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# TIMBER-MASONRY COMPOSITE SYSTEMS FOR RETROFIT OF UNREINFORCED MASONRY WALL

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**Abstract**: The need for developing new and sustainable retrofit techniques is the consequence of an increasing interest in the preservation of old construction. The global acceptance of any retrofit techniques for unreinforced masonry (URM) often depends on the availability, economy and ease of application of the proposed technique. Therefore, this study aims to investigate the possibility to adopt timber-based retrofit techniques considering that timber is economical, can be easily sourced around the globe and can be considered as a sustainable material. In this paper, the outcome of an experimental campaign to evaluate the flexural performance (out-of-plane load capacity and deflection) of oriented strand board (OSB) timber-masonry composite wall is presented. The experiments involved subjecting both plain URM and timber-masonry composite wall to out-of-plane loading using quasi-static (monotonic) loading scheme. The maximum load and out-of-plane displacement causing a full cracked state in the plain wall was observed. These values were compared to that of timber-masonry composite to estimate the efficiency of the proposed retrofit techniques. The results show a substantial improvement in the out-of-plane performance of the wall retrofitted.

**Keywords:** Composite system, Experiment, Masonry, OSB Timber, and Retrofitting.

## Introduction

Retrofitting of existing structures for improved performance is continually becoming an important issue in recent years. In the case of old unreinforced masonry (URM) buildings, the consideration is mainly for improved response to lateral forces since masonry has proven history of durability and resistance to normal gravity and compression loading but have low tensile strength (Ramos and Lourenço, 2004). Drysdale et al. (1993) among others demonstrated that URM attains partial to total collapse when subjected to extreme loading like excessive out-of-plane loads and earthquakes because they do not provide adequate resistance against flexure. These collapses are sometimes resulting in large-scale loss of lives and properties. For instance, Jorgustin (2011) claimed that around 709,589 human lives have been lost due to building collapse in 10years starting from the one in India in 2001 to that of Japan in 2011. Therefore, the priority of any retrofit techniques is to improve the performance of existing URM buildings and also minimise the risk of structural collapse and damages due to excessive out-of-plane loading.

In most cases, the outcome of these retrofits techniques is composite systems such as FRP wrap and steel bracing of masonry buildings. An alternative to this system is the proposed timber-masonry composite. Although, the use of timber panel for energy retrofit in existing masonry has been extensively studied and has found its regular use in practice, its use for structural retrofit of URM has not been fully explored. This research thus explores the possibilities of using oriented strand board (OSB) timber panels in retrofit of masonry building.

This paper presents work to discuss the application of timber-masonry composite in retrofit of URM walls. The overall experimental program for investigating the proposed techniques is presented with references to the authors' earlier works where the results of previous tests have been discussed. Thereafter, an experimental program involving subjecting both plain and timber retrofitted URM walls to out-of-plane loading using quasi-static (monotonic) loading scheme is presented here. The results of the experimental works are also presented and analysed to evaluate the performance of the proposed OSB retrofit techniques of URM walls.

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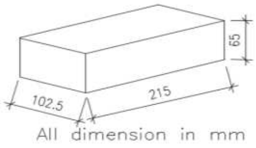
## Research program

### Stage 1: Material characterization

Brick Unit

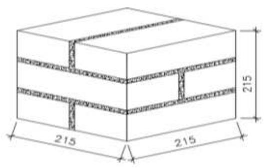



Brick units tested for dry density, water absorption, compressive strength, modulus of elasticity, and Poisson’s ratio

Mortar

Fresh mortar tested for consistency: dropping ball and flow table test. Harden mortar cube tested for compressive strength

