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Investigation of the Seismic Performance of Concrete Masonry Walls Plastered by Microsilica and Steel Fiber Admixed Mortar

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ABSTRACT: The majority of existing buildings using unreinforced masonry walls (URM) have been constructed without taking into account the earthquake event. These buildings consequently do not have enough capacity to dissipate the energy resulting from the excitation action during such an event. As a result, there is an urgent need to strengthen these walls in order to improve their ability to withstand potential seismic damage. Several strategies for seismic strengthening of masonry structures have been proposed and applied in seismically active zones. The new generation of advanced concrete technology, ultra-high performance concrete (UHPC), has created enormous possibilities for innovative construction utilization. This work addresses the behavior of strengthening concrete block masonry walls subjected to cyclic loading and retrofitted by UHPC plastering on both sides of the wall, with mortar having microsilica as strength modifier and steel fibers as reinforcing additive.

1 INTRODUCTION

Masonry wall is one of the most popular and common type of structural component in the world which has a long history and is beautiful in appearance, low cost and ease of construction. Masonry wall is the component of structures made from individual units laid in and bonded together by using mortar. The key advantages of masonry wall are the thermal mass of a building and protection of the building from fire has been increased, there is no requirement of painting and resulting reduced life-cycle costs and useful life cycle is 30 to 100 times higher than structural steel. Most common uses of masonry wall are for partition walls, structural wall, retaining wall and even in heritage structures. It is well-known that those structural elements are constructed mainly of unreinforced masonry wall (URM). In spite of this, URM structures behave critically when subjected to earthquakes. As a result, catastrophe takes place, causing a big loss in terms of lives and economy. URM is regarded as anisotropic in terms of elastic properties as well as failure criteria. Orthogonal planes of weakness are attributed to the mortar joints. Failure modes for URM components comprise of compressive crushing, diagonal tensile splitting of units, tensile cracking along head and bed joints, and the sliding shear failure of bed joints. Many researchers investigated the deficiency and tried to rehabilited the URM wall by different materials. Some reserachers tried to enhace the ductility and strength by using reinforcing bars. Horizontal and vertical reinforcement into the masonry wall had increased the strength significantly [Shedid et al (2008)]. Truss type reinforcemnent arragement was studied to enhance the overall peroformance of the walls and reported that reinforcing arrangement did not effect the overall behavior [Haach et al (2010)]. Some researchers tried to restore the strength by using CFRP strip and reported that use of CFRP could restore the strength and increase the ductility [ElGawady et al (2006), Li et al (2001)]. Some researchers tried carbon mesh with high quality mortar spray [Bischof et al (2014)], fiber reinforced mortar and fiber grids [Popa et al (2013)], GFRP strips and GFRP bars [Li et al (2005)], textile reinforce mortar (Vasconcelos 2012).

In 1990s, the development of ultra-high performance concrete (UHPC), has brought a new generation of cement based materials. It is also referred as ultra-high performance fiber reinforced concrete (UHPFRC). This material uses optimized amount of micro and nano-scale material to provide superior mechanical properties and durability compared with high performance concretes and conventional concretes. Using specialized materials, optimizing particle packing, and implementing high temperature and high pressure curing regimes, limiting the water-cementitious materials ratio (w/cm < 0.2), eliminating coarse aggregate are the key focus of UHPC. Moreover, dispersion of short fibers randomly, enhance the material’s ductility and toughness, flexural and tensile strength. Many researchers had investigated the physical, chemical and mechanical properties of UHPC [Graybeal et al (2005), Hakeem et al (2013)]. UHPC material had been studied in hybrid construction and it shows good integrity and enhancement of strength and ductility [Azad et al (2012), Chen et al (2010), Dong et al (2011)]. The high mechanical properties of UHPC and previous researches give the indication that UHPC can be used as strengthening material. This paper tried to investigate the performance of UHPC, while it was used as strengthening material.

2 EXPERIMENTAL PROGRAM

The seismic performance of unreinforced concrete masonry walls were evaluated on the basis of cyclic tests. In this test vertical and incrementally increased cyclic horizontal loads were applied to the wall. Experimental program included two tests conducted on two full-scale concrete masonry walls. The first one was unreinforced masonry wall (NCMW) and the other one was unreinforced masonry wall, plastered by 12.5 mm thickness of UHPC on both sides of the wall (NCMWR). Obtaining force-displacement hysteresis loops and failure modes and characterizing seismic performance using quantitative indexes such as ductility, energy dissipation and strength, were the main objective of this experimental research.

