The R.I.V.D. provide large inertial mass and controls structure by coupling the structure's motion to rotational motion of rotary mass and transferring kinetic energy to that rotary mass. According to the study, decrease in peak displacement response increase with increase in device damping and rotational inertia mass. This system does not change natural frequency of S.D.O.F. system which typically occurs when using inerters. Mechanism and model are presented and its behaviour and effectiveness were investigated.

Lazar et al., [13] (2014) proposes a new passive vibration control system based on the inerter device to reduce vibrations in civil engineering structures subject to base excitation. The inerter system is modelled inside a multi-storey building and is located on braces between adjacent storey. The paper also compares the inerter-based system to a TMD system using a range of base excitation inputs, including an earthquake signal, to demonstrate how the performance could potentially be improved by using an inerter instead of a TMD. The paper suggests that the proposed inerter-based system can potentially offer an alternative to traditional tuned mass dampers for reducing vibrations in civil engineering structures subject to base excitation. The inerter system can achieve a high level of vibration isolation with low amounts of added mass, making it an attractive option.

Li and Liang,[14] (2020) analysed S.D.O.F. system with C.I.D. under free and harmonic vibration. Equivalent Linearization Method (ELM) based on Statistical linearization was utilized to linearize the C.I.D. system. The E.L.M. presented in this study can accurately reflect the characteristics of the C.I.D. system and can evaluate the response of the nonlinear system. Finally, E.L.M. was extended to the multi degree of freedom (M.D.O.F.) structure based on modal

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reconstruction and had proved to be feasible and accurate to obtain the structural equivalent matrices to evaluate the structural response. The author suggests that C.I.D. should be mounted on the weak layers of M.D.O.F. structure.

Li et al. [15] (2019) has suggested that the single-degree-of-freedom (S.D.O.F.) system with a Clutching Inerter Damper (C.I.D.) shows advantage over an Inertial Mass Damper (I.M.D.). But as C.I.D. lacks linearity the author has presented 3 equivalent linearization methods (E.L.M.) for S.D.O.F. system. The E.L.M. 1, 2 and 3 are based on 3 different principles i.e., Frequency Response Function, Equivalent period and conservation of energy and Statistical linearization respectively. The equivalent inertance and damping had been calculated by all methods. The study showed that E.L.M. based on Equivalent period and conservation of energy had a clear physical meaning and direct formulas thus it should be a recommended method for small inertance-mass ratios. Besides, E.L.M. 1 and 2 shows higher accuracy under free vibration and harmonic excitation while E.L.M. 3 shows more accuracy under seismic excitations.

Makris and Kampas, [17] (2016) has investigated a mechanism that involves rack-pinion-flywheel system connected in a particular fashion that suppresses ground-induced vibrations. The arrangement was called as inerter in the study. Authors examined the dynamic response of a S.D.O.F. structure when two parallel rotational inertia systems were installed and explains that in rack-pinion-flywheel system, its resisting force is proportional to the relative acceleration between the vibrating mass and the support of the flywheels. The paper shows that the seismic protection of structures with supplemental rotational inertia has advantages, particularly in suppressing the spectral displacements of long period structures which is not efficiently achieved with large values of damping. It concluded that this happens because of transferring of the forces at the support of the flywheels and also examines to what extent the stiffness and damping of the support of the flywheels affects the dynamics of the system.

Malaga-Chuquitaype et al., [18] (2019) examined S.D.O.F. and M.D.O.F. steel structure in which twin inerter clutch devices were installed. As per the parametric study the influence of dry friction and clutch damping are limited but clutch stiffness and gear plays are important and are needed to be considered. For large suppression coefficient, increase in clutch stiffness arises nonlinearities. Play gaps in the gear system diminishes the effectiveness of the inertial damper and reduces the period lengthening effect. Experiments on small scale bare elastic structure and structure equipped with 3-d printed inerter and inerter clutch twins were carried out. Real pulse like ground motion were used to find the vibration absorbing capabilities of twin inerter clutch system. It was concluded that supplemental inertia is highly effective in suppressing steel building deflection especially for lower frequency of excitation. Twin inerter reduces peak base shear forces in compare to bare steel structure.

