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Study of flexural response of engineered cementitious composite faced masonry structures

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ABSTRACT

This study aims to develop and demonstrate the effectiveness of precast engineered cementitious composite (ECC) plates for strengthening of masonry beams by bonding them on tension face as well as both on tension and compression faces like sandwich beam. Two types of bonding materials have been used, i.e., epoxy and cement mortar for bonding the ECC plates with masonry beam. Experimental flexural response has been predicted for tension strengthened as well as sandwich beams. Detailed parametric study has been performed using ABAQUS commercial software package. The parametric study incorporates the effect of various parameters such as ECC thickness in compression and tension, epoxy and cement mortar as bonding agents, and bonding agent thickness on the flexural response of strengthened beams. All beams were tested under four-point loading systems. The numerical results obtained using ABAQUS are validated with experimental results. The present study results reveal that the application of precast ECC increases the strength and deformability of masonry beams and hence demonstrate its effectiveness as strengthening element for masonry structures. Furthermore, recommendations regarding optimum thickness of ECC strips/plates and bonding agents have been made for external strengthening of masonry beams with precast ECC strips.

1. Introduction

Over the ages burnt-clay bricks are used extensively as they offer considerable compressive strength, cost effectiveness and ready availability. However, brick and cement mortar are brittle materials and hence failure is sudden with no considerable warnings. Extensive research has been carried out for strengthening the masonry structures. Most of the research investigations have suggested strengthening of undamaged masonry walls in out of plane direction. Triantafillou [1] carried out a detailed beam test on clay brick beam specimens reinforced with carbon fiber reinforced polymer laminates to simulate in-plane bending and pointed out the importance of proper anchorage and development length. Reinhorn [2] studied the effect of in-plane cyclic loading on masonry walls strengthened with glass fiber reinforced polymer and reported that the fabric fractured along the diagonal cracking that occurred in the wall. Laursen et al. [3] tested masonry walls to failure, observed diagonal cracking and crushing of the compression side. The walls were then repaired using CFRP and retested. The results indicated 22 percent increase in the ultimate load in comparison. Abrams et al. [4] carried out experimental study with steel bars as reinforcement for seismic strengthening of masonry panels using techniques like canter core steel insertion.

One of the widely used composite material in construction industry, i.e., concrete is a brittle material. Numerous investigations have been carried out on fiber reinforced concrete/composites in past, the ECC material and technology came into existence in early nineties. The ECC is a fiber reinforced cement based composite material engineered to achieve high ductility under tensile and shear loading. Lin et al. [5] tested unreinforced masonry walls retrofitted with ECC shotcrete, and concluded that ECC is effective material to resist in-plane loading of retrofitted unreinforced masonry but additional reinforcement is required to resist out of plane loading. The experimental study was also performed on unreinforced brick masonry panels strengthened with welded wire mesh and micro concrete.

Singh et al. [6] carried out an experimental study on the behavior of steel reinforced polyvinyl alcohol ECC beams, wherein two steel reinforced ECC beams were cast and tested for under and over-reinforced flexural failure. Kadam and Singh [7] carried out

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an experimental study on unreinforced brick masonry panels strengthened with welded wire mesh and micro concrete. Results showed that unreinforced masonry (URM) specimens exhibited sudden brittle failure, while strengthened specimens failed in a more ductile fashion with increase in shear strength. Singh et al. [8] carried out experimental and parametric investigations of CFRP strengthened reinforced concrete beam using near surface mounted technique for studying the effect of various strengthening patterns applied on three types of RC beams i.e., under-reinforced, over-reinforced, and shear beams.

Based on a limited research on retrofitting of brick beams using ECC, Kyriakides et al. [9] proposed the two-dimensional nonlinear finite element micro modelling approach to simulate unreinforced masonry beams retrofitted with a thin layer of ductile fiber reinforced cement based material referred to as ECC. The study concluded that both a detailed and simplified micro-modelling approach are able to capture the experimental performance of the ECC retrofitted masonry beams.

Recently, Dhawale and Joshi [10] has demonstrated the need of new class of fiber reinforced composite such as ECC which has the strain-hardening property and can be processed with conventional equipment. The ECC can be designed based on micro mechanic approach with tensile strain capacity of about 3–5% compared to 0.01% of normal concrete. Gencturk and Hosseini [11] carried out comparative investigations at the component and system levels through a small-scale (1/8 scale factor) experimental program on RC and reinforced ECC. The system level investigation through hybrid simulation showed that the ECC structures sustain less deformation under earthquake excitation due to high energy absorption capacity of the material. Thus the objective of the present study is to analyze and study the flexural response of burnt-clay brick masonry beams externally strengthened using precast ECC plates on tension face and/ or both on tension as well as compression face of masonry beams.

