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A Review of a Few Aspects and Developments in Passive Structural Control Systems

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Abstract
This paper contains a literature review on a few aspects and developments in the field of Passive Systems for Structural Control of Multi-storeyed, High-rise & Tall Buildings with respect to earthquake and wind induced vibrations. Multiple types of passive control structural systems available for Multi-storeyed, High-rise & Tall Buildings have been reviewed as Study of a few of passive control structural systems has been undertaken. Passive Control Systems for Multi-storeyed, High-rise & Tall Buildings for earthquake and wind induced vibrations from different perspectives is the focus. Important research conclusions and future scope of research in this area are discussed.

Keywords: **Passive Control, Dampers, Seismic, Wind, Multi-storeyed Buildings, High-rise Buildings, Tall Buildings**

INTRODUCTION

The wind-induced & seismic vibrations can lead to user discomfort, as well as damage to both structural and non-structural elements. Passive control systems help in vibration control for wind as well as earthquake forces induced motion by providing auxiliary damping. Passive systems used for structural control do not require external energy and have fixed properties. Passive control systems do not require sensors or actuators.

LITERATURE REVIEW

Montgomery et al. (2021) [1] studied Applications of Solid Viscoelastic Coupling Dampers (VCDs) in Wind & Earthquake Sensitive Tall Buildings. Solid Viscoelastic Coupling Dampers provide distributed damping and improve the performance of tall buildings to dynamic loading of wind and seismic induced vibrations. They are provided in between and in place of structural members and do not occupy the architectural space. Viscoelastic Dampers are placed in braces as well as in wall panel. They can be placed in between Reinforced Concrete coupled structural walls as coupling beams and in Outriggers. Case studies of the 66 storied Toronto building, 4 towered Manila building and a 630-meter-tall building in Southeast Asia were done.

Solid Viscoelastic Coupling Dampers consist of multilayered viscoelastic material sandwiched between steel plates and connected by anchoring into the vertical structural members. Solid Viscoelastic Coupling Dampers undergo shear deformations due to the lateral forces like wind and earthquake which cause rotation of vertical structural members deforming axially. As a result of this shear the Solid Viscoelastic Coupling Dampers dynamically react to the velocity dependent force component by damping building viscously as well as to the displacement component with elastic restoring force forming couple for the connected elements.

Full scale tests were done for VCDs in various configurations like in shear and uniaxial. Uniaxial Full scale VCD tested at University of Toronto showed same backbone viscoelastic hysteresis for displacements through damper of range 0.003 mm to 9 mm. VCD tested in shear & harmonic test setup showed clear Viscoelastic response. Testing was also done by simulating Tohoku (M9.0) 2011 ground motion scaled beyond target MCE.

In 66 storied Yonge College residential tower in Toronto 42 VCDs were used on 21 floors between RC Coupled shear walls. Wind tunnel time-histories like that of 1 in 10-year storm was used and applied to ETABS model and modelling of VCDs was done as non-linear links. VCDs reduced story drift and peak horizontal acceleration.

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In 4 tower tall buildings (42, 44, 48 & 51 storey) having 5 storey retail development in SE Asia, VCDs were used. The challenge was to limit wind drifts which as per conventional design were 20% to 80% above prescribed limits. VCDs were placed between RC flag walls & columns. Modelling of Dampers for Wind & SLE was done in ETABS and for MCE in Perform-3D. For MCE connecting steel elements were designed as structural fuse.

In 630 m Mega-Tall Building in SE Asia for better seismic performance design VCDs were used. VCDs were put in Outriggers in place of 60% of diagonal RC coupling beams for entire height in core. 4 VCDs were placed at each Outrigger. Modelling of VCDs for Wind & SLE was done in ETABS & for MCE in Perform-3D.