Patel and Jangid, [23] (2022) derive the optimum parameters of Tuned mass damper (TMD) based on modal multiplicity criteria and provides closed form solution for it. The derived parameters presented depends on structural damping and mass ratio and are found to be unique for the displacement and acceleration response. Study shows that displacement response of TMD based on the optimal parameters derived gives the least peak response of the main mass under harmonic and seismic excitation. The frequency uncertainty has no impact on the peak displacement. Substantial reduction in input energy, kinetic energy, damping energy and strain energy under harmonic and seismic excitation was observed for the proposed optimum parameters.

Sadek et al., [26] (1997) uses mathematical equations and simulations and proposes a method for selecting the optimum parameters of tuned mass dampers (TMD) to reduce the response of structures to seismic loading. The method involves selecting the frequency and damping ratios for a given mass ratio that result in equal and large modal damping in the first two modes of vibration. The parameters are used to compute the response of several single and multi-degree-of-freedom structures with TMDs to different earthquake excitations. The optimum TMD parameters for single and multi-degree-of-freedom structures are presented in tabular and equation forms. The results of the paper show that the proposed method for selecting the optimum parameters of TMD can significantly reduce the displacement and acceleration responses of structures to seismic loading and the method can also be used in the vibration control of tall buildings.

Wang and Sun,[32] (2018) had compared long period structure connected with C.I.D. and I.M.D. and evaluates the response reduction effect of linear S.D.O.F. system under harmonic excitations and real earthquake records. It was found that displacement response under seismic excitation with C.I.D. reduced by 53% while with I.M.D. reduced by 24%. It is because C.I.D. has inherent property of I.M.D. which speeds up the decreasing of the velocity response from an instantaneous extremum to 0 thus leads to a much larger reduction in the resonant responses, including acceleration and displacement in compare to I.M.D. The authors also concluded that there is no need to consider amplitude of input excitation as scaling load-input results in identical scaling of response therefore, reduction effect will directly provide information about seismic reduction effect of C.I.D. Moreover, as C.I.D. has inherent nonlinear properties the authors had also presented E.L.M and simplified formula of displacement reduction factor based on energy conservation principle.

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Wang et al.,[33] (2022) demonstrates the great potential of Clutching Inerter Tuned Mass Damper (TMDCI) as an effective and affordable control strategy for the seismic protection of structures. The equations of motion were derived for the TMDCI on a SDOF structure. Subsequently, the modal properties were revealed by examining the steady-state responses under harmonic and seismic excitations. TMDCI exhibits a large damping effect which can reduce responses in both the structure and device and maintain strong robustness against frequency uncertainties. It was concluded that the optimum stiffness coefficient for the TMDCI is much greater than those for the comparable Tuned mass damper (T.M.D.) and Tuned mass inerter damper (T.M.D.I.) a large damping effect so that both the structure and device have relatively small responses. This favourable feature is due to the mass amplification effect by the inerter as well as the flywheels taking energy away from the structural system without transferring back.

Wang et al., [34] (2018) proposes a new type of dynamic vibration absorber (DVA) called inerter-based dynamic vibration absorber (IDVA) to enhance the performance of passive DVA. Six kinds of IDVAs are obtained. The methods used to obtain the optimal parameters was H ∞ optimization as the optimization criterion. The paper also uses stability maximization criterion to improve the transient vibration of the system. The results show that all the inerters connected between the primary system and absorber system do not provide improvement for the performance of DVAs, while all the inerters connected to the earth shows the best performance in vibration absorption, with more than 30% improvement compared to other IDVAs. The paper concludes that the proposed IDVAs can enhance the performance of passive DVAs and the inerter connected to the earth in the grounded DVA performs the best performance in vibration absorption.

