Review on Seismic Strengthening using Eco Friendly Ductile Cementitious Composites

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Abstract - *Unreinforced masonry (URM) is one of the most common types of partition wall systems in many of the mid-age, low-rise to mid-rise, school and hospital buildings across the world. URM partition walls are known to have very low drift limits in seismic events and the failure mechanisms are known to be mostly brittle and catastrophic during an earthquake shaking. EDCC retrofit technology developed by UBC is a cost effective method for seismic retrofit. Eco friendly Ductile Cementitious Composites (EDCCs), is a form of fiber reinforced engineered cementitious-based composite material. EDCC is applied to the unreinforced masonry wall, cured and tested. When seismic waves are applied to wall, it starts shaking rather than breaking. As a result of application of EDCC stiffness, ductility, drift capacity and overall strength are increased.*

Keywords: Eco Friendly Ductile Cementitious Composites, Unreinforced Masonry, Ductiliy, Fibre Reinforced Concrete, Seismic.

1. INTRODUCTION

Masonry has been used to construct different kinds of structures for thousands of years. Unreinforced masonry (URM) is considered one of the most common types of partition wall systems in many of the mid-age, low-rise to mid-rise, school and hospital buildings across the globe. URM partition walls are known to have very low drift limits in seismic events and the failure mechanisms are known to be mostly brittle and catastrophic during an earthquake shaking. Compared to any other partitioning systems, URM walls generally perform poorly during earthquake events. In addition, many masonry structures are or become unsafe due to poor maintenance and inefficient structural systems for resisting lateral loading. In masonry structures, the walls are usually the main structural elements expected to resist the lateral forces. Existing masonry structures in seismic areas that do not comply with the new earthquake building regulations need to be strengthened and retrofitted to increase their survivability during a seismic event. To date, different techniques have been investigated to enhance the ductility and load capacity of plain masonry walls, such as grout injection, or adding welded steel mesh or fibre-reinforced polymer (FRP) in many different shapes through techniques such as near surface mounting (NSM), external bonding (EB),textile layers covered by cementitious materials have also been applied. Another more recently proposed strengthening technique is the application of ductile fibre-reinforced cementitious composites.

The UBC developed EDCC retrofit technology is a cost effective novel methodology for seismic retrofit of existing infrastructures using Sprayable Eco friendly Ductile Cementitious Composites (EDCCs), which is a form of fiber reinforced engineered cementitious-based composite material. In particular, this retrofit strategy primarily targets strengthening of unreinforced, non-grouted, and unconfined non-load bearing masonry walls, typically referred to as URM walls, in order to provide restrain for the wall to prevent the OP failure under an earthquake ground shaking.

2. LITERATURE REVIEW

Smily,T.J. et.al(2018), studied the effect of opening in the URM structures corresponding to the seismic action. For this study different length to breadth ratio of 1150 sqft uniaxially symmetric buildings plans are taken. These plans are modelled and analysed with the help of 3MURI software. Then the performance point of all the building is determined with the help of pushover cure obtained from the software and a comparative study of all buildings were carried out.

Salman,S.D. et.al(2017), studied the performance of eco friendly ductile cementitious composite when used as a strengthening coat on unreinforced masonry. This paper elaborates on the results of shake table tests on full-scale masonry wall specimens, each about 2m wide by 3m high, retrofitted using sprayed EDCCs. Unreinforced non-grouted masonry wall specimens were assembled and then retrofitted using sprayable EDCC. The walls are tested on Linear Shake Table (LST) under different ground motions with varying intensities. The added flexibility to the system resulted in a substantial increase in energy dissipation, and thereby increasing the overall drift limits before collapsing, causing the wall to withstand extensive levels of shaking.

Salman,S.D. et.al(2017) conducted an experimental program where the effects of higher rates of loading on the tensile behaviour of EDCC are assessed. The EDCCs are fiber reinforced concrete materials having a total fiber volume of 2%. Non-oiled Poly-Vinyl Alcohol (PVA) fibers and Poly-Ethylene Terephthalate (PET) fibres are used in the EDCC mixes in three different combinations: 2% PVA, 2% PET, a hybrid mix of 1% PVA + 1% PET fibers .Results demonstrated that EDCCs are highly strain-rate sensitive materials and their performance during an earthquake should not be assessed from routine quasi-static tests.

Shrive,N. and Kaheh,P. (2016) conducted a study for assessing the effectiveness of an Eco-friendly Ductile Cementitious Composite repair material in improving the dynamic behaviour of hollow concrete blockwork walls. the dynamic characteristics of thw walls were evaluated through in- palne free vibration tests at two levels of damage before and after strenghthening. The natural frequencies, damping mechanisms and ratio have been investigated from the free vibration response data. The natural frequency of vibration increased in the strengthened walls as a result of application of EDCC material.

