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Seismic Behaviour of Multi-Storied Building by Using Tuned Mass Damper and Base Isolation: A Review

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ABSTRACT
Earthquakes create vibrations on the ground that are translated into dynamic loads which cause the ground and anything attached to it to vibrate in a complex manner and cause damage to buildings and other structures. Civil engineering is continuously improving ways to cope with this inherent phenomenon. Conventional strategies of strengthening the system consume more materials and energy. Moreover, higher masses lead to higher seismic forces. Alternative strategies such as passive control systems are found to be effective in reducing the seismic and other dynamic effects on civil engineering structures. A Tuned mass damper (TMD) is a device consisting of a mass, and spring that is attached to a structure in order to reduce the dynamic response of the structure. Tuned Mass Damper (TMD) has been found to be most effective for controlling the structural responses for harmonic and wind excitations. Base isolation is nowadays widely considered as an effective strategy to protect structures subject to seismic excitations. The performance of linear base isolation system along with tuned mass damper to mitigate seismic response of structures is investigated.
Keywords: Tuned mass damper (TMD), Base Isolation (BI), Multistoried building, and Seismic behaviour.

I. INTRODUCTION

Earthquakes are occasional forces on structures that may occur during the lifetime of buildings. As seismic waves move through the ground, they create a series of vibrations. These movements are translated into dynamic loads or inertial forces that cause the ground and anything attached to it to vibrate in a complex manner. These inertial forces cause damage to buildings and other structures. In regions where seismicity is insignificant, the conventional design approach aims at the design of structural members in such a way that static (gravitational) and dynamic loads (such as wind load) are withstood elastically. However, if this design approach was to be followed in cases where seismic excitation had to be taken into account, this might lead to energy inefficient and economically unacceptable design solutions. Moreover, this strategy leads to higher masses and hence higher seismic forces. Earthquake loads are to be carefully modeled so as to assess the real behaviour of structure with a clear understanding that damage is expected but it should be regulated. A tuned mass damper (TMD) is a device consisting of a mass, a spring, and a damper that is attached to a structure in order to reduce the dynamic response of the structure. The frequency of the damper is tuned to a particular structural frequency so that when that frequency is excited, the damper will resonate out of phase with the structural motion. Energy is dissipated by the damper inertia force acting on the structure. Base isolation (BI) is a well-established application of the passive control approach. A building mounted on a material with low lateral stiffness, such as rubber, achieves a flexible base. During the earthquake, the flexible base is able to filter out high frequencies from the ground motion and to prevent the building from being damaged or collapsing.

II. EARLIER RESEARCH INVESTIGATION

There are many researches have been carried out to know seismic behaviour of flat slab building. This section summarizes some previous studies carried out on flat slab building.

To observe the influence of several parameters like, damping ratio of structures, intensity of earthquake load, mass ratio, and damping ratio of base isolator, on the effectiveness of combined system in comparison with BI system. A numerical study demonstrates that combined system is more effective to mitigating the seismic response of the primary structure compare with only BI system [1].

On the performance evaluation of a few passive control systems such as base isolation systems and tuned mass dampers in the vibration control of a linear multi storied structure under harmonic and earthquake base motions. Base isolators such as Lead Rubber Bearing (LRB) system and Friction Pendulum System (FPS); and, a tuned mass damper (TMD) are designed for a ten storied reinforced concrete building. The building is modelled as 10 degrees of freedom shear building model and Bouc Wen model is used to describe the hysteretic behaviour of base isolators. The performance of LRB system, FPS and TMD are evaluated numerically and compared. The frequency response characteristics of the systems are also studied. From the study Base isolators and TMD are found to be effective in the neighbourhood of the fundamental resonant frequency of the structure [2].

Shear walls and Tuned Mass Dampers are assigned in the structure alternatively. Various arrangements of Tuned Mass Dampers in this 30 storey building are studied and the best arrangement among these is applied in a 50 storey building to study the effectiveness in controlling vibration. And also the characteristic of this 50 storey building is studied by applying Time History Analysis of El-Centro earthquake. The application of TMDs in 50 storey building also proved to be safe. The Base shear, Storey displacements, joint accelerations and frequency of the structure are very less [3].