Smith, [39] (2020) presents a paper that provides a better understanding of the inerter concept and device, which can be useful in the design and analysis of mechanical systems. In this paper, four major methods of construction for inerter devices are described and modelled. These methods include the use of a flywheel, a geared system, a hydraulic system, and an electromagnetic system. The paper also discusses the rotational inerter and provides insights into its behaviour. This knowledge can be applied in various fields where mechanical systems are used extensively. The paper also highlights the importance of distinguishing between the ideal inerter and its approximations, which can help in developing more accurate models for mechanical systems.

Chen et. al.,[3] (2014) derived algebraic solutions for the natural frequencies of vibration systems, and performed sensitivity analysis on the natural frequencies and mode shapes of multi-degree-of-freedom systems, derived the condition for a general multi-degree-of-freedom system of which the natural frequencies can be reduced by an inerter, and simulated a six-degree-of-freedom system to investigate the influence of inerter position on the natural frequencies. The results of the paper showed that the natural frequencies of all vibration systems can be reduced by employing inerters. And can be further reduced by increasing the inertance of any inerter. The efficiency of inerters in reducing the largest natural frequencies is verified by simulating a six-degree-of-freedom system, where a reduction of more than 47 percent is obtained by employing only five inerters.

Iwan and Yang[11] (1972) discusses different methods to analyse the stationary random response of nonlinear multidegree-of-freedom dynamical systems. The approach simplifies the determination of linear system parameters with a physical interpretation which can be useful in the design and analysis of such systems and its accuracy is demonstrated through examples. The paper discusses four basic methods which are the Fokker-Planck equation approach, the normal mode approach, the perturbation approach, and the statistical linearization approach. The study concludes that the proposed approach can be a potentially useful technique for the analysis of stochastically excited linear systems.

Wen et al., [35](2017) optimizes the parameters of tuned viscous mass dampers (TVMDs) and tuned inerter dampers (TIDs) distributed throughout the structure and tuned to multiple modes by minimizing the H2 performance of the objective responses. The equivalent stiffness and damping of the TVMD and TID were considered to demonstrate tuned inerter based dampers (TIBDs) control mechanisms, such as significant additional damping at the resonance frequency. The methods used in this paper include defining a placement index based on the H2 norm to analyse the locations and modes for tuning the TIBDs. Further, the effectiveness of TIBD schemes was validated by subjecting 3-story and 10-story buildings to earthquakes with different spectra characteristics. The results of the paper show that the use of multiple TIBDs can be an effective way to mitigate the seismic responses of MDOF structures and distributed TIBDs tuned to properly selected modes significantly reduce the root-mean-square (RMS) responses of displacement and acceleration and perform superior than the viscous dampers and viscous mass dampers in reducing the peak displacement.

Takewaki et al.,[29] (2012) uses mathematical modelling and analysis to investigates the fundamental mechanisms of earthquake response reduction in building structures with inertial mass dampers for three recorded ground motions. The influence of inertial mass dampers on the ground-motion input can be expressed by the influence coefficient vector, which can be used to determine the optimal placement of inertial mass dampers in a building structure. In order to reduce the influence coefficient at a floor level, it is necessary to allocate the inertial dampers at all the stories below that floor level. When an inertial damper is taken out from one story, the influence coefficient above that story becomes 1 meaning that the inertial dampers above that story do not influence the input acceleration. The results of this paper can be used to

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estimate the earthquake input energy under an acceleration input with a constant Fourier spectrum depending on the influence coefficient vector. The closed-form expression of the influence coefficient vector presented in the study can be used to determine the optimal placement of inertial mass dampers in a building structure.