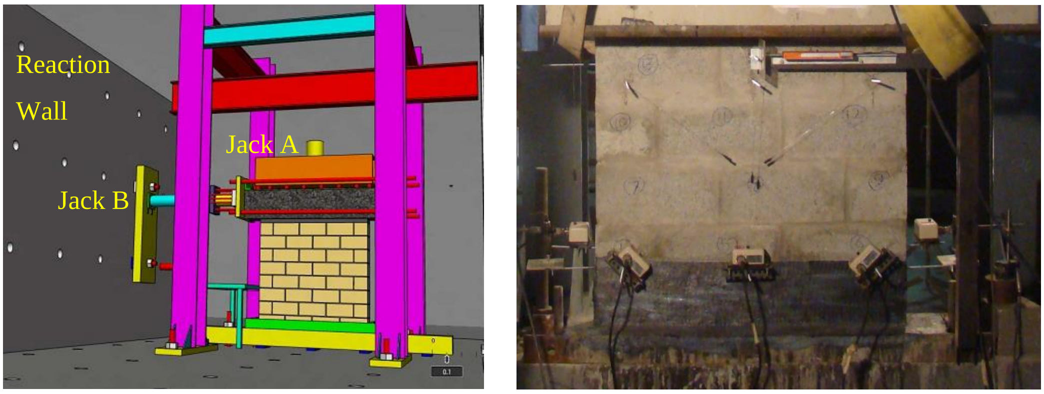
2.1 Construction of Test Specimen

In this study, two unreinforced concrete masonry walls were used under cyclic loading. The walls were made of concrete masonry blocks (400×200×100 mm) and Portland cement mortar. One wall (NCMWR) was plastered with UHPC by 12.5 mm thickness. The aspect ratio for both walls was kept to be 1. Height to thickness of the wall ratio was 100.

The key ingredients of UHPC include micro silica and steel fiber. There were two types of steel fibers used in the same mix. One of these steel fibers was straight and other one was hooked end. Hooked end steel fibers were used for better gripping and anchorage. The developed UHPC mix was utilized for strengthening. The UHPC was mixed in a horizontal pan mixer. After casting specimens were cured for 28 days under water curing process. After curing period was completed, the specimens were tested.

2.2 Experimental Setup, Instrumentation and Procedure

To conduct the test, the walls were placed in the proper position within a steel frame fabricated for purpose of testing the wall under cyclic loading. Placing of the walls was critical issue in



(a) (b)

Fig. 1: (a) Experimental Setup Frame, (b) Experimental Setup

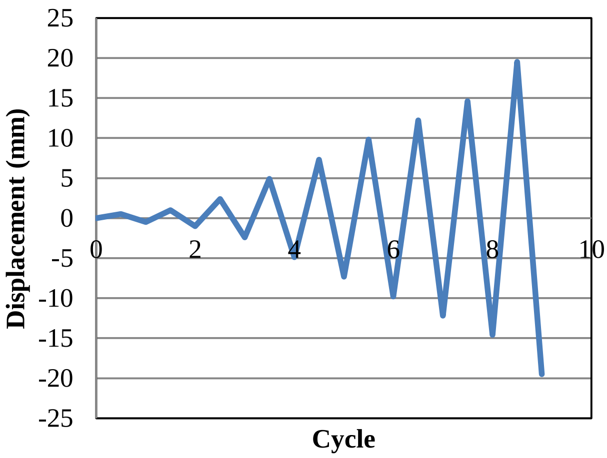


Fig. 2: Displacement-Cycle History Diagram

which the wall has to be perfectly aligned vertically and horizontally so that the application of horizontal load using the cyclic hydraulic jack actuator will not result in any out of plane action and also to prevent eccentricity when applying load. Laser level was used so that perfect alignment could be achieved. The walls was subjected to pre-axial compression stress of 2.16 and 3.95 MPa, for NCMW and NCMWR respectively. The axial as well as horizontal forces were exerted on the wall though a stiff concrete beam attached to the top of the wall. High strength mortar (BASF EMACO S88C) was used to attach the stiff concrete beam to the top of the wall. This high strength mortar ensures uniform distribution of the axial and horizontal force on the wall without any stress localization. The wall movements and deformations were captured and recorded using several LVDTs attached to the wall at different positions (Fig. 1). A CFRP wrapping was used at the bottom of the specimens to prevent premature rocking failure. The CFRP fibers are directed horizontally and just to confine the bed course.