The effectiveness of TMD in controlling the seismic response of structures and the influence of various ground motion parameters on the seismic effectiveness of TMD have been investigated. The structure considered is an idealized single-degree-of-freedom (SDOF) structure characterized by its natural period of vibration and damping ratio. Various structures subjected to different actual recorded earthquake ground motions and artificially generated ground motions are considered. It is observed that TMD is effective in controlling earthquake response of lightly damped structures, both for actual recorded and artificially generated earthquake ground motions [4].

A series of geotechnical centrifuge tests was conducted to investigate the effects of TMDs on the response of a multiple storey sway frame structure undergoing dynamic soil structure interaction (SSI). Structural responses were recorded for a wide range of input motion characteristics, damper configurations and soil profiles [5].

The single linear tuned mass dampers problem is treated and it is assumed that earthquake can be represented by a stationary filtered stochastic process. Minimize the maximum of the dimensionless peak of displacement of the protected system with respect to the unprotected system. Moreover, the constrained optimization problem is also analysed, in which a limitation of tuned probability of failure is imposed, where failure is related to threshold crossing probability by the maximum displacement over an admissible value. Examples are given to illustrate the efficiency of the proposed method. The variation of the optimum solution versus structural and input characteristics is analysed for the unconstrained and constrained optimization problems. A sensitivity analysis is carried out, and results are presented useful for the first design of the vibrations control strategy [6].

The optimisation of TMDs is firstly carried out within a range of earthquakes and primary frame structures, in order to achieve the ideal optimum setting for each considered case. Then, the outcomes of the investigation are gathered and analysed all together, to outline general trends and characteristics, towards possible effective design of TMDs in the seismic context. The output of this paper should enrich the current knowledge on this topic towards potential extensive applications of TMDs in the field of earthquake engineering [7].

Base isolation techniques is special emphasis and a brief on other techniques developed world over for mitigating earthquake forces on the structures. The provisions of FEMA 450 for base isolated structures are highlighted. The effects of base isolation on structures located on soft soils and near active faults are given in brief. Simple case study on natural base isolation using naturally available soils is presented. Also, the future areas of research are indicated. This study also seeks to evaluate the effects of additional damping on the seismic response when compared with structures without additional damping for the different ground motions [8].

The comparative performance of three proposed schemes of coupled building control involving Magneto rheological (MR) damper and elastomeric base isolation, named as, Semi active, Hybrid 1 and Hybrid 2. The results of numerical study showed that Hybrid controls are more effective in controlling the response as compared to semi active control. Further, influence of device parameters on control performance has been investigated through a parametric study [9].

The tuned mass damper technique is enhancing the drift, acceleration, and force response of buildings to wind and earthquakes. The response of buildings to wind and earthquakes was observed to be more enhanced by increasing the story-mass ratios and the number of floor utilized as TMDs [10].

The MTMD with the optimal parameters can actually flatten the transfer functions of building responses. Numerical verifications show that the increase of height–base ratio of an irregular building and the decrease of relative stiffness of soil to structure generally amplify both SSI and MTMD detuning effect, especially for a building with highly torsionally coupled effect. With appropriately enlarging the frequency spacing of the optimal MTMDs, the detuning effect can be reduced.

Moreover, the results of numerical investigations also show that the MTMD is more effective than single TMD as the SSI effect is significant [11].

TMDs are beneficial devices in reducing wind-induced vibrations of tall buildings. In particular, they are more effective for the higher soil stiffness. This study will help researchers better understand mechanisms of wind-induced responses for a building with a TMD when SSI is taken into account. It will also improve the understanding of wind-resistant designs for high-rise buildings [12].

A benchmark structure in which the non-linear response of isolation devices (elastomeric and friction pendulum) is explicitly considered has been recently defined. By using this model, they investigate the non-linear behaviour of the benchmark isolated structure when a mass damping system is applied on the isolation layer, in order to study the effectiveness of this strategy in reducing the seismic response of the isolation layer [13].

