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A Review on Seismic Performance of Reinforced Masonry Structures

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Abstract: The traditional masonry buildings without any earth quake resisting features had proved to be the most vulnerable to earthquake forces and had suffered maximum damage in past earthquakes. Therefore, it is necessary that realistic stone masonry houses as are being constructed in rural and hilly regions and should be tested dynamically for evaluating various seismic strengthening measures in order to prove their effectiveness. Revolutionary changes in the construction method such as Base isolation, Dampers etc., may not be feasible to adopt in practical masonry construction due to lack of knowledge and increase in cost. But by doing some simple modifications in the traditional masonry construction methods it is possible to make them EQ resistant. It should be easily understood and adopted by the local artisans. Masonry being a brittle material will undergo sudden failure under lateral loads causing large amount of damage to human life and property. Therefore to make the masonry ductile it has to be reinforced with a material that gives warning before failure. The present paper makes a review on seismic performance of reinforced masonry structures.

Keywords: *Masonry structures, Shake table testing, Seismic Performance, brittle material, Reinforced concrete moment-resisting Frame, Ductile*

1. Introduction

Masonry is generally a highly durable form of construction. Masonry is a common technique used for the construction of buildings, retaining walls and buildings. In general, masonry may be defined as a structural assemblage of masonry units with a binding material known as mortar. Stones, bricks and concrete blocks are the most common types of masonry units [9]. Since stones and bricks are used in the masonry construction, they increase the thermal mass of the building thus protecting the building from fire. So masonry is called as non-combustive product. Masonry structures can withstand the normal wear and tear for centuries [3]. Masonry being a brittle material will undergo sudden failure under lateral loads causing large amount of damage to human life and property. Therefore to make the masonry ductile it has to be reinforced with a material that gives warning before failure.

2. Objective of the Study

The main objective is to study the various materials used as reinforcement and their seismic performance in masonry structures.

3. Review of the Literature

I. Lakshmi Keshav et.al (2012) [1]

Conducted shake table tests on two reduced models that represent normal single room building constructed by Compressed Stabilized Earth Block (CSEB) from locally available soil. One model was constructed with earthquake resisting features (EQRF) having sill band, lintel band and vertical bands to control the building vibration (model S2) and another one was without Earthquake Resisting Features (model S1).

Acceleration, Velocity, and displacement at roof level for CSEB-solid block model without EQRF are 1.056 times more than that of CSEB-solid block model with EQRF.

Many of the damages observed in Model S1 during testing were similar to the actual earthquake damage. Separation of Brick layer (failure) occurred at CSEB solid block model without EQRF.

II. Thakkar K Shashi et. al. (2000) [2]

Constructed full scale models of one storied stone masonry houses with two different combinations of strengthening measures and have been tested under progressively increasing intensity of shock on shock table facility. After the damage of models during shock table testing, these are retrofitted by existing techniques prescribed in the IS code and tested again.

But the cracking in the piers of walls still occur. There is a good agreement in the region of cracking in the shock table tested model with that determined by finite element analysis.

The injection of cementitous grout on localized damaged areas can restore the original strength and stiffness. The introduction of external horizontal tie bar to a wall can increase the strength and ductility of the model. Moreover, welded wire mesh in damaged region not only increases the lateral resistance of the wall but also prevents shear and flexure failures of the models.

III. Y. Belmouden et. al. (2009) [3]

Presented a novel equivalent planar-frame model with openings. The model deals with seismic analysis using the Pushover method for masonry and reinforced concrete buildings. Each wall with opening has been decomposed into parallel structural walls made of an assemblage of piers and a portion of spandrels. As formulated, the structural model undergoes inelastic flexural as well as inelastic shear deformations. The mathematical model is based on the smeared cracks and distributed plasticity approach. Both zero moment location shifting in piers and spandrels can be evaluated. The model can support any shape of failure criteria. An event-to-event strategy is used to solve the nonlinear problem. Two applications are used to show the ability of the model to study both reinforced concrete and unreinforced masonry structures. Simplified formulation of an equivalent frame model is arrived. The model permits to consider many relevant features of structural behavior such as structural wall coupling, zero moment location shifting, axial force–bending moment interaction, axial force–shear force interaction, and failure modes prediction. However, in the case of URM buildings, it is well known that smeared crack approach suffers from a few limitations. The smeared crack model is enabling to represent effectively the rocking and bed joint sliding mode of failures.

