Experimental and Analytical Study on Masonry Panels Strengthened with Geotextile - A Comparison

Beyoola Wilson[1], Prof. Deepa Varkey[2]

[1] *M. Tech student, Dept. of Civil Engineering, MACE Kothamangalam, Kerala, India*
[2] *Professor, Dept. of Civil Engineering, MACE Kothamangalam, Kerala, India*

***

Abstract - *Masonry buildings are vulnerable to seismic loads because of their relatively high mass and lack of ductility and energy absorbing capacity. Due to shear failure mode, masonry walls tend to develop a diagonal failure along the bed and head joints for strong masonry units and weak mortar, across the masonry units for weak units and strong mortar. In this study the in-plane strength of solid clay brick masonry panels with and without non-woven geotextile was studied experimentally and analytically. The panels were strengthened on one side with different geometric patterns and subjected to diagonal compression. Analytical models are created using the software ANSYS Worbench17.0 and compared the results with experimental results.*

Key Words: Masonry Structures, Geotextile, Diagonal Compression, Shear Failure, Sliding Failure, Crushing Failure.

1. INTRODUCTION

Masonry is one of the oldest and most widely used construction material. More than 80% of buildings are built by masonry. Many of these masonry structures are historical buildings that should be preserved as cultural heritage. Therefore, it is needed to improve their seismic performance by strengthening. Un-reinforced masonry walls have two possible failure mechanisms under seismic loading: in-plane and out-of-plane. In-plane shear failure mode is the most important under earthquake loading. Past researchers show that during an earthquake, the predominant failure mode is a shear failure. In this study the in-plane strength of solid clay brick masonry panels with and without strengthened with non-woven geotextile was studied analytically and experimentally. The panels were strengthened on one side with different geometric pattern and subjected to diagonal compression. Analytical models of masonry walls with and without strengthening have been created using finite element software ANSYS Workbench 17.0.

1.1 Masonry Structures

Masonry is a composite material with the building brick units and the mortar as the joining material, which are bonded together. The basic mechanical properties of the masonry are strongly influenced by the mechanical properties of its constituents namely, brick and mortar. When the masonry is under compression, the masonry unit and the mortar will be under multi-axial state of stress. The structural shear walls of a masonry building subjected to horizontal loading commonly present two types of failure. The first one is out-of-plane failure, where cracks appear along the horizontal mortar joints. The second one is in-plane failure, generally characterized by a diagonal tensile crack. If the out-of-plane failure is avoided, then the structural resistance is mainly influenced by the in-plane behaviour of the shear wall[1]. The principal in-plane failure mechanisms of masonry walls, subjected to earthquake actions, are as follows:

- Shear failure: Masonry wall subjected to seismic loads, and it can take place where the principal tensile stresses, developed in the wall under a combination of vertical and horizontal loads, exceeds the tensile strength of masonry.
- Sliding failure: In the situation of low vertical load and poor quality mortar, seismic loads frequently cause shearing of the wall, causing sliding of the upper part of the wall at one of the horizontal mortar joints.
- Rocking failure and toe-crushing failure: In the case of high moment/shear ratio or improved shear resistance, the wall may be set into rocking motion or toe crushing depending on the level of the applied normal force.

The principal in-plane failure mechanisms of masonry walls is depicted in Fig. 1.

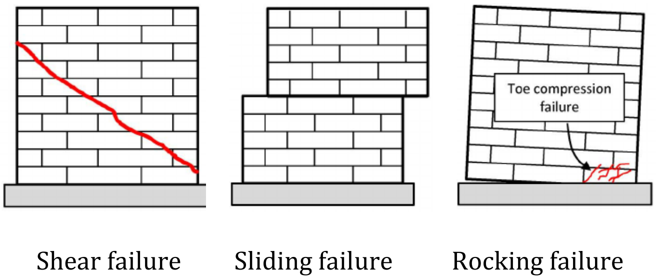


Fig -1: The principal in-plane failure mechanisms of masonry walls

1.2 Geotextiles

Geotextiles have proven to be among the most versatile and cost-effective ground modification materials. Their use has expanded rapidly into nearly all areas of civil, geotechnical, environmental, coastal, and hydraulic engineering. They form the major component of the field of geosynthetics, the others being geogrids, geomembranes and geocomposites. Geotextiles are defined as permeable textile materials used in contact with soil, rock, earth or any other geotechnical related material as an integral part of civil engineering project, structure, or system. The different synthetic fibres used in geotextiles are nylon, polyester, polypropylene while some natural fibres like ramie, jute etc. can also be used [4].