Nakamura et. al.,[21] (2014) presents a new type of electromagnetic damper combined with an IMD called as electromagnetic inertial mass damper (EIMD) that can control vibrations of structures during earthquakes. The authors have derived theoretical formulae for an inertial mass and a damping force and the device has been tested for reduced-scale and full-scale to verify the basic characteristics of the damper. Shaking table tests of a three-story structure was conducted with EIMDs. The paper concludes that the EIMD is an effective device for reducing story drifts and acceleration responses during earthquakes. The EIMD is able to generate a large inertial mass by the rotating flywheel and variable damping by the built-in electric generator. The generated inertial mass reduces the apparent input excitation to the structure and elongates the natural period of the structure, while the induced damping increases the damping factor of the structure. The EIMD can be used in the construction of new buildings or retrofitted into existing structures to improve their seismic performance.

Zheng et al.,[37] (2022) discusses the basic principles and main structural motion equations of four types of inerters used for structural vibration control which includes the traditional inertial mass damper (IMD), clutch inerter damper (CID), CID all-damped and CID part-damped respectively. The methods used includes mathematical modelling and numerical simulations to analyse the energy composition. The paper compares the control effect of displacement for the uncontrolled structure and the four inerter-based single-degree-of-freedom systems and proposes optimal parameters based on energy indexes. The paper provides a better understanding of the principles and effectiveness of different types of inerters for structural vibration control. The proposed optimal parameters can be used to design more efficient and effective vibration control systems for structures. The results show that the clutch inerter damper with partial damping is the most effective in controlling structural vibration.

Ikago et al. [10](2012) presents a new seismic control device called the tuned viscous mass damper (TVMD) that uses a ball screw mechanism as an apparent mass amplifier and a simplified method for estimating the seismic response of a multiple-degree-of-freedom (MDOF) TVMD seismic control system. The proposed method involves calculating the square root of the sum of the squares (SRSS) of the maximum modal responses derived from the undamped real eigenvalue analysis. The analysis example presented in the paper shows that the SRSS estimation gives a good approximation of the actual maximum modal responses in practical terms. The paper concludes that the proposed TVMD device can be used for effective seismic control using a tuned mass, and the simplified method for estimating the seismic response can be used by structural designers at the preliminary design stage to understand the seismic response characteristics of the structure in terms of modal responses.

Pietrosanti et al.[25] (2017) presents optimal design and performance evaluation of a Tuned Mass Damper Inerter (TMDI) system to reduce dynamic vibrations. The paper proposes three different design methodologies for the TMDI system: displacement minimization, acceleration minimization, and maximization of the ratio between the energy dissipated in the secondary system and the total input energy. The TMDI system is compared with conventional and non-conventional Tuned Mass Damper (TMDs) and its robustness is assessed with a sensitivity analysis varying the design parameters. The paper assumes a white noise process as the base input for the optimal design of the TMDI system. The effectiveness of the optimally designed TMDI system is evaluated under earthquake base excitation. The results concludes that the proposed design methodologies are effective in obtaining the optimal design parameters for the TMDI system. The TMDI system has superior performance and robustness compared to conventional and non-conventional TMDs and is an effective solution for reducing dynamic vibrations in structures.

Marian and Giaralis[19] (2014) proposes a new passive vibration control configuration called the tuned mass-damper-inerter (TMDI) to suppress the oscillatory motion of stochastically support excited mechanical cascaded systems and shows that it outperforms the classical tuned mass-damper (TMD) in minimizing the displacement variance of undamped single-degree-of-freedom (SDOF) white-noise excited primary structures because the TMDI takes advantage of the "mass amplification effect" of the inerter to achieve enhanced performance compared to the TMD. The paper provides closed-form solutions for optimal TMDI parameters for SDOF systems and numerical data for a 3-DOF classically damped primary structure base excited by stationary colored noise to exemplify the effectiveness of the TMDI and to suppress the fundamental mode of vibration for MDOF structures. The results show that the TMDI can be used to achieve lightweight passive vibration control solutions or improve the performance of the classical TMD for a given TMD mass. The TMDI can be viewed as a generalization of the classical TMD for both SDOF and MDOF support excited primary structures, and all established procedures for optimum design ("tuning") of the classical TMD are readily applicable to achieve "optimal" performance for the new TMDI configuration.