Analysis of symmetrical moment resistance frame (MRF) 10th,12th,14th,16th,18th, and 21th storey three – dimensional model with tuned mass damper and without tuned mass damper by using software ETABS, moment resistance frames are column and girder plane frames with fixed or semi rigid connections. They can be constructed from concrete, steel or composite material. Moment resistance frames can be sufficient for a building up to 20 storeys. A tuned mass damper (TMD) is placed on its top and through it to study its effects on structural response due to time history analysis with and without the tuned mass damper (TMD) in an ETABS. The result obtained from software analysis of 10th, 12th, 14th, 16th, 18th, and 21th storey building with and without tuned mass damper and from this we have to conclude that for the regular building frame, 5% TMD is found to effectively reduce top storey displacement [14].

The successful implementation of a tuned-mass damping system to reduce the steady-state vibrations of the long span, cantilevered, composite floor system at the Terrace on the Park Building in New York City. The experience with this implementation suggests that tuned mass dampers (TMDs) can be successfully employed to control steady-state vibration problems of other composite floor systems [15].

The BI technique applies an open-loop control law and that TMD uses as closed-loop control law. Seismic performance of combined system are summarised showing numerical response tests of models subject to some recorded seismic excitation in linear and nonlinear range and to stationary Gaussian random processes. Control effectiveness of TMD in reducing seismic vibration of base isolated systems is compared with that produced by adding damping in the isolation layer [16].

The situation of earthquake protective systems used in Turkey, this technique is not yet very common, but a number of research activities are going on in order to investigate the behaviour of the isolated buildings. Civil engineers, architects, constructors and owners have great responsibilities concerning applications of these systems, but especially the users have sanction, therefore widely use of the earthquake protective systems will be provided by the users' awareness [17].

The applicability of an innovative seismic isolation system (called SPI) form perspective views of any further advantages to other existing systems, its effectiveness against various types of earthquakes through energy analysis, and its cost effective performance. For this purpose, results of a multi-purpose experimental model have been examined. Results of a case study for 5, 10 and 20 story moment resistant frame buildings show that utilization of the SPI system is economically comparable with conventional design, while providing the required level of safety [18].

The use of TMD enhances the ability of the structures to store larger amounts of energy inside the TMD that will be released at a later time in the form of damping energy when the response is not at a critical state, thereby increasing the damping energy dissipation while reducing the plastic energy dissipation. This reduction of plastic energy dissipation relates directly to the reduction of damage in the structure [19].

Damping of the structure and absorber installed on top of it is represented by frequency independent one on the base of equivalent visco-elastic model that allows the structure with absorber to be described as a system with non-proportional internal friction. A ground movement is modelled by an actuator that produces vibration with changeable amplitude and frequency. To determine the optimum absorber parameters, an optimization problem, that is a minmax one, was solved by using nonlinear programming technique (the Hooke-Jeves method) [20].

The technique for reducing building response motion is based on extending Den Hartog work from a single degree of freedom to multiple degrees of freedom. Simplified linear mathematical models were excited by 1940 El Centro earthquake and significant motion reduction was achieved using the design technique [21].

The response reduction by using DTMD and the efficiency of DTMD is evaluated from the analytical results it was concurred that although DTMDs are more efficient than single mass TMDs in the range of total mass ratios, they are only slightly more efficient than TMDs in the practical range of mass ratios (0.01-0.05) [22].

A laminated rubber bearing isolator has been designed and the properties of the isolator are obtained. Then the dynamic analysis of the structure has been carried out and the performance of the building with and without isolator is studied. The results can be used in the implementation of a real time structure to improve its seismic performance [23].

Firstly, in order to meet with the objectives of the study, a theoretical four-story plane frame is selected without any passive energy dissipation system. Secondly, the structure is assumed to be base isolated using high damping laminated rubber pads. Thirdly, the viscoelastic dampers are diagonally installed at each floor level of the frame and the seismic analyses are repeated with and without base isolation. In each scenario, the calculations have been carried out using both the equivalent seismic load method and also the linear time history analyses. Linear time history analyses have been based on two different earthquake records, with T1 = 0.13 sec and T2 = 1.43 sec predominant spectral periods. The N-S component of the earthquake ground motion recorded at the Tofaş automobile factory in Bursa, during the August 17, 1999 Kocaeli Earthquake, is taken as a basis. In each case the maximum ground acceleration has been raised to 0.40g. The results for these two different earthquakes, which represent the hard and soft soil conditions, respectively, have been compared by each other [24].