IV. Huanjun Jiang et. al. (2015) [4]

Conducted a study on seven full-scale, single-bay and single-storey RC frame specimens, five with masonry infill wall and flexible connection, one with masonry infill wall and rigid connection, and one without infill wall, were tested under low-cycle reversed loads. For the specimens with flexible connection, the variable parameters are the type and amount of constructional column, the amount of tie steel bar, and the amount of vertical slit set in the infill wall. Based on the test results, the damage behavior, lateral strength, displacement ductility ratio, stiffness degradation, and energy dissipation of the specimen are compared. The influence of constructional details of infill walls on the seismic behavior of RC frames is analyzed.

Compared with the bare frame, the lateral strength, the stiffness and the energy-dissipation capacity of the masonry infilled RC frame with rigid connection increase very significantly while the displacement ductility ratio decreases very significantly. The infill wall with rigid connection has very remarkable effect on the seismic performance of the RC frame.

The seismic performance of the infilled frame with flexible connection falls in between the bare frame and the infilled frame with rigid connection. As the infilled frame with flexible connection is concerned, the constructional details of the infill wall have a little effect on the seismic performance of the frame.

V. Ahmad N et. al. (2012) [5]

The performance of low-rise confined masonry (unreinforced masonry walls confined with horizontal and vertical lightly reinforced concrete elements) structures is assessed against earthquake induced site amplified strong ground motions using a probabilistic-based approach. The basic mechanical characteristics of structural material is obtained through experimental investigations on masonry material, structural walls and reduced scale structural models, which are employed for the design, mathematical modeling and seismic analysis of confine masonry structures. The seismic performance of two case study (two storey) structure types is assessed for various scenario earthquakes with moderate to strong ground motions. The typical confinement of masonry walls can avoid the total structural collapse in most of the strong ground motions thereby minimizing the occupant's injuries, however the damages to structures in large earthquake events are significant.

Investigating on the seismic behavior of structures in scenario earthquakes show that the typical confinement of masonry walls ensure excellent performance of structures against earthquake induced ground motions, avoiding the structural collapse in most cases thereby ensuring safety of the occupants in even in larger earthquake events.

In most of the test scenario earthquakes, the structures are found with slight to moderate damages in the form of cracking (more or less extensive) in masonry structural walls which may require repair in the form of cement grouting to restore the structure's lateral stiffness and strength. Due which the structures may cause significant economic losses in regions with moderate to high frequent seismicity.

A ten percent increase in the wall density (when wall length is increased only) didn't cause appreciable difference in the seismic performance due to the reason that the better performance is governed by the deformation capacity (ductility) of the system.

VI. Sang-Cheol Kim et. al. (2004) [6]

A simplified multiple degrees-of-freedom approach developed by the authors is applied to the building. The study focuses on defining appropriate structural properties for accurate prediction of the dynamic response. A model calibration process is performed to determine the required structural properties based on the elastic and inelastic test responses. This approach is necessary since it is difficult to quantify accurately the in-plane and out-of-plane stiffness, strength, and hysteresis using simplified equations specified in current seismic codes and standards.

The dynamic behavior of the out-of plane wall and the flexible diaphragm can be predicted well when the proposed MDOF approach is used with appropriate values of the structural properties.

VII. Saeid Mojiri et. al. (2014) [7]

This paper presents detailed analyses of experimental shake table test results with the goal of providing a better understanding of the seismic performance of lightly reinforced fully grouted masonry shear walls. This includes quantifying the walls' displacement ductility levels, extent of plastic hinge zones, and equivalent plastic hinge lengths based on the experimental results. Separation of the various energy components of the system, including those of the shake table, the walls, and the external mass support system, based on the experimental results, is also carried out.

The results from this study demonstrate that the displacement ductility capacity of the reinforced masonry (RM) walls and their capability to dissipate energy through plastic hinging are higher than what is currently recognized by the National Building Code of Canada.

VIII. M. Umair Saleem et. al. (2016) [8]

Evaluates the seismic performance of fiber-reinforced polymer (FRP) retrofitted buildings with openings at different FRP reinforcement levels. Required objectives are achieved by performing five shake table tests on 1=4-scale models of single-story boxlike masonry buildings. Out of five building models, one was an unreinforced masonry (URM) building model whereas the other four were retrofitted with different quantities and layouts of FRP reinforcement. FRP reinforcement is reduced by decreasing FRP strip widths and strip spacing and applying FRP strips on either the inside or outer faces of walls. Each building model was subjected to the same series of input ground motions with gradually increasing amplitudes.