1.3 Finite Element Modeling

Masonry strength is dependent upon the characteristics of the masonry unit, the mortar and the bond between them. Utilizing the material properties obtained from the experiments and using actual geometric details of both components and joints, the behaviour of the brick masonry was analysed using ANSYS Worbench 17.0. The finite element model was developed to understand the behaviour of the brick masonry walls. A three dimensional linear finite element model was developed to determine the strength, deformation and the stress distribution throughout the masonry wall. Masonry itself is a composite material that consists of two materials depending upon the properties of the masonry unit brick and the mortar. There are three approaches towards its representation depending upon the level of accuracy and simplicity desired. They are (i) micro level modelling (ii) meso level modelling and (iii) macro level modelling.

- Micro level modelling: Masonry Units and mortar are modelled separately. They are represented by continuum elements, whereas the interface between brick and mortar is represented by discontinuous elements. Each constituent of the masonry material and their characteristics are considered in this model, thus it reflects the realistic behaviour of masonry but at the cost of great computational effort. However, this model can be adopted for simulating laboratory results satisfactorily.
- Meso level: In this approach, masonry units are represented by continuum elements whereas mortar joints and unit-mortar interface are modelled with discontinuous line interface elements. The units are expanded in order to keep the geometry of the whole structure unchanged. Thus, with the simplification of the model, the computational cost gets reduced.
- Macro level modelling: Without distinguishing the units and mortars, the units, mortar and the unit-mortar interface are smeared out in a homogeneous continuum. Mechanical properties of homogeneous elements represent the whole structure. The model is unable to show micro-mechanisms occurring in the masonry, but it is very effective from the computational point of view as it requires a very less computational time.

These different simulations depend upon the methods offered by different degrees of accuracy and therefore they should be used according to the requirements of individual situations. The first approach offers the detailed interaction between the masonry units brick and the mortar as it is most suitable for the current study. It provides the most detailed accuracy during simulation. The second approach offers a better accuracy of the behaviour of a masonry structure and is suitable to study the concentration of stress. The last approach studies a general behaviour simulation of the structure and is better suited for studying large size structures for the global in-plane shear behaviour of the masonry wall. The finite element model traces the progressive crack growth and the stress distribution patterns in the masonry units and the mortar and understand the results of the shear, diagonal compression tests on masonry wall panel.

2. OBJECTIVE

After conducting the literature review, the gap area identified to the best knowledge of researcher is, comparitive study of the strength attained by the masonry panels constructed using locally available bricks with geotextile strips of different patterns experimentally and analytically.

3. SCOPE

To attain the above objective, following are the scope of study

- The burned clay brick of class B.
- Mortar proportion 1:4.
- Non-woven geotextiles.
- Analytical study using ANSYS Workbench 17.0.

4. METHODOLOGY

The materials like cement, fine aggregate, and brick were collected and tested. The experimental program was designed to study the behavior of masonry panel under diagonal compression. For that, masonry panels are constructed and strengthened with geotextile. Un-strengthened panel is considered as the reference model. Testing of panels are done under suitable laboratory conditions. The results obtained are tabulated. After the experiment program, the panels are analysed using software. The panels are modelled in the software ANSYS Workbench

17.0. The values obtained from both the studies are compared to arrive at specific conclusions.

5. MATERIALS USED FOR MASONRY

Ordinary portland cement 53 grade was used for the present study. The tests were conducted according to Indian Standard recommendations. The physical properties of cement tested are standard consistency, initial setting time, final setting time, specific gravity and compressive strength. The cement tested satisfied the provisions.