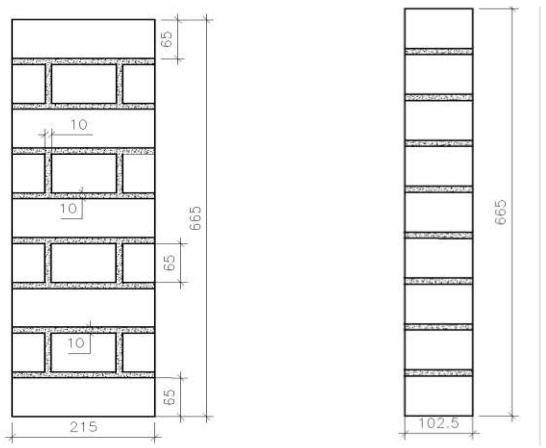
Masonry Cube




Masonry cubic specimens tested for compressive strength

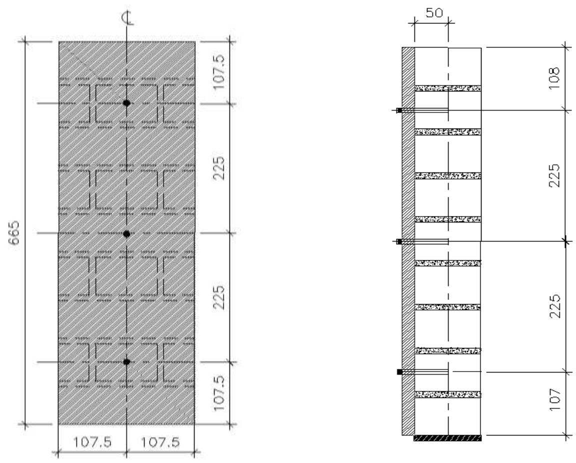
### Stage 2: Flexural bond strength of masonry prism

Plain MP




3 plain MP specimens tested

Retrofitted MP

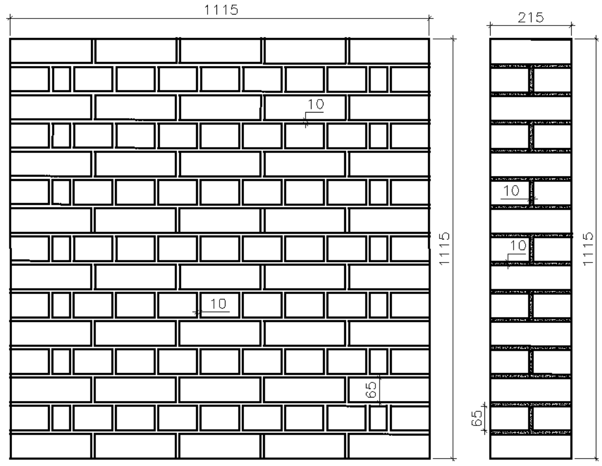



3 MP specimens retrofitted with C1: adhesive anchor

3 MP specimens retrofitted with C2: mechanical connection

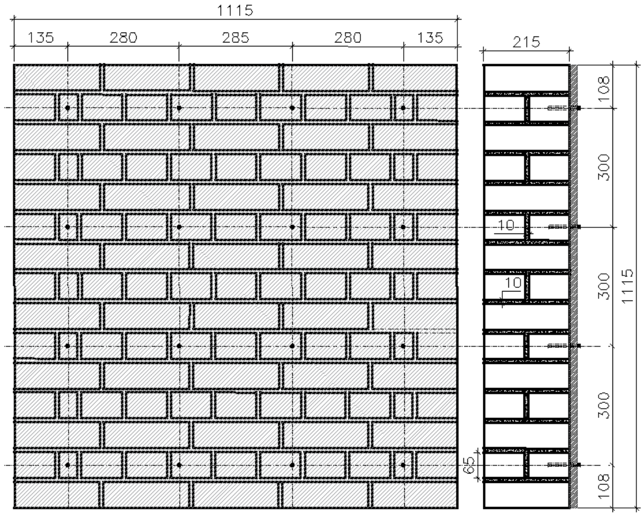
**Stage 3: Flexural strength of masonry wall**

Plain wall



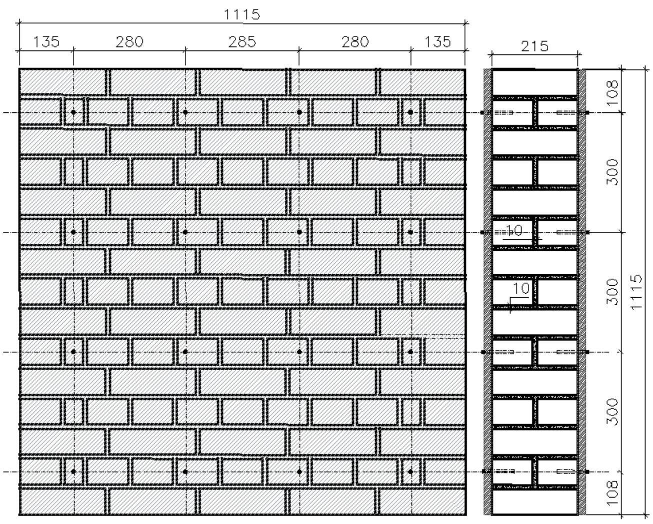

2 plain wall specimens tested

One sided retrofitted wall




2 one sided retrofitted walls tested

Two sided retrofitted wall




2 double sided retrofitted walls to be tested

Table 1. Full experimental program

Table 1 presents the full experimental campaign for the study. The program is articulated into the three main following stages:

1. Material characterization: Dauda et al (2018) has discussed in full the experimental characterisation of mechanical properties of masonry components (UK fired clay solid bricks and mortar). The reasons for selection of each materials used in this study have also been highlighted in the referenced paper.
2. Small-scale test (flexural bond strength of masonry prism): Results from nine out-of-plane flexural bond strength tests in form of four-point bending test performed on masonry prisms have been presented in Dauda et al (2019).
3. Big-scale test: out-of-plane flexural strength of masonry wall; In this paper, the part results of an ongoing large-scale experimental campaign on 1115 x 1115 x 215mm single leaf, double wythe solid URM walls is presented.

## Out-of-plane flexural strength of timber-masonry composite wall

### Material

Masonry test specimens were built using an engineering class B fired clay solid bricks with UK standard size 215 x 102.5 x 65mm (length x thickness x height). The brick unit has an average strength of 87 N/mm$^2$ (CoV of 7%) and 4% water absorption (CoV of 5%). The unit strength affects the behaviour of the specimens under loading and the water absorption is important for the bond between the brick and mortar. If the brick water absorption is too high, the mortar dries up quickly causing dry shrinkage in mortar and if the bricks absorb more water than recommended it causes reduction in strength and durability of the specimen. For these reasons, it is important to clarify these two significant properties (brick strength and water absorption) in this paper, other properties of the bricks can be found in Dauda et al. (2018).

The mortar used for the construction of all specimens is type N (general purpose) mortar mix with ratio of 1:1:6 (Type II Cement: aerial lime: sand) by volume. The mix ratio gives and average dropping value of 10.2mm and average cube strength of 7.1N/mm$^2$ at 28 days. For conformity, the mortar was sampled during the construction of all specimens and gave comparable results.

For the retrofit materials, an 18mm thick engineered wood-based panel (OSB type 3) was selected for this study. The board has an average density of 650kg/m$^3$, internal bond strength of 0.3N/mm$^2$, and modulus of elasticity of 3000N/mm$^2$ and 1400N/mm$^2$ for both bending in major and minor axis, respectively (Anon, 2018). In addition, the best performed connection i.e C1: adhesive connection identified from small scale test (Dauda et al. 2018) was used. The adhesive anchor connection is a combination of FIS V 360 S injection mortar and FIS A4 anchor rod selected from Fischer® group.

### Wall specimen construction

Three single leaf, double wythe URM wall specimens of 1115 x 1115 x 215mm (length x height x width) were constructed. The geometry of the walls means that each of the two wythes of the wall has 15 courses with each course having 5 units of brick bonded together by 10mm thick mortar joint. The walls were built in English bond consisting of alternate rows of headers and stretchers which is the oldest form of brick bond popular in UK until the late 17$^{th}$ century. The specimens were constructed on 1315 x 150 x 350 mm (length x height x width) reinforced concrete (RC) footing with 1mm thick polymer (nylon) placed on top of the RC footing to prevent the bottom of the wall from bonding to the RC to avoid toe crushing failure during testing.

The wall specimens (Fig. 1) were constructed and tested in place, no movement of the wall to prevent any significant disturbance of the wall. The specimens were cured by wrapping them with a polythene sheet for 14 days and then cure for further 14 days in laboratory under normal air condition. For the specimens that were retrofitted with OSB timber panel, the brick units were pre-drilled in the predetermined connection location to avoid disturbing the specimen after construction which might have caused the failure of the joint before testing.

Plain wall One sided timber Retrofitted wall

Figure 1. Wall specimen for plain and retrofitted sample.