Kaheh,P. et.al(2016),the study was aimed at investigating the effects of bonding EDCC repair material to the surfaces of plain hollow concrete block masonry walls on the in-plane behaviour of the walls. The stiffness degradation, ultimate resistance, ductility and energy dissipation capacity of the walls were investigated. The EDCC repair material improved the behaviour of the walls.

3. EXPERIMENTAL INVESTIGATION ON EDCC

Eco-Friendly Ductile Cementitious Composite (EDCC) is a new type of High Performance Fiber-Reinforced Cementitious Composites (HPFRCC) with 2% volume fraction of fibre that shows high ductility. Under tensile loading, EDCC shows a relatively significant strain-hardening type behavior with great ultimate strain capacity. Adding a high volume of fly ash to these composites helps to reduce the matrix-fibre interfacial bond strength and the matrix toughness; thus, contributing in the achievement of high strain capacities during tensile loading. This high capacity is obtained through development of multiple cracking.

3.1 Out of plane loading

3.1.1 Experimental set up and testing

In this experimental work, the six full-scale walls were tested with uniaxial shaking out-of-plane under different ground motions with varying intensities. For this experimental phase, six full scale URM wall specimens of 2.8 m height , 1.6 m width and 4 inch thickness were casted and got field cured for a few weeks. The specimen is as shown in figure 1. The specimens are then retrofitted using Sprayable Eco-Friendly Ductile Cementitious Composites (EDCC) , followed by another 56 days of field curing for EDCC, and subsequently tested, one wall at a time. The 56 days of curing is highly recommended as the repair material consists of high volumes of fly ash, which can delay the long-term hardening and maturity of the repair system. The walls are fully instrumented and data are collected in 34 different channels, as follow: 1. Accelerometers @ 10 channels 2. Displacement sensors (string pods) @ 8 channels 3. Strain sensing (strain gages) @ 8 channels 4. Time-synchronized video recording by 8 cameras.

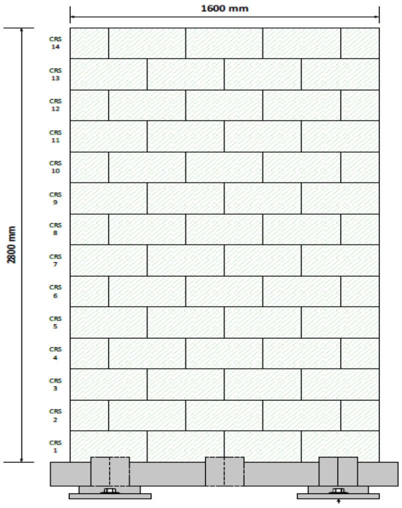


Fig-1: Specimen [4]

Out of the six walls, three of them were retrofitted only on one side and three of them were double sided retrofit. The walls were tested with different ground motions of all three types of crustal, sub-crustal, and subduction, with different intensities, as previously discussed. Generally, each wall is first tested with 100% of the actual intensity of the targeted ground motions, from the same records used throughout the analytical phases of the SRG III. Thereafter, the intensity was subsequently increased until the failure and eventually collapse of each wall. Figure 2 shows the extreme deformations of single sided wall.

Fig-2: Extreme deformations of single sided wall [4]

3.1.2 Result

Considering the week mortar joints, which hold the masonry units together, the wall becomes non-linear at the very first moments of the ground motion. Due to the very weak nature of the masonry mortar joints in tension, the wall usually develops a major crack at the mortar joint located at about 40% of the wall height from the top of the wall, and then start rocking about the same joint. Although the mentioned localized crack is sometimes referred to as a “plastic hinge”, the formed hinge shoes almost zero plastic type deformation, so having zero stress carrying capacity, it mostly acts as pivot point which lets the masonry blocks above and below the joint to rotate about it, creating a rocking mechanism for the wall. The more plastic hinges formed usually results in a more energy dissipative rocking behaviour during the motion, leading the wall to stay upright, and not collapse, for a longer duration of time during the seismic event. As a result of the EDCC retrofit the base rotation is much more evident during the ground motion. Not only does this decrease the out of plane base shear demand on the wall, which sometime causes sliding and collapse for such walls, it also keeps the deformations more uniform and the geometrical instability happens at much higher drift limits for the wall. When an URM wall undergoes rocking, the center of the weight goes back and forth with respect to the center of the geometry of the wall out of its own plane during the ground motion. Anytime that the center of weight is pushed away from the center of geometry, beyond the half-thickness of the wall, by the momentum of the wall rocking, there is a significant p-delta effect which puts an extra overall bending demand on the wall. A typical URM wall has a very low bending capacity, due to its rocking type behaviour, whereas, now the wall will be able to withstand the bending forces, through some base rotations, and restore its position back to upright.

3.2 In- plane loading

To understand the effectiveness of the proposed strengthening technique on the in-plane behaviour of plain concrete masonry walls, nine straight walls were built with hollow concrete blocks representing partition walls in schools in BC, Canada. The specimens were constructed from lightweight, hollow concrete masonry units of nominal dimensions, 400 × 200 × 200 mm (actual 390 × 190 × 190 mm), and premixed type S mortar. Lintel blocks were used for the top course, which was grouted.