Corresponding to MCE_R, DE and SLE different design response spectra were taken. Seven scaled MCE time-histories were taken. Comparison with respect to conventional building design Peak Response parameters with that of design done using VCDs for median response was done. Addition of VCDs reduces inter-story drift ratios & floor accelerations for entire building height. Reduction of inter-story drifts in comparison with conventional building for various ground motion for SLE is 25%, DE 23% & MCE_R 15% when design uses VCDs & peak floor accelerations reduce up to 44% for SLE, 31% for DE & 24% for MCE_R.

SP3 2016 Program was used for estimating downtime & intensity-based financial loss for both conventional & VCD designed buildings. VCDs reduce the cost of repairs by 78% for SLE, 35% for DE, & 30% for MCE_R. Direct repairs cost less than the long downtime loss. VCD designed buildings have less downtimes for earthquake hazards & time required for functional recovery reduces by 100% for SLE, 62% for DE, & 46% for MCE_R.

VCDs can be used for wind and seismic hazard reduction and increasing damping by coupling beams and in outrigger systems. They require minimum maintenance and help maximize revenue. Tuning and monitoring is not much required. They have better performance for wind and seismic hazards with respect to other conventional systems. There is damage delay in structural and non-structural members. The 630 m megatall building structure was estimated to cost less by $20 Million (including VCDs cost). Estimated saving in steel was of 3000 tonnes, reinforcement of 500 tonnes & concrete of 15,000 m^3. The reduction in thickness of foundation slab was by 2 meters. Construction time reduction was estimated to be 6 months. Construction complexity was also reduced.

Ardila et al. (2023) [2] studied Seismic and Wind Performance of Tall Reinforced Concrete Buildings in Vancouver with Outrigger Viscoelastic Coupling Dampers (VCDs). VCDs provide supplemental damping through VEM embedded with Steel plates and anchored into the reinforced concrete structural elements. Shearing of VEM provides supplemental damping and decreases the wind and earthquake loading. It is implemented in RC Core Wall structures and outriggers coupling concrete cores to external columns in many world regions.

Using VCDs was beneficial in 47 storied tall building in downtown Vancouver, reducing lateral wind loads and acceleration. Number of floors were added to the Benchmark building to study the effect of additional VCDs on other floors that whether they are impacting the original structural design configuration.

VCDs are placed in coupling structural elements in tall buildings, such as lintel beams & outriggers without compromising architectural space. Outriggers add stiffness & stability in combination with VCDs that increase damping. VE Damper is made of VEM placed between steel plates and anchored into vertical structural elements. VE Dampers give elastic hysteresis response for low frequency shaking and viscoelastic-plastic one for maximum level events. VCD elements acting as structural fuses can be replaced quickly after damage during maximum level events.

Building CW47 has 47 storeys, is 141 m high, plan size is 25 m x 31 m. Lateral load resisting system in y direction is of ductile shear RC cantilever walls and in x direction of coupled shear walls. Surrounding concrete core are squat columns mostly for gravity loads. It has 8" post-tensioned concrete slabs. Concrete strength is 70 MPa at base to 50 MPa at upper levels. Building CW47 earthquake drifts complied to code limit and design forces for wind and earthquake viz. for base shear and base moments for 1 in 50-year wind & 1 in 2500-year earthquake were taken.

Height of the building was increased till it no longer met design requirements by adding floor levels in small increments while evaluating wind maximum roof accelerations and inter-storey drifts and maximum wind service level limit state (SLS). VCD outriggers were added above 57 stories to comply with NBCC code requirements for tall building drift of 0.2% & 18 milli-g roof acceleration.

Two CW57 (+10 storeys) & CW65 (+18 storeys) tall buildings were selected. CW57 & CW65 were modelled in ETABS. Outriggers & VCDs were provided at top roof and maintenance levels with 3 VCDs per Outrigger flag wall. Generalized Maxwell Model consisting of springs in series & dashpots able to get VEM frequency dependency was used for Damper modelling for 25°C temperature. DBE experiments show numerical capability of this GMM model to capture multifrequency building response.