Test matrix

Out-of-plane load control tests have been performed on three wall specimens at the moment as indicated in table 2. Two walls were tested as plain specimen with PW1115-1 tested with a vertical pre-compression load that varies as the applied out-plane load increases while PW1115-2 was tested with a constant pre-compression load. The last wall of the three specimens tested so far is a URM wall retrofitted at the back using an 18mm thick OSB type 3 and adhesive anchor system.

| **Specimen ID** | **Description** | **Vertical Loading Scenario** |
|---|---|---|
| PW1115-1 | Plain specimen | Variable pre-compression load |
| PW1115-2 | Plain specimen | Constant pre-compression load |
| 1SRW1115-1 | Retrofitted specimen | Constant pre-compression load |
| PW stands for Plain wall<br>1SRW stands for one side retrofitted wall | | |

Table 2. Test matrix

Test set-up

The test wall specimens constructed on the RC footing were initially rested on four 60mm square pipes at each corner to allow the placement of 50mm diameter roller under the specimen before the start of load application. The specimens were tested with simply supported boundary condition and vertical pre-compression load on top of the wall. After all the setup has been completed, the 50mm diameter roller was slide under the specimen and the four 60mm square pipes were removed. This is to allow the wall specimen to rest on the 50mm diameter cylindrical roller with axis of the roller parallel to the face of the specimen to allow it to freely rotate around its base while deflecting out-of-plane and prevent restrained end condition.

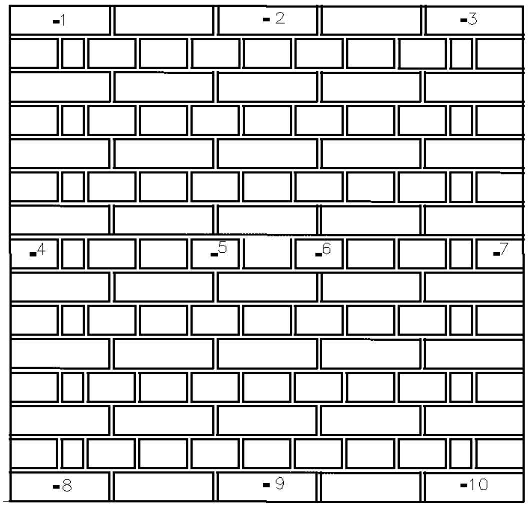
The simply supported boundary condition of the test specimen was achieved by supporting the back of the wall specimen across the middle of the top and bottom courses with supporting steel frames connected to an existing stanchion at top and bottom respectively. Between the face of the wall and the supporting steel is a Ø25mm rollers fixed to the supporting steel frames to provide for smooth distribution of load action across the length of the wall and avoid point contact. On the front side of the specimen, two number of 50 x 5mm thick metal plates were fixed at 1/4th and 3/4th of the height of the specimen each to provide contact for which the loading roller rest on (Fig. 2). The loading is such of a four-point testing arrangement where the loads were applied on the specimen using an Hi-force hydraulic jack and distributed through a spreader beam. The spreader beam spanned between two Ø25mm cylindrical rollers placed across 1/4th of the height from top and bottom support of the test wall specimen. The direction of the load application is perpendicular to the wall specimen surface. The test is load controlled, and the loading scheme is such that an initial load is applied continuously at a rate of 1kN/min for up to 5KN and then maintains the load for 5mins period. The reasons for maintaining this load is to permit the assembly to come to substantial rest prior to taking the second set of reading and to observe any time-dependent deformation and load redistribution (ASTM E72). The load step (Fig. 3) is repeated continuously for 10KN, 15KN, 20KN, 25KN, and 30KN load and maintain for 5mins period at each load step. Thereafter, increase the load continuously to the failure of the test specimen.

For the constant pre compression load, a 305 x 305 x 240 UC section amounting to 3kN load was placed on top of the wall. In the case of variable vertical load, a hydraulic jack is placed on top of the UC beam with an initial load of 10KN (self-weight of UC inclusive) which further increases as the applied out of plane load increases.

Instrumentation

The values of the applied load on the prism were monitored using a 200KN capacity ring load cell. Simultaneously, 10 linear variable displacement transducers (LVDTs) were used to record the deflections of the test specimen along the wall centre, mid top and bottom. The locations of these gauges are as shown in figure 2. All the ten LVDTs used during the test were fixed on an independent steel tripod stand, which is not connected to the test rig. The force and the displacements were real-time monitored by connecting the measuring equipment (load cell and LVDTs) to an electronic acquisition unit interfaced with a computer.