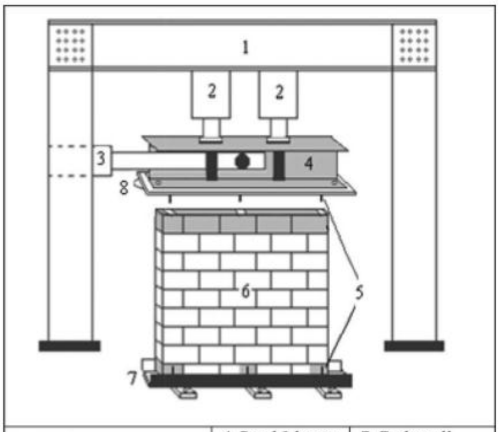
Three experimental groups were designated to attain the aim of the research. Group I, the control group, consisted of three specimens, which were not strengthened using the EDCC. For the second and third groups, six masonry walls were strengthened by applying the EDCC with a thickness of 20 mm: Group II had the repair material on one side only (asymmetrical strengthening) and Group III had the EDCC placed on both sides of the walls (symmetrical strengthening).Table 1 shows the summary of different specimens tested.

Table-1: Summary of specimens

Group	Specimen ID	Strengthening Pattern
Group I	Control -1	None
Group II	Control-2	One side
Group III	Control-3	Two sides
	1S-20-1	
	1S-20-2	
	1S-20-3	
	2S-20-1	
	2S-20-2	
	2S-20-3	

3.2.1 Experimental set up and testing

The test frame used in this study consisted of a steel frame and three hydraulic actuators, two vertical actuators and one horizontal. The capacity of each vertical actuator was 1.5 MN, and the horizontal one was able to apply a lateral force of 500 kN with a maximum stroke of 150 mm. The specimens were built on steel C-channels, which were equipped with three shear pins with a height of 200 mm to prevent the wall sliding on the channel. A steel I-beam was placed on top of the specimen to distribute both vertical and lateral load to the specimen, as shown in figure 3. The cap plate, bolted to this cap beam, was connected to the last course through three steel dowels with a height of 50 mm, which were welded along the cap plate.



1-Steel Frame	4-Steel I-beam (Cap beam)	7-C-chanell (Base beam)
2-Vertical actuators	5-Shear pins	8- Cap plate
3- Horizontal actuator	6-Wall	

Fig-3: Test set-up [1]

To test the specimens, the axial load was first applied to the wall using the vertical actuators to reach an axial stress of 0.1 MPa. The axial actuators were programmed to maintain the same axial load throughout the test. The force-controlled stage, was imposed on the wall with a low loading rate, 0.03 kN/s, until the stiffness of the wall started to descend. When the cycle in which the initial stiffness started to decrease was complete, control was switched to displacement control. The cyclic displacement-controlled loading included sixteen stages with different amplitudes from 0.25 mm to 7 mm with a displacement rate of between 1 mm/ min and 5 mm/min. Each complete cycle was repeated two times at the same amplitude and displacement-controlled stages of lateral loading.

3.2.2 Result

For unstrengthened walls, the average ultimate resistance was 9.8 kN, while in the strengthened specimens the peak resistances averaged 29.0 and 33.4 kN for the one-sided and two sided strengthened walls, respectively. Therefore, the ultimate load was almost tripled on average for the one-side strengthened specimens. The failure mode altered in the strengthened specimens compared to the plain specimens due to the changes in stiffness and ductility resulting from the application of the EDCC repair material. For the one-side strengthening pattern, there were two different failure scenarios. First, the grouted blocks, located in the base course at the ends of the walls and containing the shear pins, failed in tension. This was the failure mode of wall 1S-20–2, and could be caused by an interaction between the grouted blocks and the shear pins as the EDCC repair material restricted widening of the cracks in the bed joints of the unreinforced side where the stress was concentrated. In the second failure mode for this type of wall, the EDCC repair material reached its tensile capacity and started cracking before the grouted block failed, for wall 1S-20–1. The force-displacement histories for walls 1S-20–1 and 1S-20–2. In all asymmetrically strengthened walls, a clear twisting was recorded through the laser-based displacement transducers due to a noticeable stiffness difference on the opposite sides.

4. CONCLUSIONS

1. Plastic hinges are formed in walls with EDCC, which resulted in more energy dissipation.
2. The fundamental rocking behaviour is changed to a bending type behaviour with application of 20mm thick layer of EDCC.
3. The failure mode altered in the strengthened specimens compared to the plain specimens due to the changes in stiffness and ductility resulting from the application of the EDCC repair material.
4. Application of EDCC increases the stiffness of the wall, ultimate load capacity, ductility and drift capacity.
5. Tests conducted by varying thickness of EDCC showed that, applying 20mm thickness of EDCC on both sides of the wall gives best result.

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