Fine aggregate used for the present study is manufactured sand. Fine aggregate under saturated surface dry condition was used for casting. The physical properties of fine aggregate tested were water absorption, specific gravity and bulk density. Sieve analysis of fine aggregate sample was done and particle size distribution curve of fine aggregate is studied. It is observed that the sand belongs to Zone II and satisfied the relevant Indian Standard. The physical properties of burned clay brick were tabulated in Table 1.

Table -1: Physical Properties of Burned Clay Brick

Properties	Test Results	Remarks
Compressive strength	7.8MPa	Belongs to Class 7.5 [15]
Water absorption	17.03%	< 20% is safe upto class 12.5% [15]
Efflorescence	< 50% of area covered by deposit	Moderate efflorescence [15]
Initial Water Absorption	$28.09gm/30in^2/min$	$< 30gm/30in^2/min$ [16]

Portable water which is available at the laboratory premises was used for mixing of cement mortar ingredients.

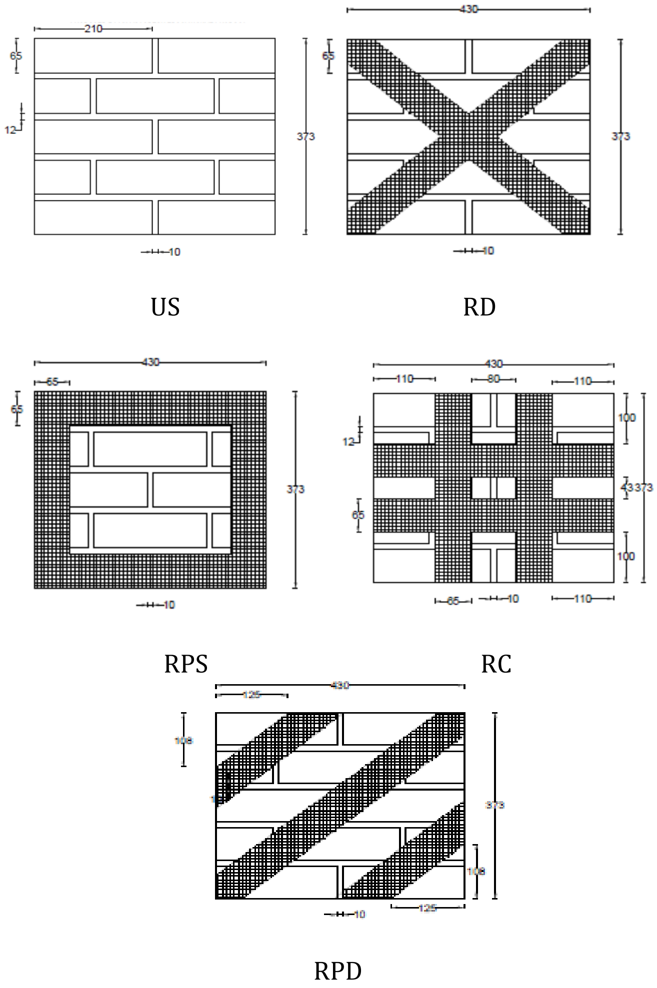
Non-woven high performance geotextiles, manufactured from the finest raw materials produced by the advanced petrochemical industry, using a unique state of the art needle punching technology is used for the study. The physical properties of geotextile from the manufacturer are tabulated in Table 2.