1.1. Research significance

The study is useful for repair and strengthening of masonry structures using precast ECC sheets to upgrade the load carrying capability to sustain flexural loading. Furthermore, a nonlinear finite element modelling has been developed for parametric study which incorporates the effect of various parameters such as ECC thickness in compression and tension, epoxy and cement mortar as bonding agents, and bonding agent thickness on the flexural response of strengthened beams. Moreover, recommendations regarding optimum thickness of ECC strips/plates and bonding agents have been made for external strengthening of masonry beams with precast ECC strips.

2. Experimental investigation

The experimental investigation of this study was carried out in four subsequent steps: (1) four ECC sheets were cast and ECC plates of required size were obtained using cutter; (2) eleven masonry beams were cast each with nine clay bricks and 1:3 cement mortar; (3) beams were strengthened by ECC on tension face (i.e., tension strengthened beam) as well as on both tension and compression faces (i.e., sandwich beam with masonry as core and ECC as face layer) using two sets of bonding agent, i.e., epoxy and cement mortar; (4) tests were performed on control and strengthened masonry beams. Furthermore, detailed parametric study has been performed to examine the effect of various parameters such as precast ECC strip thickness, type and thickness of bonding agents in tension and compression on the flexural response of beams strengthened on tension face only (i.e., tension strengthened beam) and on both the tension and compression faces (i.e., sandwich beam).

2.1. Details of test beams

A total of 11 burnt-clay brick masonry beams of 230 mm (width) × 110 mm (depth) cross-section and 860 mm length were cast. The masonry beams have nine brick units with eight mortar joints, each of approximately 20 mm thickness. Out of the 11 beams, 4 beams were strengthened on bottom (tension face) with ECC sheet of 35 mm thickness and 4 beams were strengthened on both sides (compression and tension faces) like sandwich beam with ECC sheet of 35 mm thickness. The other three beams acted as control beams (i.e., unstrengthened). Two types of bonding materials were used for strengthening purpose i.e., epoxy and cement mortar. The thickness of epoxy and cement mortar are maintained approximately 0.1 mm and 4 mm, respectively. Portland pozzolana cement and local river sand were used in the mix proportion of 1:3 (cement:sand) for casting of masonry beams. The material properties of the Portland pozzolana cement and local river sand used are same as described by Singh et al. [12]. The beams were cured for 28 days before testing. The burnt clay bricks of size 230 × 110 × 75 mm (length × width × height), locally available in Rajasthan (India) were used in this study. The average compressive strength of burnt clay bricks and masonry prisms are 8.24 MPa and 2.85 MPa, respectively. The masonry prisms were cast with five brick unit stack bonded using cement mortar with cement/sand ratio of (1:3). The water absorption of burnt clay bricks were observed to be 13.65%. The tests to measure the compressive strength and water absorption were performed according to IS 1905:1987 [13] and IS 3495:1992 [14], respectively. The average compressive strength of 70.7 mm cubes of cement mortar is obtained as 20.85 MPa. In addition to the masonry beams, two numbers of ECC sheets of size 860 mm (length) × 230 mm (width) × 35 mm (depth) were also tested under 4-point flexural loading to predict the flexural response of ECC sheets. Table 1 depicts the nomenclature and descriptions of beams used in the study. To distinguish the tested specimens, and analytical modelled specimens, the designation ‘X-E’ and ‘X-A’ are used, where ‘X’ indicate the specimens described in Table 1; ‘E’ stands for experimentally tested specimen; ‘A’ refers to the numerically modelled specimen.

2.2. Constituents of ECC

Generally, ECC mix consists of silica sand, cement, water, fly-ash, super plasticizer and polymeric fibers. Present study used polyester fibers (Fig. 1) with a unique triangular cross-section which gives 40% more surface area for bonding compared to other shapes. The fiber length and diameter are 12 mm and 25–35 μm, respectively. The tensile strength, elongation, specific gravity, and melting point of polyester fiber are 480 MPa, 30%, 1.31, and 250–265° C, respectively.

Portland pozzolana cement having specific gravity of 3.15 was used in this investigation. Fine silica sand was used as fine aggregate in the mix. Fly-Ash confirming to IS 3812-1981 [15], and water confirming to IS 456:2000 [16] were used. Polycarboxylic ether was used as super plasticizer. The mix proportion of ECC has been presented in Table 2. The average compressive strength of the 70.7 mm ECC cube is 62.78 MPa after the age of 28 days and test was performed as per IS 516:1959 [17]. Five specimens of ECC coupons of size 310 × 75 × 13 mm were tested in automated deformation controlled hydraulic Universal Testing Machine to determine the tensile properties of ECC. The average