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Seismic Response of Open Ground Storey with Metallic Damper A Review

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***Abstract:* In the past it was a common practice to ignore the masonry infill walls in the design of reinforced concrete frame buildings. Many buildings were constructed with open ground storey, resulting in a serious threat when struck by a lateral load like earthquake. Thus the requirement of seismic strengthening of such buildings was felt all over the world. Various types of energy dissipating devices based on wide range of concepts were explored to seismically strengthen the structures. Metallic dampers as an energy dissipating passive device can be effectively used to address such problem. In the present study, the literature review is divided into two parts. In the first part the seismic behavior of the open ground storey buildings, and the mathematical modeling of infill masonry panels are discussed. Whereas the second part reviews the previous work carried out on the metallic dampers.**

I. INTRODUCTION

Reinforced concrete (RC) is the most commonly used construction material used these days, primarily owning to its low cost, easy availability of materials, simpler execution without requirements of any special machineries or labor. Generally, the RC buildings are analyzed and designed such that the moment resisting frame actions are developed in each member. The masonry infill walls are normally considered as non structural elements used to create partitions or to protect the inside of the building and, thus are ignored while analysis and design. Such construction practices are followed in many countries including India. However, under the action of lateral forces like the once due to earthquake and wind, these infill wall panel's stiffness, strength and mass affect the behavior of RC frame building.

At times, due to uneven distribution of mass, strength and stiffness in either plan or in elevation, irregularities are introduced in RC frame buildings. If the masonry walls are not symmetrically placed, then in that case, the eccentricity between centre of mass and centre of rigidity may induce torsional effects causing additional stresses. In recent times it has been a common practice to construct RC buildings with open ground storey i.e. the columns in the ground storey do not have any infill walls between them. This provision generally kept for the purpose of parking, garages, and various recreational purposes introduce a vertical irregularity in the structure.

An open ground storey building is one where columns in the ground storey and both partition walls and columns in the upper storey have two distinct characteristics, namely:

(a) It is relatively flexible in the ground storey, i.e., the relative horizontal displacement it undergoes in the ground storey is much larger than what each of the storey above it does.

(b) It is relatively weak in ground storey, i.e., the total horizontal earthquake force it can carry in the ground storey is significantly smaller than what each of the storey above it can carry.

Thus, there is a requirement of seismic strengthening of such open ground storey RC frame buildings. Various types of energy dissipating devices based on wide range of concepts have been explored in the recent past.

Recently, metallic plate dampers have received increasing attention from earthquake engineering community and their implementation in new building design and retrofitting of existing buildings were cited in several comprehensive review articles by many researchers. The idea of utilizing separate metallic dampers within a structure to absorb a large portion of seismic energy began with theoretical and experimental work of Kelly et al.[1972], and this work was extended by Skinner et al. [1995] and Tyler [1978]. During the ensuing years, considerable programs has been made in the development of metallic devices, most of which are made of mild steel and lead, metallic devices such as flexural plate systems, tensional bars dampers, yield ring dampers and extrusion devices Skinner et al. [1980]. Bergman and Goel [1987] and Whittaker et al. [1989]have studied metallic dampers with the help of experiments. Xia et al. [1992] studied the influence of metallic damper parameters on building seismic response as well as proposed design of supplemental steel damping devices, subsequently, employed in seismic retrofit projects discussed by Martinez-Romero [1993] and Perry et al. [1993]. Tena-Colunga [1997] mathematically modeled metallic dampers. Soong and Dargush [1997] was the first to publish a book on passive energy dissipation systems. Later, another book on seismic design with supplemental energy dissipation devices was again published by Hanson and Soong [2001]. First study in India on passive energy dissipaters was done by Kumar et al. [2003]. Kokil and Shrikhande [2007] proposed an approach to find the optimal placement supplemental dampers in structure systems. Recently, Seyed et al. [2008], studied the behavior and performance of structures installed with metallic dampers Climent [2011] investigated the energy based method for seismic retrofit of existing frames using hysteretic dampers. Pujari and Bakre [2011] evaluated the seismic response of multistoried buildings by optimum placement of X-plate dampers.

II. SEISMIC BEHAVIOR OF OPEN GROUND STOREY BUILDING AND MATHEMATICAL MODELING OF INFILL WALL

Arlekar *et al.*(1997) analyzed the seismic response of four storey RC frame building with open ground storeys using equivalent static analysis and response spectrum analysis to find the resultant forces and displacements. They argued for immediate measures to prevent the haphazard use of soft first storeys in buildings, which are designed without regard to the increased displacement, ductility and force demands in the first storey columns. Some alternate measures involving stiffness balance of the open first storey and the stiffness above, were proposed to reduce the irregularity introduced by the open first storey.

Negroand Verzeletti.(1996) studied the effects of the infills on the global behavior of the structure by performing series of pseudo-dynamic tests on the full-scaled four-storey reinforced concrete frame. The response of structure in three configuration i.e. bare frame, uniform infilled frame and partial infilled frames has been compared. They plotted time history curve and base shear for all three structures and concluded that the presence non-structural masonry infills can change the response of structure to a large extent. Irregularities in the panels were found to result in unacceptably larger damage to the frame as a result of high ductility demands. They also found that masonry infill increases stiffness, strength and energy dissipation capacity.