The walls under cyclic loading were tested in two steps. At first, vertical load, matching to some percentage of the compressive strength, was applied at 1 kN/s, slowly. The wall was then subjected to a cyclic loading (Load-Unload) using a displacement control load with a loading rate of 0.05 mm/s. The horizontal displacement load was monitored by horizontal LVDT, which was connected to the top center of the wall. The lateral loading adopted in this study was based on drift ratio. Fig. 2 shows the displacement-cycle history diagram that the wall was subjected to and the associated lateral displacement. The lateral displacements were measured at the top center of the wall.

2.3 Material Properties

Mechanical properties of various wall components, like concrete masonry block unit, mortar, and UHPC, were found out by experimental tests. The compressive load capacity of masonry prism was also determined expermentilly for ascertaining the load to be applied on the wall. According to EN 772-1 European Standard 2000, compressive strength of concrete masonry blocks was obtained and average value was 9.46 MPa. Modulus of elasticity and Poisson ratio of concrete masonry blocks was 39 GPa and 0.15, respectively.

Blocks were assembled in the walls by mortar. The water/cement and cement/sand ratio was kept to be 0.6 and 1:3 respectively. Compressive and flexural strength of mortar was 30 MPa and 2 MPa respectively. Specimens were tested after same age curing of walls. The modulus of elasticity was recorded to be 20.5 GPa and Poisson ratio to be 0.18. In case of UHPC, average compressive strength found to be 128 MPa (150×150×150 mm specimens) in compression test and 11.5 MPa was found in direct tension test. The modulus of elasticity was obtained 45 GPa and Poisson ratio was 0.26. According to ASTM C 1314 and European Standard EN1052-1(1999), masonry prisms (NCMW and NCMWR prisms) were tested under uniaxial comressive load. The compressive strength of the NCMW and NCMWR prisms were 5.41 and 14.92 MPa.

3 RESULTS

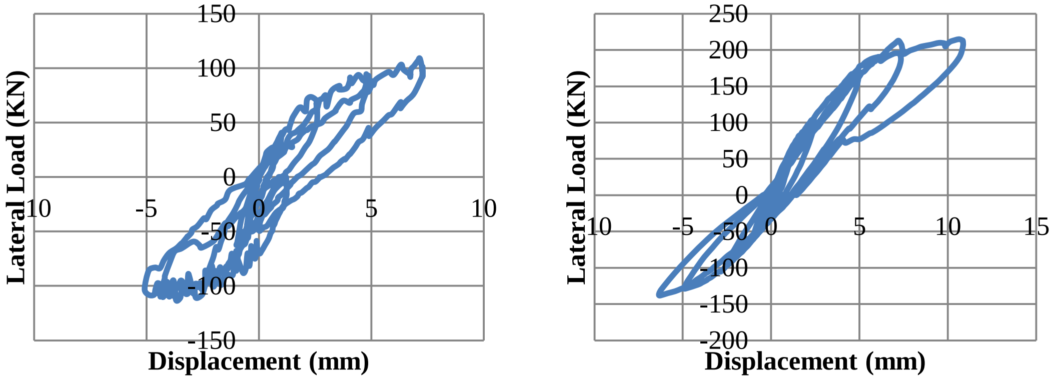
3.1 Failure mode and force-displacement hysteresis diagrams

Fig. 3 illustrates the cracking pattern in the walls. The walls exhibited mixed flexure and shear failure mode. In case of NCMW specimen, the shear crack was observed after 4th cycle at the top left corner at 72 kN. The crack developed progressively following a diagonal path throughout mortars and blocks. Crushing failure also occurs from the 5th cycle at 108 kN. But that crack did not progress with the cycle. In 4th and 5th cycle rocking failure was observed in the second course of the bed joint, at 100 kN (pull) and 88 kN (push) respectively. The NCMW specimen failed completely in 5th cycle. The ultimate load it could carry before failing was 108 kN in push and 102 kN in pull. The load and displacement was recorded during the test. Figure 4(a) is showing the load-displacement diagram.