Table -2: Physical Properties of Geotextile

Properties	Value
Thickness	1.4mm
Mass per unit area	$100gm/m^2$
Poisson's ratio	0.28
Young's modulus	1060MPa
Tensile strength	4.8kN/m
Elongation	45%

6. SAMPLE PREPARATION

The failure pattern and the load deformation behavior of the specimen are studied. The brick dimension is 210mm×105mm×65mm. Masonry panels, having dimensions 430mm×373mm×105mm, were constructed in the laboratory environment. The panel consists of 5 rows of brick mortar layers. One panel is kept un-strengthened and used as the reference panel. All other panels are strengthened with geotextile strips of 65mm width. Mortar proportion considered for study is 1:4. The thickness of mortar bed joints and head joints were kept 12 mm and 10 mm, respectively. Each panel was built with 5 courses of brick. The panels are named as US(Un-strengthened), RD (Strengthened Diagonal), RPS (Strengthened Parallel to Sides), RC (Strengthened Cross), RPD (Strengthened Parallel to Diagonal). The masonry bond patterns with and without geosynthetic is shown the Fig. 2.



US

RD

RPS

RC

RPD

Fig -2: The masonry bond patterns with and without geosynthetic.

All test panels were cured for at least 28 days before the application of geotextile. Out of them, three panels were kept un-strengthened, named as US, and considered as reference panel. The remaining panels were strengthened with geosynthetic. The width of the geosynthetic wrapping strip was 65 mm. The geosynthetic was wrapped in one layer on all strengthened panels. Epoxy resin adhesive, mixed with hardener was used to wrap the geosynthetic. Extensive care was taken for the surface preparation before wrapping since premature de-bonding of geosynthetic can occur due to their irregular surface or due to any gap between the geosynthetic and the masonry. A schematic test setup of diagonal compression test is shown in Fig. 3.

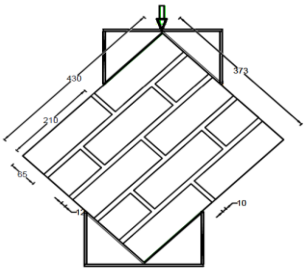


Fig -3: Schematic test setup of diagonal compression test

7. ANALYTICAL STUDY

Analytical study was conducted using ANSYS workbench 17.0. The ANSYS Workbench is an intuitive up-front finite element analysis tool that is used in conjunction with CAD systems and/or Design Modeler. ANSYS Workbench is mainly used for performing structural, thermal, and electromagnetic analyses. The dimensions of the panel, patterns of strengthening are same as the experiment work done. The support and loading are chosen comply with the practical conditions. The discretization is such that, the bricks and the mortar joints had been represented by separate layers of elements. Each type of element was represented with its own properties. Brick and the mortar joint were modeled using the micro-modeling approach representing joints as continuum elements and assuming a perfect bond between the brick unit and the mortar joint. Each model was assumed to be subjected to diagonal compressive load. The end of one diagonal opposite to the applied load, is provided with a metal shoe. The end is considered as fixed supported. Brick and mortar units are modeled using SOLID187 element. Fig. 4 illustrates the element SOLID187. It is a higher order 3-D, 10-node element. It has a quadratic displacement behaviour and is well suited to modelling irregular meshes such as those produced from various CAD/CAM systems. The element is defined by 10 nodes having three degrees of freedom at each node: translations in the nodal x, y, and z directions. The element has plasticity, hyper elasticity, creep, stress stiffening, large deflection, and large strain capabilities. It also has mixed formulation capability for simulating deformations of nearly incompressible elastoplastic materials, and fully incompressible hyper elastic materials.

The mortar, brick and geotextile contacts are modelled using the element CONTA174. It is an 8-node element that is intended for general rigid-flexible and flexible-flexible contact analysis. In a general contact analysis, the area of contact between two or more bodies is generally not known in advance. CONTA174 is applicable to 3-D geometries. It may be applied for contact between solid bodies or shells. The element also allows separation of bonded contact to simulate interface delamination. Detailed illustration of CONTA174 element is shown in figure.

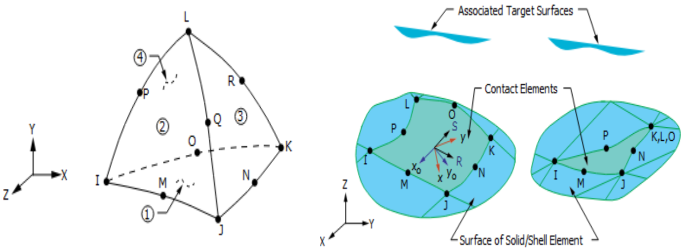


Fig -4: SOLID187 CONTA174 Element

Tetrahedron meshing method is used for the models. Mesh size used for brick and mortar is 20mm and 15mm respectively. Meshing of US panel is shown in Fig. 5.