Typical wall test arrangement




Position of LVDTs on wall

Figure 2. Test setup

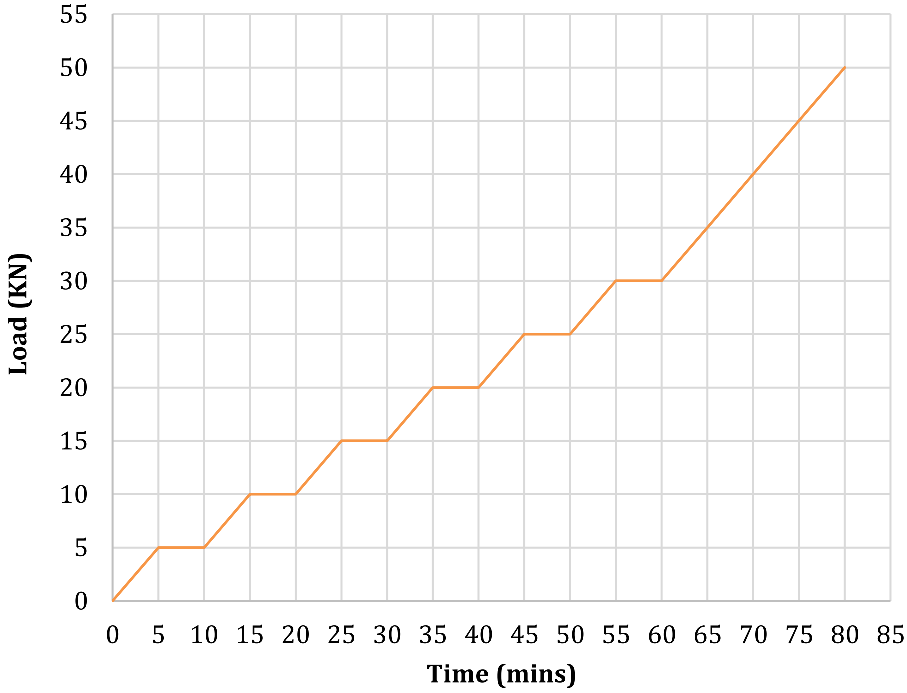


Figure 3. Applied out-of-plane load history.

## Experimental Results

In order to obtain the baseline for estimating the effectiveness of the retrofit technique, a reference test of a plain wall (PW) was first conducted and the out-plane load capacity and the corresponding displacement at the peak load were investigated. Figure 4 shows the load displacement curve for the tested specimen. For the two PW specimens, the load displacement curve shows a matching quasi-linear behaviour up to about 15KN load, which corresponds to the onset of crack formation in PW1115-2. Thereafter, the load continuously increases with a little increase in the out-of-plane displacement prior to the failure of the specimen. At the failure point, the displacement suddenly increases; this is due to the brittle nature of the failure pattern. The maximum load attained by PW1115-2 is 38.33KN and the corresponding maximum associated displacement at this point is 5.25mm.

Meanwhile, specimen PW1115-1 appears very stiff (Fig. 5) because the applied pre compression loads keep increasing as the load increases, preventing significant out of plane displacements . However, at about 25KN load capacity, there is an onset of crack 1 in the specimen which later failed at maximum load of about 40KN with a corresponding displacement of 3.1mm. Then, because of the increasing pre-compression, there is a redistribution of the stresses in the wall which then allow the load to increase again with another crack formation (crack 2) at a load of 56KN. To avoid the collapse of the wall and damage to the instrument, the loading was stopped after the failure of crack 2. It is obvious that higher pre compression loads increases the out-of-plane capacity of the wall. However, the increase of pre compression load as the out-of-plane loads increases is not realistic. Therefore, PW1115-2 with a constant pre-compression load is chosen as the baseline specimen to evaluate the effectiveness of the timber-retrofit technique. For this sake, figure 5 shows the load-displacement curve of PW1115-1 up to crack 1 formation.

Figures 5 also show the load displacement curve of the retrofitted specimen. The developed retrofit technique clearly demonstrates a substantial increase in the out-of-plane load capacity, with 1SRW1115 reaching 116KN. In particular, the specimen showed a first crack at 52KN load, a second crack at 83KN load and a third final crack at 116kN. If compared with the plain wall PW1115the retrofitted wall shows a about 300% of strength gained. Also, the brittle behaviour of the plain wall has also been improved by the timber, so that the specimen could displace more in the out-of-plane direction which then avoid the sudden collapse of the wall (Fig. 5).