Moghimi and Makris,[20] (2021) investigate the seismic response of yielding structures equipped with inerters at the first story. The paper provides a new strategy for response modification of civil structures during earthquakes and presents a

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stable nonlinear response analysis methodology that implements a state-space formulation for seismic response of yielding structures equipped with inerters. The effectiveness of a single inerter versus the use of a pair of clutching inerters is examined, and the paper concludes that a single inerter suppresses effectively the displacement response of inelastic structures by outperforming the response modification with supplemental damping in particular when the supporting frame of the response modification devices is compliant. The paper also shows that when a yielding structure is equipped with supplemental rotational inertia, the equal-displacement rule is valid starting from lower values of the pre yielding period.

III. APPLICATION ON M.D.O.F. SYSTEM

The optimal parameters of displacement are determined from the transfer function and are further used to determine how much the mechanism is able to reduce the responses when 3 real earthquake motions which includes Denali Alaska, Chamba and Bhuj earthquake is applied to the structure. The work is done by referring to the study done by Sadek et al.[26] The same data has been taken and is compared with the above paper as well as with the study of Patel and Jangid[23]. Comparison of 10 storey building has been carried out. The general data is as follows.

- $\xi = 0.05$
- $\mu = 0.10$
- Optimal frequency Ratio of present study= 0.8875
- Optimal Damping Ratio of present study = 0.1925
- Optimal frequency Ratio as per Sadek et al (1997) = 0.8954
- Optimal Damping Ratio as per Sadek et al (1997) = 0.3470
- Optimal frequency Ratio as per Patel and Jangid (2020) = 0.8954
- Optimal Damping Ratio as per Patel and Jangid (2020) = 0.3466

TABLE I : PROPERTIES OF 10 STOREY FRAME

Stiffness ($1*10^3$) kN/m	Mass ($1*10^3$) kg
34.31	98
37.43	107
40.55	116
43.67	125
46.79	134
49.91	143
53.02	152
56.14	161
52.26	170
62.47	179