In ETABS free vibration analysis for 2 modes was done to get damping provided by each outrigger schemes. Hat Outrigger & Two Outrigger schemes had better roof accelerations & inter-story drifts than bare structure due to additional damping & stiffness. For CW57 roof acceleration reduced from 19.65 milli-g for Hat and Two Outrigger configurations & fundamental period reduced from 6.87 s to 6.02 s. For CW65 roof acceleration reduced from 28.45 milli-g for Hat Outrigger to 17.12 milli-g & for Two Outrigger to 13.33 milli-g.

For CW57 & CW65 code drift limits are not complied for bare building. 0.2% SLS drift limit is complied by using Hat or Two Outrigger configurations for CW57 & CW65. ULS wind forces of these structures were above capacity of baseline CW47 building but complied when designed for Hat Outrigger for CW57 or Two Outrigger schemes for CW57 & CW65.

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Using VCDs was beneficial in CW57 & CW65 buildings. Building height increase without changing the lateral load resisting system was studied by providing additional damping by VCDs. VCDs were installed at the roof and maintenance levels and integrated seamlessly with other structural elements. Single outrigger level with a total of 24 VCDs can increase the height of the baseline building by 10 stories, while adding a secondary outrigger level at mid-height with 24 additional VCDs can lead to an increase in height of 18 stories without modifying the structure. Tall towers met code requirements, saved sellable architectural space, and did not create abrupt stiffness changes. Further improvements are possible for construction time reduction, reducing downtime & repair after earthquake, and to improve resilience.

Barkhordari et al. (2020) [3] did a study for Ranking Passive Seismic Control Systems by Their Effectiveness in Reducing Responses of High-Rise Buildings with Concrete Shear Walls Using Multiple-Criteria Decision Making. Dual system of steel moment resisting frames & RC shear walls are used for high-rise buildings. Effectiveness of TMD, Viscous damper, friction damper, & lead core rubber bearing for damage control & seismic response of high-rise structures with shear walls were investigated. Five buildings (10, 15, 20, 25, and 30-story) with passive seismic control systems were analyzed in OpenSees using 50 seismic records. Structural responses viz. acceleration, drift, displacement, velocity, and base shear were taken as criteria. Criteria were made non-dimensional by defining measure for relationship between inputs (ground motions) and outputs (structural responses). For problem of selecting more efficient energy dissipation systems there is a need for better solution. Hence Multi Criterion Decision Making (MCDM) was studied and used to rank passive seismic control systems and to select the best one.

Five buildings (10, 15, 20, 25, and 30-story) having dual lateral force resisting system of steel frame-concrete shear walls with passive seismic control systems were studied. Buildings have 5 bays each of 4 m width & 4 m story height. Design DL is 5.5 kN/m^2 & LL is 2 kN/m^2. Compressive strength of concrete was taken as 40 MPa for walls. Yield stresses for longitudinal & transverse reinforcements were taken as 470 MPa & 430 MPa respectively. Steel beams & columns were taken as having yield strength of 350 MPa. Structural member Rayleigh damping was taken as 2%. Leaning Column for gravity framing was taken and linked to main structure. Building site had design parameters of seismic design category D, Risk category I, Soil classification D & Strouhal number for different geometric cases S_s (g) = 1.5 and S_1 (g) = 0.6.

Passive control systems with different specifications like different viscosity coefficient for nonlinear viscous dampers, different slip load for friction dampers, various modal periods for all and other parameters for tuned mass dampers and lead rubber isolation bearings were modelled in OpenSees.

Structural responses were affected by earthquakes of different frequencies. 50 seismic records were taken for the study. 18 near-field earthquake records of minimum magnitude 6 & distance from fault less than 15 km were selected from PEER database. Other earthquake records were of far-field type. Seismic records were scaled in PEER Ground Motion Database by linear scale factor to meet target spectrum of period range 0.2T to 1.5T in mode 1 vibration. Average value of 5% damped response spectra was not less than ASCE design spectrum. Responses of all building to all the different selected Ground motions were studied.