The results of diagonal compression tests and building model shake table tests show that FRP can significantly enhance the seismic resistance of new and existing URM buildings.

IX. Khaled Galal et. al. (2010) [9]

Assessed the out-of-plane flexural performance of masonry walls that are reinforced with glass fiber-reinforced polymers GFRPs rods, as an alternative for steel rebars. Eight 1m and 3m full-scale walls were constructed using hollow concrete masonry units and tested in four-point bending with an effective span of 2.4 m between the supports. The walls were tested when subjected to increasing monotonic loads up to failure. The applied loads would represent out-of-plane loads arising from wind, soil pressure, or inertia force during earthquakes. One wall is unreinforced; another wall is reinforced with customary steel rebars; and the other six walls are reinforced with different amounts of GFRP reinforcement. Two of the GFRP-reinforced walls were grouted only in the cells where the rods were placed to investigate the effect of grouting the empty cells. The force-deformation relationship of the walls and the associated strains in the reinforcement were monitored throughout the tests. The relative performance of different walls is assessed to quantify the effect of different design variables. The range of GFRP reinforcement ratios covered in the experiments was used to propose a capacity diagram for the design of FRP-reinforced masonry walls similar to that of reinforced concrete elements.

X. Tomas Kasparik et. al. (2014) [10]

Conducted an experimental program to study the performance of partially grouted, nominally reinforced (PG-NR) concrete block structural walls under in-plane seismic loading on a shake table. Five reduced-scale structural walls were constructed and tested under scaled versions of the 1940 El Centro, California earthquake, using its N-S component record with a constant axial compression load that represented a single-story building. The test walls were grouped into three categories. Type I and III walls had reinforcement at the wall end cells only, with vertical reinforcement ratios of 0.07 and 0.12%, respectively, based on the gross cross-sectional area of the walls. Type II walls were similar to Type I walls, but with an additional reinforcement bar located mid length of the wall with a vertical reinforcement ratio of 0.10%, also based on the gross cross-sectional area of the wall. The experimental results were documented and discussed with respect to wall lateral load capacity, stiffness degradation, period shift, displacement ductility levels attained, and relevant seismic-force reduction factors. The test results showed that PG-NR masonry walls can comprise a ductile seismic force-resisting system. Subsequently, PG-NR masonry walls have the potential to bridge the gap between unreinforced and reinforced masonry systems. The use of PG-NR masonry also results in a reduced cost compared with traditional reinforced masonry systems used in seismic zones that are typically fully grouted within the plastic hinge zones and require higher reinforcement ratios.

XI. Erol Guler et. al. (2014) [11]

Conducted reduced-scale shaking table testing is a useful tool for understanding the seismic behavior of geosynthetic-reinforced soil walls.The results from a series of reduced-scale shaking table tests on eight different configurations shows the effects of change in peak ground acceleration, reinforcement length and spacing, model scale, treatment of the top two facing block layers on the accelerations on a wall face, maximum displacements of the wall face during shaking, permanent displacements, and strains in reinforcement are investigated. Maximum accelerations measured on the wall face during shaking increased from bottom to top. Geotextile length and spacing did not affect the maximum accelerations and face displacements when the geotextile length met the minimum requirements of established design procedures. No significant permanent displacements were observed. Decreasing the geotextile length and increasing the geotextile spacing increased the geotextile strains when the geotextile was long enough to provide anchorage beyond the potential failure surface.

XII. Maryam Eidini S et. al. (2013) [12]

Hybrid masonry is an innovative technology for seismic design of buildings. The system uses reinforced masonry panels within a steel-framed structure, where steel connector plates link the steel frame to the masonry panels. Current research is underway to extend the application of hybrid masonry for use in high-seismic regions.

In this paper, the overall approach for seismic design of one type of hybrid masonry systems is studied, and the steps of a capacity design process are presented, where two favorable ductile modes of behavior may be exploited: steel connector plates behaving as fuses or flexural yielding of the masonry panels. Moreover, this research applies the two design options for 3-, 6-, and 9-story prototype buildings located in a high seismic region and evaluates viability of hybrid masonry as a new seismic lateral-load resisting system. On the basis of this design framework and the exploratory studies, both approaches are shown to be feasible for developing realistic system configurations.

Nevertheless, for the case of flexural yielding of the masonry panels, the steel connector plates must carry significant shear force demands. The structural system then requires more hybrid panels compared with corresponding systems when plasticity is concentrated in the steel connector plates.