Al-Chaar (2002) in an attempt to determine the seismic vulnerability of masonry-infilled non-ductile reinforced concrete frames, carried out an experiment to evaluate the behavior of five half scale, single-storey laboratory models with different number of bays. They concluded that the masonry infilled RC frames and more number of bays show higher ultimate strength, residual strength and initial stiffness.

Davis et al.(2004) illustrated the influence of masonry infill on the response of multi-storeyed building under seismic loading by considering two existing buildings in which one building has soft storey while the other is symmetric. The infill was modeled using equivalent strut approach. The buildings were analyzed using linear static method, response spectrum method (linear dynamic method) according to IS 1893 (Part 1): 2002, non-linear static method (pushover analysis) by using the finite element analysis software, SAP 2000. They found that the presence of masonry infill panels modify the structural force distribution significantly, increasing the total storey shear force as the stiffness of the building increases. They described the lateral load resisting mechanism of the masonry infilled frame like a braced frame resisted by a truss mechanism formed by the compression in the masonry infilled panel and tension in the column, in contrast to the bare frame that act primarily as moment resisting frame. They stated that the existing building with open ground storey are deficit and thus require retrofitting.

A. Review on Metallic Dampers

A.T. Colunga [1997] briefed the importance of modeling of energy dissipating devices such as added damping and added stiffness devices. The study proposed method to evaluate the properties for the variation of the cross-section using the flexibility method. The study validated the expressions obtained in the study with the help of direct derivation and numerical integration solutions. The study compared the closed form expressions obtained in the study with elastic stiffness and the strength of the ADAS devices available in the literature. The hysteresis curves obtained in the study were compared with those obtained experimentally from shaking table tests.

M. Fabio *et al.* [2006] designed a six storey reinforced concrete structure for a medium risk seismic region and performed nonlinear seismic analysis of framed structures installed with different types of dampers such as friction, metallic yielding, viscoelastic and viscous dampers. The study reported the effectiveness of metallic yielding devices designed for medium risk region and successively performed when retrofitted for high risk seismic region.

H.N. Li and G. Li [2007] evaluated the performance of “dual function” metallic dampers as these dampers show good energy dissipation behavior along with added structural stiffness. The study investigates the performance of a steel structure equipped with dual function damper experimentally with the help of shake table under selected earthquake excitations. Moreover, finite element program such as ANSYS software was also used to model a building with the selected metallic damper. The study reported that metallic damper improves the performance of building.

Mariella Diaferio [2009] developed an optimal design procedure for an energy dissipation device made of aluminium and steel. The design is developed such that maximum energy is dissipated by the device. The study evaluates the performance of a 3D frame building equipped with damping device and subjected to compatible earthquake ground motions as per Eurocode 8. The optimal response obtained from the characterization tests exhibits a good dissipative behavior of the device, highlighted by a wide enough hysteresis cycle.

Saman Bagheri et al. [2011] discussed the importance of proper selection of design properties of metallic dampers. The study reviewed the parameter such as bracing member stiffness to the damper devise stiffness (B/D) as it governs the distribution of ductility. Two models of 5-story and 10-story steel frame buildings with V-shaped bracings and ADAS dampers under three different earthquakes were analyzed in SAP2000 finite element program. The results showed that in the optimum state a *B*/*D* ratio more than 2 is needed in the upper stories, whereas a ratio less than 2 is needed in the lower stories. However in the previous studies a constant B/D was considered. It was also observed that the story drifts in the optimum state have become remarkably uniform and the maximum shear story drift has been decreased in all models and the behavior of the dampers was also improved after optimization procedure.

R. Vargas and M. Bruneau [2009] reviewed thegeneral design approach studied in past to maintain the main structure in elastic region with minor inelastic deformations and allow damage on structural elements such as structural fuses. The study proposed a new design technique for multi degree of freedom structures equipped with structural fuse based on the parametric studies.

N. N. Pujari and S.V.Bakre [2012] investigated the seismic effectiveness of an XPD for steel buildings. The study varied the sizes of XPD whereas the optimal locations of XPD were fixed. Moreover, the geometrical properties of XPD i.e. height (a), width (b) and thickness (t) was also studied based on the seismic response of building under uni-directional excitation of four components of real earthquake ground motion and peak response quantities were plotted against the geometric properties of the XPD. The study evaluated the damage indices in the form of peak relative displacement, peak absolute acceleration and base shear. In addition, percentage energy dissipated (Ed) by the XPD was also noted. The relative displacement and the absolute acceleration of building were found to be crucial from design point of view of the XPD and the building. It was also observed that the base shear was directly proportional to the forces exerted on the building.

III. CONCLUSIONS

The detailed review of the research work pursued by the various researchers till date is presented. Silent observation emerging from the literature survey is discussed and subsequently, gaps in the literature are cited. Based on this, the significance of the proposed study is underscored.

Following observations made from the literature survey are as follows –

A. There is serious threat to the buildings with open ground storey when struck by a lateral load like earthquake.
B. It is a common practice in densely populated cities of India to provide buildings with open ground storey, which need to strengthen to avoid life and economic loss.
C. The infill-masonry panels can be mathematically modeled as a diagonal strut.
D. Metallic dampers are one of the most economical passive energy dissipating devices.
E. It is possible to model metallic damper using Bouc-Wen model.
F. The non-linear computer packages like SAP2000, ETABS, ANSYS, etc. can be used for modeling metallic dampers using Bouc-Wen model.
G. Use of economical and effective metallic dampers for strengthening open-ground-storey RC building is not studied

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