Randomly changing ground motion records with different frequencies do not correlate similarly with scale factor & maximum drift. Also, the effects of higher modes are important for high-rise structures. Hence measures to correlate scale factor & criteria were established. Decision matrix was formed first based on measures & simulations.

In the second step the decision matrix was normalized. The column specific normalization for each criterion was done. In the normalized decision matrix, all criteria were made positive after normalization.

In third step by using decision matrix normalized for m number of alternatives and n number of criteria and through entropy method the weights of various criteria were determined.

Lastly, the Decision-Making Model was selected as TOPSIS in which the criteria need to be at a minimum distance from the positive ideal solution & at maximum from negative ideal solution. For this weighted normalized decision matrix was formed & positive & negative ideal alternatives determined. Positive ideal criterion is best alternative in each column & negative ideal criterion is worst alternative in each column. Subsequently distances from positive & negative ideal alternatives are calculated and relative distance to positive ideal alternative determined. The parameter remains in the 0-1 range. Higher value is considered better.

High-rise buildings with dual steel frame-concrete shear wall system and viscous dampers, friction dampers, TMD, and lead-rubber bearings were checked for structural control and seismic response reduction. Five buildings of 10, 15, 20, 25, & 30 storeys were reinforced with above-mentioned passive control systems and subjected to 50 seismic records. Structural responses of acceleration, drift, velocity, displacement & base shear were taken as criteria, and quantitative indicators were established for relation between inputs (ground motion) and outputs (responses). The TOPSIS method for MCDM was used for finding best alternative of energy dissipation systems for reinforcement and shear wall damage and control. Friction dampers showed the highest score with other dampers coming second based on different stories. For 20 & 30 storeys TMD was second and third. Structural parameters like time-period and their correlation with modes, velocity & vibration frequency affect the building response. Hence, for such complexity using MCDM is advisable.

Rasool et al. (2024) [4] undertook the study of Enhancing Seismic Resilience: Evaluating Buildings with Passive Energy Dissipation Strategies. Hysteretic, friction, viscous, and viscoelastic dampers were studied for building response in ETABS. The effect of different dampers along with configurations on three prototype concrete buildings (3, 5, and 10-storey) was studied by performing a time history analysis. Response of buildings was observed for storey drifts, base shear, and displacement without using dampers, while gradually increasing the damping ratio from 0 to 40%. Then, the response of buildings was evaluated in terms of

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displacements and base shear using various types of dampers with different configurations. Results showed that the effectiveness of viscous and viscoelastic dampers is higher for 3 and 5-storey buildings, while friction and hysteresis dampers are more suitable for 10-storey buildings.
For the buildings the Compressive Strength of Concrete was 21 MPa. Buildings were modelled in ETABS. The height of the 1st floor was 4.57 m, and all other floors had height 3.65 m. Buildings were originally designed for moderate seismic zone but were checked for seismic performance of buildings and passive control devices by using seismic records of high seismic zone. Both gravity loads (DL & LL) & dynamic loading using El Centro earthquake (1940) time history East-West component were applied.
Four types of dampers, viz. hysteretic, friction, viscous & viscoelastic were placed in the central bay of the building. Three types of damping distribution variations were taken viz. uniform (U), reverse triangular (R), & triangular (T).
For uniform distribution damper properties remained the same throughout all floors. For triangular & reverse triangular distributions the top & bottom dampers were assigned 1/4th damping respectively & intermediate values were linearly interpolated. DP is the Damper Parameter for friction or yield force or damping coefficient.
After increasing damping from 0% to 40% for the buildings the response was noted. Free Vibration Analysis & Time history analysis were used for studying the behaviour of buildings. Assessment of response was done by parameters of Storey drift and Base shear. Maximum Storey Drift decreased as damping increased from 0% to 40%. The decrease in Base shear was comparatively less with increase in damping from 0% to 40%.
Displacement reduced for 10 Storey Building by Hysteretic Dampers was 38.36% (U), 22.95% (T), & 32.20% (R), by Friction Dampers was 44% (U), 28% (T), & 38.3% (R), by Viscous Dampers was 80.95% (U), 71.8% (T), & 78.45% (R) and by Viscoelastic Dampers was 81.59% (U), 70.13% (T), & 78.51% (R).
Base Shear reduced for 10 Storey Building by Hysteretic Dampers was 42.33% (U), 28.91% (T), & 36.61% (R), by Friction Dampers was 33.46% (U), 18.23% (T), & 32.58% (R), by Viscous Dampers was 48.69% (U), 53.45% (T), & 48.55% (R), and by Viscoelastic Dampers was 56.45% (U), 57.29% (T), & 55.72% (R).
Different passive control devices viz. hysteretic, friction, viscous, and viscoelastic dampers were investigated for their response to structure using ETABS for 3 buildings with similar structural configuration having 3, 5 and 10 storeys. Different dampers configuration were used and time history analysis done using El Centro earthquake. Building response was observed for storey drifts, base shear, displacements without dampers & increasing damping ratio from 0 to 40%. Building response to dampers was observed for base shear and displacement. Viscoelastic and viscous dampers performed better for 3 storied building & the same can be used for 5 storied buildings. Friction dampers performed better for 10 storied building. Choice of distribution pattern for damping plays an important role for reducing base shear and controlling displacement.