XIII. Mustafa Taghdi et. al. (2000) [13]

Four concrete block masonry and two reinforced concrete walls were designed to simulate lowrise nonductile walls built decades ago, before the enactment of earthquake-resistant design provisions. Two masonry walls were unreinforced and two were partially reinforced. The concrete walls had minimum reinforcement.

One wall from each pair was retrofitted using a steel strip system consisting of diagonal and vertical strips that were attached using through-thickness bolts. Stiff steel angles and anchor bolts were used to connect the steel strips to the foundation and the top loading beam. All walls were tested under combined constant gravity load and incrementally increasing in-plane lateral deformation reversals. The lightly reinforced concrete walls were also repaired using only vertical strips and retested. These tests showed that the complete steel-strip system was effective in significantly increasing the in-plane strength and ductility of low-rise unreinforced and partially reinforced masonry walls, and lightly reinforced concrete walls.

XIV. Chungsik Yoo et. al. (2006) [14]

A geosynthetic reinforced segmental retaining wall was collapsed during a monsoon season, three months after the completion of wall construction. The circular type global slope failure was the dominant failure mode. The as-built design was examined for its appropriateness in meeting the current design requirements and the global slope stability. A comprehensive stress-pore pressure coupled finite-element analysis was additionally conducted with due consideration of both positive and negative pore pressures in saturated and unsaturated zones. A number of relevant tests were also carried out on the backfill and the reinforcement collected from the site. The investigation revealed among other things that the inappropriate design and the low-quality backfill were mainly responsible for the wall failure, although the primary triggering factor was the rainfall infiltration. The results of the stress-pore pressure-coupledfinite-element analysis provided sound evidences as to the wall performance over the rainfall period, supporting the field observation. Practical implications of the findings from this study are also discussed in view of reinforced wall design.

XV. Tim Stratford et. al. (2004) [15]

This paper investigates strengthening masonry walls using glass fiber reinforced polymer(GFRP) sheets. An experimental research program was undertaken. Both clay and concrete brick specimen were tested with and without GFRP strengthening. Single sided strengthening was considered as it is often not practicable to apply the reinforcement to both sides of a wall. Static test were carried out on six masonry panels, under a combination of vertical preload and inplane horizontal shear loading. The mechanisms by which the load was carried were observed varying from the initial, uncracked state, to the final full cracked state. The results demonstrate that a significant increase of the inplane shear capacity of masonry can be achieved by bonding GFRP sheets to the surface of masonry walls. The experimental data were used to assess the effectiveness of GFRP strengthening, and suggestions are made to allow the test results. To be used in the design of sheet GFRP strengthened for masonry structures.

XVI. Richard E Klinger et. al.(2013) [16]

This paper describes a coordinated experimental and analytical study that investigated the seismic performance of wood- stud-construction with clay masonry veneer designed according to the current US building codes. As part of this study two one storey buildings were tested on a shaking table. Both had a clay veneer on the outside. One had wood- frame walls for the backing and load-resisting system, whereas the other had RC masonry walls. With one exception, the behavior of the veneer in the wood framed building was satisfactory up to levels of shaking consistent with the design level earthquake.

That exception was related to the relatively low pullout strength in wet wood of the conventional nails used to attach the veneer connectors to the wood-stud wall. On the basis of this study, code changes have been implemented to require the use of higher capacity fasteners for such application. The wood-frame building specimen itself did not collapse under levels of shaking consistent with the maximum considered earthquake. Behavior of the RC masonry building and the veneer on that building was satisfactory up to levels of shaking well in excess of the maximum considered earthquake.

XVII. James E et. al.[17]

States the seismic design requirements and method for masonry design of buildings.The performance of unreinforced and reinforced in numerous earthquakes.

From a review of past earthquakes and the performance of unreinforced and reinforced masonry buildings to these dynamic forces, it is evident that development of the design methods being used is improving the performance of our buildings. The design of the reinforced masonry buildings with an adequate amount of reinforcing steel, the details for integrity for tieing the structure together, the concepts of ductility and flexibility are providing safe structures that will perform in an earthquake.

Modern, reinforced masonry buildings have been designed and built in high seismic areas and their performance has proven that principles of the reinforced masonry designs are sound in resisting the forces of earthquakes.

The future of masonry as a seismic resistant material is excellent and the development of new parameters in the research are providing new opportunities for the engineer to use and exploit an old material.

4. Conclusions

The following conclusions were drawn after reviewing many journals available on seismic performance of reinforced masonry structures.