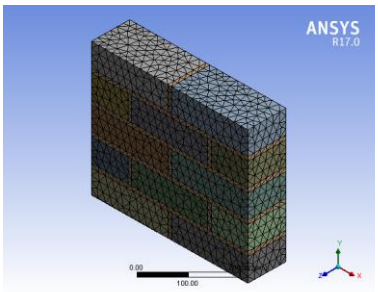


Fig -5: Meshing of US panel

The diagonal compression test mechanism was composed of a set of metallic elements fixed at the one corner of a diagonal end of the panel. In this test, a compressive force was applied gradually along a diagonal end of the specimen to study the in-plane shear behavior of the masonry wall panel. The applied compressive force may cause a diagonal tension in the specimen which in turn led to the failure of the specimen with splitting cracks parallel to the direction of the load. Load is applied as displacement. It is given at the opposite end of the support in a constant rate.

8.RESULTS AND DISCUSSIONS

8.1 Experimental Observations

The behaviour, failure mode, deformation and strength of the test panels, subjected to diagonal compression, is discussed in this section. The un-strengthened panel (US) failed by crushing of brick and splitting of layers. Crushing of brick was the first occurred and it was observed in line with the applied diagonal compressive load, near to the mortar. Further increase in load showed splitting of layers. Brick-mortar rows got detached from the under lying rows. The detached rows slid to the sides. The first row slid first, causing the failure of the structure. The un-strengthened panel failure is summarised as sudden and brittle. The compressive strength observed is 88.2kN. The deformation occurred in diagonal direction is 3 mm. This load and deformation values are considered as reference values, to compare with the results of reinforced panels.

The next panel tested was the panel strengthened along two diagonals (RD). This panel failed by shear. Shear failure is a typical mode of failure of a masonry wall subjected to seismic loads, and it can take place where the principal tensile stresses, developed in the wall under a combination of vertical and horizontal loads, exceeds the strength of masonry. The failure occurred along the brick mortar joints in the diagonal direction. The compressive strength obtained is 127.4kN, which is 44.45% greater than the un-strengthened one. The deformation observed is 4.5mm, which is 50% greater than the un-strengthened one. It shows that, the panel remained stable even after a large load and the corresponding large deformation compared to US panel.

RPS panel was the next studied one. It is observed that the failure was began by the tearing of bottom vertical geotextile strip. The strips at the sides are observed more vulnerable to diagonal loads. They hardly bore the load and started to tear fastly. The shear failure along the mortar brick joints was started just after the lower strip began to tear. The compressive strength obtained is 107.8kN, which is 22.23% greater than the un-strengthened one. The deformation observed is 3.5mm, which is 16.67% greater than the un-strengthened one.

RC pattern was the next studied one. In this case, the failure was started by separation of brick-mortar layer and subsequent partial slid to the side. Sliding failure occur in the situation of low vertical load and poor quality mortar, seismic loads frequently cause shearing of the wall, causing sliding of the upper part of the wall at one of the horizontal mortar joints. RC pattern was highly reinforced compared to other patterns. That is 65.08% reinforcement to total area. Due to this high reinforcement, the layers did not slid completely to the sides. The failure was complete after the crushing of some interior brick. The compressive strength obtained is 112.7kN, which is 27.79% greater than the un-strengthened one. The deformation observed is 4mm, which is 33.33% greater than the un-strengthened one.

The next panel tested was the panel RPD. This panel was failed by two factors. Failure was started by separation of one layer. This separation led to the beginning of the debonding of geotextile strips. Sliding of layer was increasing corresponding to the debonding of geo textile strips. The compressive strength obtained is 122.5kN, which is 38.89% greater than the un-strengthened one. The deformation observed is 4mm, which is 33.33% greater than the un-strengthened one. It shows that, the panel remained stable even after a large load and the corresponding large deformation compared to US panel.