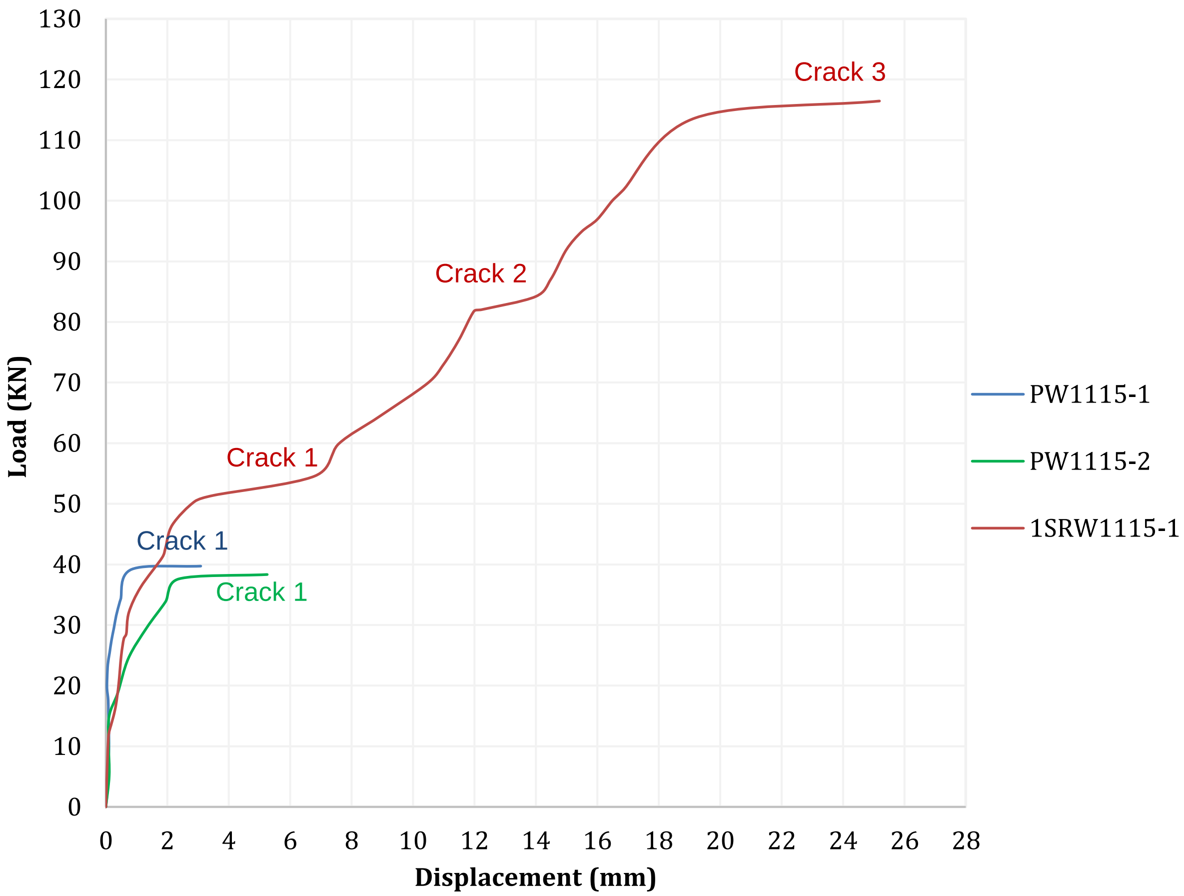



Figure 4. Load vs Displacement curve for specimens.


PW1115-1 PW1115-2 1SRW1115

Figure 5. Specimen samples at the end of testing.

## Conclusion

In this paper, a new retrofit technique for URM wall has been presented. The preliminary study (Dauda et.al, 2019) has shown that the use of oriented strand board (OSB) type 3 connected with adhesive anchor in retrofit of URM wall is promising. Therefore, the extension of earlier study is presented here in terms of the out-of-plane loading test on 1115 x 1115 x 215mm single leaf, double wythe solid URM walls. The main conclusion from this study is that oriented strand board (OSB) type 3 can considerably increase the flexural capacity of masonry wall when subjected to out-of-plane loading. An astonishing increase of about 300% load capacity can be achieved in a double wythe masonry wall and can be up to about 500% increase in a more weaker wall such as single leaf masonry wall as previously demonstrated in the earlier study (Dauda et.al 2019).

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