The seismic performance of reinforced masonry structures can be improved upon by proper selection of reinforcing material. Glass fiber, geosynthetic materials could be an alternative to the existing steel reinforcement to improve the ductile behavior of masonry structures.

The different modes of failures are observed and these structures can be designed economically with high resistance to earthquake with nominal reinforcement. It was also observed that up to 10% increase in the overall density does not affect the seismic performance of the masonry structure since it is mainly governed by its ductility. It can also be observed that seismic performance of existing un reinforced masonry structures can be improved by adopting different retrofitting techniques.

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References

[1] Lakshmi Keshav, Srisanthi .V.G, Rajkumar.N, “Behavior Of 3-D Masonry CSEB Block Models Under Dynamic Loading”, *IJCESCAE*, Vol 6, NO. 12, 2012.

[2] Thakkar K Shashi And Agarwal Pankaj, “Seismic Evaluation Of Earthquake Resistant And Retrofitting Measures Of Stone Masonry Houses”, *12 WCEE*, 2000

[3] Y. Belmouden and P. Lestuzzi “An equivalent frame model for seismic analysis of masonry and reinforced concrete buildings” *Elsevier ,Science direct*, Construction and Building Materials, 23 (2009), Pg 40–53

[4] Huanjun Jiang, Xiaojuan Liu and Junjie Mao, “Full-scale experimental study on masonry infilled RC moment-resisting frames under cyclic loads” *Elsevier ,Science direct*, Engineering structures, 91 (2015), Pg 70-84

[5] Ahmad N, Ali Q, Ashraf M.,Naeem Khan , Alam B, “Performance assessment of low–rise confined masonry structures for Earthquake induced ground motions” *IJCSE*, Volume 2,issue 3, 2012

[6] Sang-Cheol Kim, Donald W. White, “Nonlinear analysis of a one-story low-rise masonry building with a flexible diaphragm subjected to seismic excitation” *Elsevier ,Science direct*, Engineering structures, 26 (2004) 2053–2067

[7] Saeid Mojiri, Michael J. Tait, and Wael W. El-Dakhakhni, “Seismic Response Analysis of Lightly Reinforced Concrete Block Masonry Shear Walls Based on Shake Table Tests” *ASCE*, 2014.

[8] M. Umair Saleem, Muneyoshi Numada, Muhammad Nasir Amin, and Kimiro Meguro “Shake Table Tests on FRP Retrofitted Masonry Building Models”, *Journal of composites for construction, ASCE*, 2016

[9] Khaled Galal and Navid Sasanian-“Out-of-plane flexural performance of GFRP-reinforced masonry walls”, *Journal of composites for construction, ASCE*, 2010

[10] Tomas Kasparik, Michael J.Tait and Wael W El-Dakhakhni – “Seismic performance assessment of partially grouted nominally reinforced concrete-masonry structural walls using shake table testing”, *Journal of performance of constructed facilities, ASCE*, 2014.

[11] Erol Guler. M. and Oznur Selek- “Reduced-scale shaking table tests on geosynthetic- reinforced

soil walls with modular facing", *Journal of Geotechnical and Geoenvironmental Engineering, ASCE*, 2014.

[12] Maryam Eidini S, Daniel P. Abrams and Larry A. Fahnestock– "Seismic design and viability of hybrid masonry building systems", *Journal of structural engineering, ASCE,* 2013.

[13] Mustafa Taghdi, Michel Bruneau and Murat Saatcioglu- "Seismic retrofitting of low-rise masonry and concrete walls using steel strips", *Journal of structural engineering, ACSE,* 2000

[14] Chungsik Yoo. A.M and Hye-Young Jung "Case history of geosynthetic reinforced segmental retaining wall failure", *Journal of Geotechnical and Geoenvironmental Engineering, ASCE,* 2006

[15] Tim Stratford, Giovanni Pascale, Odine Manfroni, Barbara Bonfiglioli, "Shear strengthening masonry panels with sheet glass fiber reinforced polymers", *Journal of composites for construction, ASCE*, 2004.

[16] Richard E Klinger, W Mark Mc Ginley, P Benson Shing, David I Mc Lean, Seongwoo JO, Hussein Okali, "Seismic Performance of low-rise wood framed and reinforced masonry buildings with clay masonry veneer" *Journal of structural engineering, ASCE*, 2013.

[17] James E and Amrhein "Design construction and performance of reinforced masonry building subjected to seismic loads" *Structural Engineers Director of Engineering- Masonry Institute of America Los Angeles*, California U.S.A.