Maximum crushing load was observed for the RD pattern, which is 127.4kN. The deformation bore was also high for the RD pattern. The crushing load increased from un-strengthened to RD strengthened. The failure mode of each panel is shown in Fig. 5. The maximum crushing loads are given in Table 3.

US RD

RPS RPD

RC

Fig -5: The failure mode of each panel

Table -3: The maximum crushing loads and deformations

Pattern	Crushing Load (kN)	Average Deformation (mm)	% Increase in Load	% Increase in Deformation
US	88.2	3	-	-
RD	127.4	4.5	44.45	50
RPS	107.8	3.5	22.23	16.67
RC	112.7	4	27.79	33.33
RPD	122.5	4	38.89	33.33

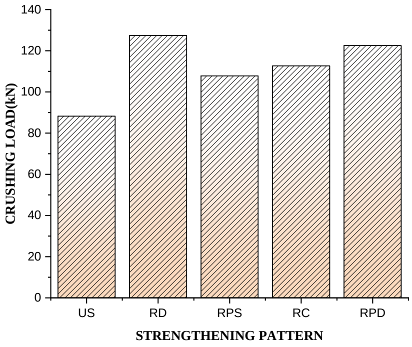


Chart -1: Crushing load Vs pattern graph

8.2 ANALYTICAL OBSERVATIONS

The micro level approach led to structural analyses characterized by great computational effort. Nevertheless, this approach can be successfully adopted for reproducing experimental tests. The simulation was carried out in sub-steps. The failure of masonry under concentric compression is related to the interaction between the masonry unit and the mortar as a result of their differing deformation characteristics.

Shear stress distribution of the panels are studied. The maximum shear stress observed for the US panel is 11.73MPa. The shear strength of US is considered as the reference value to compare with the rest of the models. The maximum shear stress observed for the RD, RPS, RC and RPD panels are 26.216MPa, 19.286MPa, 19.46MPa and 23.309MPa respectively. As the diagonal load was applied on the wall panel specimen, the stress was formed as a diagonal band along the direction of the application of the load.

The maximum deformation observed for the US panel at the failure load is 3.27mm. The deformation of US is considered as the reference value. The deformation obtained from the analytical study showed a variation of 0.27mm, which is 8.25% from the experimental study. The maximum deformation observed for the RD, RPS, RC and RPD panels are 4.62mm, 3.86mm, 4.38mm and 4.21mm respectively. The deformation obtained from the analytical study showed a variation of less than 10% from the experimental study. The RPD panel was loaded in two ways. In the first model, load is given from the end parallel to geotextile strip and the other is perpendicular to the geotextile strip. The first case showed more ultimate load and deformation. This study has led to the assumption that, geotextile strips along the load occurring diagonal prevent crack formation along the diagonal and thus resist more load. When the load is along perpendicular direction, the geotextile strips are in great stress and vulnerable to failure.

The ultimate load obtained for US panel is 91.63kN which is 3.9% greater than the value obtained from the experiment. The ultimate load obtained for other panels are,132.68kN for RD panel,108.87kN for RPS panel, 108.87kN for RC panel and 108.87kN for RPD panel. The loads showed less than 5% variation from the experimental results. The experiment program may show variance due to various working and environmental conditions. The load vs deflection graph is plotted in chart 2.