Friis et al. (2021) [5] did a study on Two-level friction damping and its application for passive multi-functional vibration control of high-rise buildings. High-rise buildings are built taller and slender and provided with distributed passive damping devices for supplemental damping. Friction dampers have relatively low cost, high efficiency & reliability and so are popular. Conventional friction damper has limitations and can only mitigate single deformation shape at single vibration amplitude. Passive two-level friction damper is studied to address the shortcomings of conventional friction damper. Study for seismic and wind loading or vibrations is done. Two level friction damper is up to certain limit able to address the limitations of the one-level friction damper with respect to seismic and wind vibration application.
The two-level Friction Damper is made up of two conventional one-level friction dampers placed in series and having different slip forces with movement limited for the lowest slip force. This type of damping device can be customized for meeting different passive control performance objectives in various configurations by incorporating changes in elements of already market available friction dampers. Comparison of performance gained over the one-level friction damper by implementation of the two-level friction damper and of the two-level friction damper to the one-level friction damper to mitigate both wind and earthquake induced vibrations in high-rise building is done. Two-level friction damper can be placed throughout the structure at locations having high deformation and structurally integrated with other structural elements of the lateral load resisting system like between shear walls or in bracing.
Conventional friction damper is placed between points having high deformations during vibrations like between the ground and the roof of a one-story and one-bay frame. When displacement is small the friction damper stays in stick state and when deformation increases it slides as force on damper is greater than slip force. Similarly in two-level friction damper connected in series the displacement of first friction damper is limited and when that displacement is reached then the friction damper comes back to stick state which requires higher force to exceed slip force for the 2nd level friction damper opening up possibility of having two different friction forces for multi-function vibration control.
First the effects of two-level friction damper parameters on dynamic properties and performance were studied for a simplified system. Four cases were taken into consideration. The linear parameters of m, c and k remained the same for all cases. For cases 1, 2 & 3 – stiffness of damper & slip force for level 1 were same and slip force for level 2 was increased from case 1 to 3. The 4th case is like 2nd case except that the damper stiffness varies. Simulations were done for time step of 0.01 sec & duration 1100 sec.
2-level & 1-level friction damper simulations were compared. 100 Simulations to quantify STD defined for 50-65 data-points for equivalent linear modal parameters & response reduction variation were carried out. For 2-level friction damper for equivalent damping ratio 2 peaks at varying distances were noticed for various excitation magnitudes. Variation of response reduction e.g. displacement reduction for various excitation was also analyzed. These depend on damper stiffness & vibration mitigation need.