The effectiveness of TMDs on reducing the response of the same structure during different earthquakes, or of different structures during the same earthquake is significantly different; some cases give good performance and some have little or even no effect. This implies that there is a dependency of the attained reduction in response on the characteristics of the ground motion that excites the structure. This response reduction is large for resonant ground motions and diminishes as the dominant frequency of the ground motion gets further away from the structure's natural frequency to which the TMD is tuned. Also, TMDs are of limited effectiveness under pulse-like seismic loading [25].

The optimal parameters of the TMD in Taipei 101 Tower are first determined. Then a finite element model of this high-rise building, equipped with a TMD system, is established. A detailed dynamic analysis is conducted accordingly, to evaluate the behavior of the structure-TMD system. The simulation results obtained are compared with the wind tunnel test data and the recorded field measurements. The accuracy of the established computational frameworks is then verified. Findings of this study demonstrate that the use of the TMD in this building is materially effective in reducing the wind-induced vibrations. However, it is not as effective in mitigating remote seismic vibrations responses [26].

Finite Element Analysis can be effectively used to model dynamic systems and its response, hence possible solutions could also be sought. The adaptability of the current tuned mass absorber system when subjected to varying external frequencies is a new feature of the design [27].

Structures exposed to strong winds are considered. Excitation forces, which are functions of wind velocity fluctuations, are treated as random forces. The spectral density functions of wind velocity fluctuations are assumed as proposed by Davenport. The correlation theory of random vibration is used and the root mean squares of displacements and accelerations are determined. Several remarks, concerning the effectiveness of multiple tuned or mass dampers, are formulated from the results of calculation [28].

Tuned mass damper systems as vibration controller in multistoried building is studied, and study about its analyze the effectiveness of their use in large structures, in order to preserve structural integrity. The idea behind a tuned mass damper is that if a multiple-degree-of-freedom system has a smaller mass attached to it, and the parameters of the smaller mass are tuned precisely, then the oscillation of the system can be reduced by the smaller mass [29].

The effect of superstructure damping, isolation damping, TMD damping, mass ratio, tuning frequency ratio, superstructure time period isolation period on the response of base isolated structure with tuned mass dampers is investigated. The response of base isolated structure with tuned mass dampers is found to be less in comparison to the corresponding response without tuned mass dampers, implying that the TMD is effective in reducing acceleration, forces and displacement in the system. It is also found that the superstructure damping, isolation damping, TMD damping, mass ratio, tuning frequency ratio, superstructure time period and isolation period have considerable influence on the response of a base isolated structure with tuned mass dampers [30].

It is demonstrated that by minor modifications of the spectral density integrals very accurate explicit results can be obtained for the variance of the response to wide band random excitation. It is found that the design can be based on the classic frequency tuning, leading to equal damping ratio for the two modes, and an accurate explic it approximation is found for the optimal damping parameter of the absorber and the resulting damping ratio for the response [31].

A five storey building as a case study has been taken into consideration through simulated analysis for both, with and without base isolation systems. Numerical analyses are applied in order to observe dynamic behaviour of such structures under seismic loads. Brief review of the economy and practical effectiveness of base-isolation systems is reported for completeness [32].

The main advantage of performance based design is the predictable seismic performance with uniform risk. The reliability of this approach may ultimately depends on the development of explisit and quantifiable performance criteria that can be related to the calculated response parameters such as stress, strain, displacement, acceleration [33].

III. CONCLUSIONS

It is very evident that with certain drawbacks,

1) TMD and BI can be successfully used to control vibration of the structure and are very effective tool to protect the structures from various lateral forces, like Wind loads, Seismic effects.
2) Although TMD is more effective in reducing the displacement responses of structures with low damping ratios, it is less effective for structures with high damping ratios.
3) Base isolators are found to be superior in controlling the acceleration response.
4) Current trends in construction industry demands taller and lighter structures, which are also more flexible and having quite low damping value.
5) This increases failure possibilities and also, problems from serviceability point of view.
6) Several techniques are available today to minimize the vibration of the structure, out of which concept of using of TMD and BI is the one among them.

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