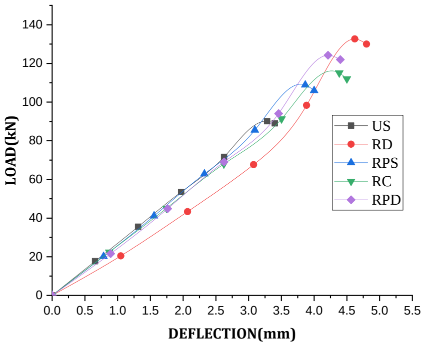


Chart -2: Crushing load Vs deflection graph

9. CONCLUSIONS

The in-plane strength of solid clay brick masonry panels, with different strengthening patterns, using non-woven geotextile of geosynthetic, were studied under diagonal compression tests. The panels were strengthened on one side with different geometric configurations. Based on the present study, the following remarks are outlined:

1) In the experimental programme, the strengthened panels increased the failure load 44.45% from US to RD.
2) The un-strengthened panel showed brittle failure.
3) It was also observed that the panel with strengthening gave more stiffness.
4) The experiment study showed that the shear resistance of the panels are also significantly increased for strengthened panels

REFERENCES

[1] Hasim Ali Khan, Radhikesh Prasad Nanda, Diptesh Das "In-plane strength of masonry panel strengthened with geosynthetic", Construction and Building Materials, vol. 156, 2017, pp. 351-361

[2] M.T Mansourikia, A. Hoback "Retrofit of Unreinforced Masonry Walls Using Geotextile and CFRP", Electronic Journal of Structural Engineering, vol. 156, 2014, pp. 351-361

[3] Najif Ismail, Jason M. Ingham "In-plane and out-of-plane testing of unreinforced masonry walls strengthened using polymer textile reinforced mortar", Engineering Structures, vol. 118, 2016, pp. 167-177

[4] Bipin J Agrawal "Geotextile: It's Application to Civil Engineeering – Overview", National Conference on Recent Trends in Engineering & Technology ,2011

[5] N.G. Shrive "The use of fibre reinforced polymers to improve seismic resistance of masonry", Construction and Building Materials, vol. 20, 2006, pp. 269-277

[6] S.Chuang, Y.Zhuge, P.C. McBean "Seismic Retrofitting of Unreinforced Masonry Walls By Cable System", 13th World Conference on Earthquake Engineering, 2004

[7] Mohamed A. ElGawady, Pierino Lestuzzi, and Marc Badoux "Static Cyclic Response of Masonry Walls Retrofitted with Fiber-Reinforced Polymers", Journal of Composites for Construction, vol. 11, 2007, pp. 50-61

[8] Kalali, M.Z. Kabir Cyclic "behavior of perforated masonry walls strengthened with glass fiber reinforced polymers", Transactions A: Civil Engineering, vol. 19, 2012, pp. 151-165

[9] M. Isabel, M. Pinto "Geotextile Reinforced Brick Faced Retaining Walls", geo textiles and geo membranes, vol. 14, 1996, pp. 449-464

[10] Saleh H. Alsayed, H.M. Elsanadedy, Zaki M. Al-Zaheri, Yousef A. Al-Salloum, H. Abbas, "Blast response of GFRP-strengthened infill masonry walls", Construction and Building Materials, vol. 115, 2016, pp. 436-451.

[11] Robert F. Blanks and Henry L. Kennedy, The Technology of Cement and Concrete, Volume 1, Concrete Materials, John Wiley & Sons, pp. 52

[12] IS 12269:2013,Indian standard– "Ordinary Portland Cement, 53 Grade – Specification", Bureau of Indian standards, New Delhi, India.

[13] IS 383 : 1970, Indian standard- "Specification for Coarse and fine Aggregate from Natural Sources for Concrete", Bureau of Indian Standards, New Delhi, india

[14] Properties of Concrete, A.M. Neville, Addison Wesley Longman Ltd., pp. 126

[15] IS 1077 : 1992, Indian standard- "Common burnt clay building bricks – specification", Bureau of Indian standard, New Delhi, India.

[16] ASTM C67-01 : 2002, American standard- " Standard Test Methods for Sampling and Testing Brick and Structural Clay Tile", ASTM International, West Conshohocken, PA.

[17] IS 3495 Parts 1 to 4 : 1992, Indian standard- " Methods of tests of burnt clay building bricks", Bureau of Indian standard, New Delhi, India.

[18] IS 2260 : 1990, Indian standard- " Code of practice for preparation and use of masonry mortars", Bureau of Indian standard, New Delhi, India.