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Commonwealth Advisory Aeronautical Research Council (CAARC) building of 180 m height, plan dimensions 30 m x 45 m with sharp corners, was used for study, simulations & wind tunnel testing. Building has 18 DOFs, lumped mass (160 kg/m³) decreasing linearly with height & stiffness also reducing with height. The first 3 modes have damping ratio of 1.25%, 1.75%, & 2.25% and other 15 modes have damping ratio of 1.7√2.

A 1:400 scale acrylic wind tunnel model with replica of city center of Copenhagen was made. As per EN 1991-1-4 parameters wind flow was simulated. 110 pressure taps were placed in front while the others at back amounting to a total of 224. For 50-year, 27 m/s 10 minute basic wind speed the characteristic wind speed was taken and changed to 29.7 m/s for 10 year to be applied at 180 m top. 19 independent 10-minute wind load time history events for full scale were taken. Mean load distribution was converted to loading forces. For different storm events at various DOFs power spectra were calculated for 19 x 10-minute time histories.

For earthquake events moderate to high seismicity area was considered with Magnitude M_w higher than 6, & mostly epicentral distance greater than 20 km. Seven earthquake records were selected & scaled to have average spectrum exceeding 90% of target spectrum between 20% to 200% of buildings fundamental period which was 3.85 s. Target spectrum from Eurocode EN 1998-1 parameters was for surface-wave earthquake magnitude higher than 5.5, importance factor = 1, PGA on rock formations = 0.25 g, damping ratio 1.25% & site class C.

Simulation of four Setups of building models were compared: (1) without dampers, (2) 1-level friction damper optimized for earthquake loading, (3) 1-level friction damper optimized for Wind loading, & (4) 2-level friction damper optimized for both mitigating earthquake & Wind for 19 events of wind excitation & 7 earthquake ground motions.

Compared to no damper setup, friction damper setups of 1-L WL, & 2-L on average reduced the STD of acceleration response in DOF 10 to 19 by up to 70% but the 1-L EQ could reduce it up to about 35% since the damping is not triggered as slip force is optimized higher for EQ loading. For earthquake motions all 1-L WL, 1-L EQ & 2-L friction damper setups reduced interDOF drift & acceleration standard deviation, but the 1-L EQ performed best followed by 2-L. Optimal performance of friction damper increased response amplitude range when employing two-level friction damper in comparison to one level friction damper. Thus, two-level friction damper was able to successfully reduce accelerations during wind events and reduce interstorey drifts and accelerations during earthquakes while the one-level friction damper could only satisfy one vibration mitigation objective and then fail on the other. Complexity of friction damper design is increased compared to conventional one-level friction damper.

Hejazi et al. (2024) [6] undertook the study of Seismic performance of structure equipped with a new rubber bracing damper system. Vibration dissipation devices such as viscous dampers are used widely nowadays. One drawback of viscous dampers is high maintenance due to oil leakage. Rubber Bracing Damper is proposed as an alternative with high damping rubber material for diagonal bracing members. RBD design and finite element model analysis has been done and prototype tested. Three story Finite Element Model analyzed for RBD. Results indicate that RBD device leads to a reduction in the occurrence of plastic hinges and lateral displacements of the structure.

RBD is suitable for structures exposed to extreme dynamic loads for energy dissipation. Finite Element model showed promising performance for incremental displacements. The thickness of rubber influences resulting damping. Experimental results corroborate finite element analysis. RBD devices can reduce displacements up to 66.97%. Axial forces in the main columns increase and shear and moment decrease. RBD protects structure under severe vibrations and dissipation movement.

Farzam et al. (2022) [7] studied regarding the Passive Control of Vibrations of High-Rise Structures by using Tuned Liquid Damper under the Wind and Earthquake Excitations. Tuned Liquid Damper was used for controlling vibration of structure under dynamic lateral loads. High-rise structure was modelled in ANSYS for far and near-field earthquake analysis and interaction of wind forces. Tuned Liquid Damper was used to reduce response to far (El-Centro 1940 & Hachinohe 1968) and near-field earthquakes (Northridge 1994 and Kobe 1995), and wind. Responses such as displacement, acceleration, velocity, pressure, streamlines around structure were analyzed and aerodynamic behaviour was investigated for wind. Tuned Liquid Damper could reduce the maximum displacement of the structure up to 16% under far-field records, 0.5% under near-field records for earthquake, and up to 13% under the wind.