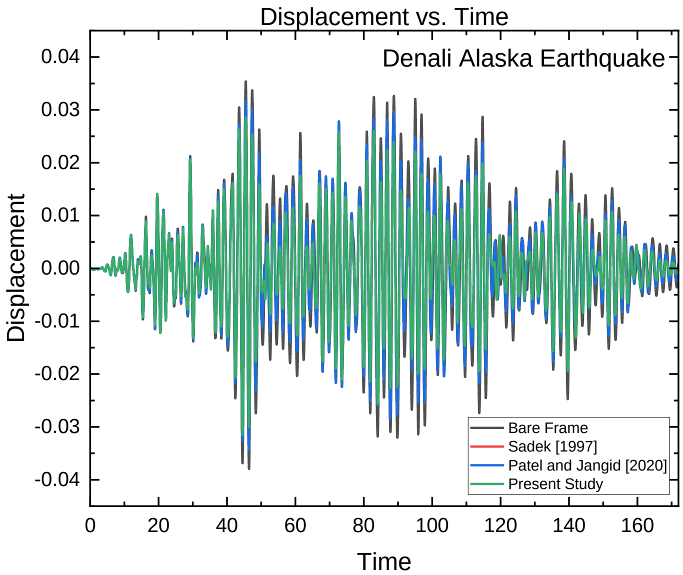

Fig. 2 Displacement response under Denali Alaska Earthquake

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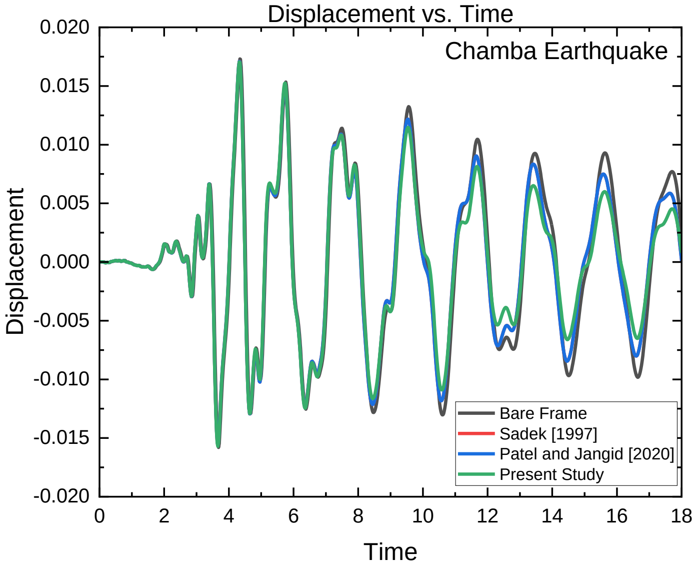

Fig. 3 Displacement response under Chamba Earthquake

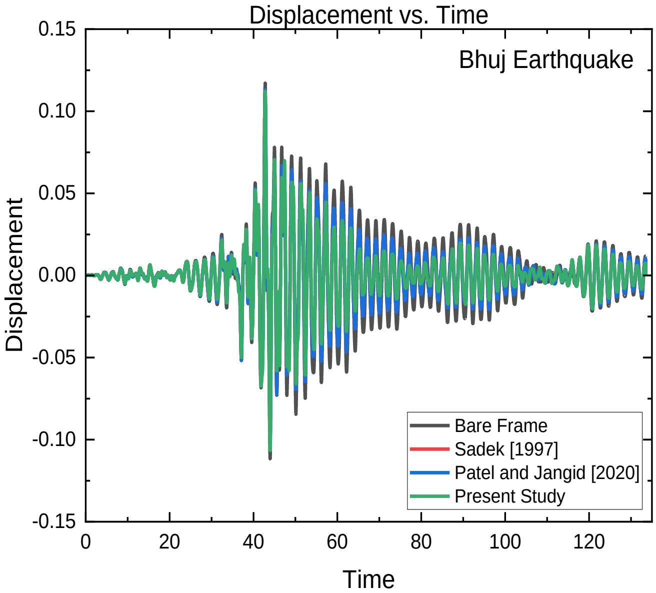

Fig. 4 Displacement response under Bhuj Earthquake

TABLE II COMPARISON OF DISPLACEMENT AT TOP STOREY

Earthquake	Present Study	Bare Frame	Sadek et al (1997)	Patel and Jangid (2020)
Denali Alaska	28.5847	35.3643	31.7525	31.7554
% Reduction in Displacement response of present study		19.17	9.98	9.98
Chamba	17.0442	17.3095	17.0952	17.0954
% Reduction in Displacement response of present study		1.53	0.30	0.30
Bhuj	111.9378	116.9829	113.1031	113.1079
% Reduction in Displacement response of present study		4.31	1.03	1.03

Table 2 shows peak displacement response at 10th storey under various earthquake and gives the % reduction in displacement values for present study containing CID which is compared with other studies.

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It can be observed that for Denali Alaska, Chamba and Bhuj earthquake present study gives 19.17%, 1.53% and 4.31% reduction in displacement value when compared with Bare frame. Reduction in response is also compared with other studies and it is found that maximum reduction is seen from the present study.

IV. CONCLUSION

The Clutching Inerter Damper (C.I.D.) is a reliable tool that is useful in structural engineering as it showed a good amount of reduction in displacement response under various earthquake and also gave higher % reduction when compared with other studies. Thus, it can be said that it is a unique device that can be used as a vibration-controlling tool to safeguard tall buildings during earthquakes. The current study explains the working mechanism of this system and the evaluations included reflect the system's current state, and it is clear from them that more research needs to be done on this mechanism to optimize its design and performance because CID has inherited non-linear characteristics. Therefore, the effectiveness of CID are still to be researched and more investigations are needed to carry out so that their potential applications can be expanded.

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