The NCMWR was exhibited higher energy dissipation in each cycle than the NCMW specimen. The highest strains were recorded in the diagonal directions. In the middle section of the wall, bisecting point of the diagonals, strain gage gave the maximum readings. It was 1063 μ. From the readings of the patriot and LVDT's it is also noticed that maximum stress was acting along the diagonal directions. NCMWR specimen could take 215 kN in push and 138 kN in Pull. NCMWR showed approximately 100% increase in load carrying capacity in the cyclic test. There were some hair size cracks started to show up. The cyclic capacity of the NCMWR was expected to be 25-30% more. But due to the limitations of the hydraulic jack, the full capacity could not be recorded. Load-displacement hysteresis is shown in Fig. 4 (b).

(a) (b)

Fig. 3: Cracking Pattern in (a) NCMW and (b) NCMWR



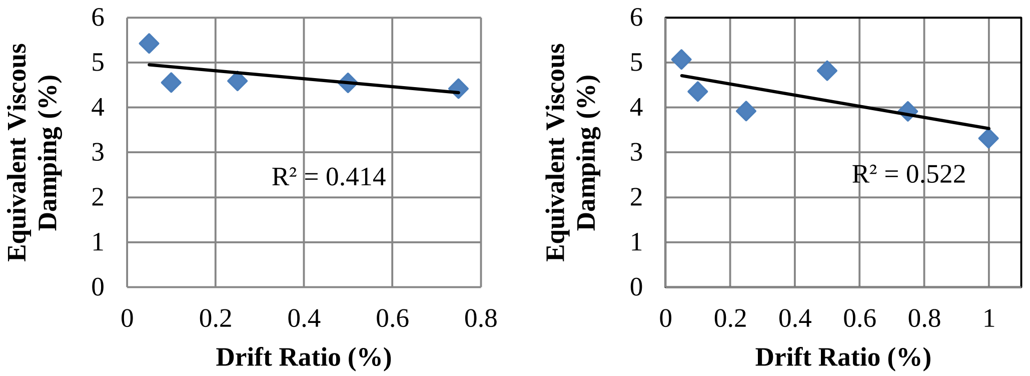
(a) (b)

Fig. 4: Load-Displacement Hysteresis (a) NCMW (b) NCMWR

3.2 Evaluation of Seismic Performance

3.2.1 Energy Dissipation and Equivalent Viscous Damping

For the cyclic response of masonry walls, energy dissipation and equivalent viscous damping are important parameters. Equivalent viscous damping is defined the energy dissipated per cycle (area under force-displacement curve) divided by the product of 4π and the strain energy for a complete cycle (DesRoches 2004). The energy dissipation recorded in NCMWR was higher than the NCMW and equivalent viscous damping was quite similar for both the experiment (Fig. 5). Because of the limitations of the hydraulic jack, the full capacity of the NCMWR could not be captured. That’s why the equivalent viscous damping was decreasing with drift ratio in case of NCMWR. But it was expected that the NCMWR would show nealy same values. Plaster did not contribute to increase/decrease equivalent viscous damping, which is concluded by many researchers, while they were using CFRP as strengthening material.



(a) (b)

Fig. 5: Equivalent Viscous Damping (a) NCMW (b) NCMWR

4 CONCLUSION

An innovative system for strengthening concrete masonry walls using UHPC plaster has been investigated. As a retrofit measure that is congruous and compatible with the existing NCMW in contrast to other retrofitting techniques including use of CFRP and other non-cementitous materials. Following conclusions can be drawn from this study:

- UHPC plaster of plaster thickness to wall thickness ratio of 0.25 was able to increase the strength of the URM wall by an order of 100%.
- Use of UHPC plaster resulted in increase of overall stiffness of the URM wall.
- Very little effect on equivalent viscous damping was noted due to UHPC plaster.
- UHPC plaster allowed the wall to undergo larger number of cyclic loadings and increased displacement.

Further studies are currently going on, including cost effectiveness of UHPC plaster as a retrofitted technique and non-linear finite element modeling for prediction of failure mode and ultimate capacities of UHPC plastered NCMW.

5 ACKNOWLEDGMENTS

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