The structural responses under wind, far and near-field earthquakes have a reduction. Reduction percentages of structural responses for maximum displacement, velocity, and acceleration are 22%, 11%, and 3% under El-Centro, and 10%, 12%, and 0% under Hachinohe. Reduction of maximum displacement, velocity, and acceleration for the Kobe earthquake was equal to 0%, 5%, and 8%, and for the Northridge earthquake was 1%, 1%, and 3%. Maximum displacement, velocity, and acceleration under wind vibration are 13%, 6%, and 2%. Average response reduction for maximum displacement, velocity, and acceleration at different heights of the structure is 9%, 5%, and 3%. TLD is better performing in reducing displacement than velocity and acceleration.

CONCLUSION

Passive structural control devices are effective and useful for different parameters in multi-storeyed, high-rise and tall buildings.

VCDs can be used in coupling beams and outrigger systems for better wind and seismic performance.

For the wind-critical tall building in Toronto, VCDs replaced several RC core beams increasing inherent damping for wind and maximized revenue and eliminated need for long term maintenance, tuning or monitoring with a tuned system.

For wind- and seismic-performance based design of 4-tower building, the VCDs were used in RC flag-wall configuration for better wind and seismic performance as being comparatively better than other options.

VCDs increased seismic performance of 630 m Mega-tall building in SE Asia compared to conventional structure and delayed damage in structure and non-structural components for all hazard levels. VCDs reduced cost and construction time by $20M and 6 months respectively.

The height of CW47 tall building in Vancouver could be increased without changing the lateral load resisting system using 24 VCDs up to 10 stories and by using 48 VCDs up to 18 stories in outrigger levels.

Investigation done into control and reduction of seismic responses of high-rise buildings with concrete shear walls using viscous dampers, friction dampers, TMD, and lead-rubber isolation bearings for five buildings with 10, 15, 20, 25, and 30 stories showed that friction damper had highest score using TOPSIS MCDM.

Study done for hysteretic, friction, viscous, and viscoelastic dampers for three reinforced concrete buildings (3, 5, and 10-storey buildings) showed that for 3 & 5 storey buildings viscoelastic and viscous dampers were most effective while for 10 storey building friction dampers performed better. For base shear reverse triangular distribution pattern was effective and for displacement the uniform distribution pattern proved effective.

Two-level friction damper successfully reduced accelerations during wind events and reduced interstory drifts and accelerations during earthquakes while one-level friction damper could satisfy only one vibration mitigation objective. Two-level friction damper design is more complex than one-level friction damper and so for design and damper setup there is need to be more careful.

Further a new Rubber Bracing Damper (RBD) developed based on viscoelastic behaviour of high damping natural rubber showed that reduction in displacement up to 66.67% is possible.

The TLD leads to average response reduction for maximum displacement, velocity, and acceleration at different heights of the 180 m structure by 9%, 5%, and 3%, respectively and thus performs better for displacement reduction than velocity and acceleration. Structural responses reduction is both for near and far field earthquakes and wind.

FUTURE SCOPE

By using VCDs further study is possible to check for speedy construction, less downtime and repair after major earthquake, and better resilience.

MCDM can be studied further for complex high-rise buildings configurations with higher stories.

Other different types of distribution patterns and configurations can be studied for real life high-rise and tall buildings for hysteretic, friction, viscous, and viscoelastic dampers.

Application of Two-level friction damper and new Rubber Bracing Damper can be studied in future for more configurations in more real-life tall buildings.

Use of TLD in different types of real life symmetrical and asymmetrical tall buildings such as with shear wall, outrigger and other such configurations can be studied in the future.

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