Experimental Study on the Effect of Horizontal Reinforcement on the Shear Strength of Concrete Masonry Walls

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Abstract: **The vulnerability of unreinforced masonry walls (UMW) to seismic forces led to the use of horizontal reinforcement to improve the performance of the masonry walls and to increase (as thought) the resistance of the walls to horizontal forces. There is no doubt that the use of horizontal reinforcement enhances the post crack performance of the walls, but there has been a debate of whether the use of horizontal reinforcement increases or does not affect the overall shear resistance of the masonry walls. An experimental program was designed to examine the effect of horizontal reinforcement in bond beams and its distribution on the shear resistance of the walls. The results showed that the use of reinforcing rebars in bond beams had no significant effect on the maximum shear resistance of the walls. Also, distributing the same area of reinforcement over the height of the walls did not affect the maximum resistance of the walls but affected the crack pattern. Statistical analysis methods were used to verify the obtained results.**

Keywords: **Shear resistance, masonry, bond beams.**

1. INTRODUCTION

The effect of using horizontal reinforcement in masonry walls has been extensively studied by many researchers in order to explore its benefits and advantages on the shear behavior of masonry walls. The investigations was divided in two main groups, where some researches focused on studying the effect of bed joint reinforcement e.g. Schultz et al. 1998, Jasinski 2010 and Oan and Shrive 2010.While the other group of researchers investigated the effect of horizontal reinforcement embedded in bond beams e.g. Scrivener 1969, Matsumura 1987, khattab and Drysdale 1993 and Nolph and ElGawady 2012

In both cases, the reinforcement has proven to improve the post crack behavior of the masonry walls, but the effect of the shear reinforcement on the maximum shear resistance of the walls has been a point of debate of whether it increases or does not affect the shear resistance. For example Voon and Ingham 2006 showed that the horizontal reinforcement increases the shear resistance of the walls, while other researchers showed that adding the horizontal reinforcement does not affect the maximum shear resistance e.g. Oan and Shrive 2014. Also, Shing et al. 1989 showed that the initiation of diagonal cracks depends on the applied axial load and the tensile strength of the masonry units and does not depend on the amount of reinforcement which supports that the resistance of horizontally reinforced walls is independent of the steel content of the wall.

Grouting the masonry walls can increase the shear resistance of the walls as have been proved in many studies e.g. Voon and Ingham 2002. In the same way, if a grouted beam is added to the wall (i.e. bond beam) the shear resistance will increase and that is what some investigators ignore when studying the effect of horizontal reinforcement in bond beams and relate the increase in shear resistance to the shear reinforcement only and ignore the effect of adding another structural element (the bond beam) to the wall which divides it into two panels and increase the resistance e.g. Ghanem et al.1992 and Maleki et al. 2009.

The masonry in not a homogeneous material and there should be some variation in results, for example the Canadian Code (CSA 2004) states that when testing five prisms to obtain the compressive strength of masonry if the variation in results is more than 15%, then ten prisms should be tested, which means inclusively that it allows for variation in results up to 15%, and hence one can argue about the significant effect of shear reinforcement where most of the researchers who showed that horizontal reinforcement increases the shear resistance of walls had results showing less than 10% increase in shear resistance which can be insignificant e.g. Gouveia and Lorenco 2007, Schultz et al.1998. More over most of the carried out research was based on testing one of kind of each specimen when comparing the different configuration of walls which can be a point of argument about the accuracy of the conclusions made.

Therefore, an experimental program was designed to test the effect of shear reinforcement in bond beams with three replicate of each test specimen and the control walls was designed to have bond beams without reinforcement to study the effect of reinforcement separately from the effect of adding grouted beam in the wall.

2. EXPERIMENTAL PROGRAM

The experimental program included testing a total number of twelve partially grouted concrete masonry walls, the walls were divided into four different groups (A, B, C and D) with three replicates of the same reinforcement configurations in each group to allow for the use of statistical analysis.

All the walls were 1.8 m long by 1.8 m high i.e. having an aspect ratio of one. The walls were built on a C-Chanel steel beams with three vertical 15M rebars located at the first, fifth and ninth core from either sides. Group A was the control group without any horizontal reinforcement and with two bond beams located at the fifth and ninth courses, group B was similar to group A but the beam at the fifth course had a 15 M rebar as horizontal reinforcement, group C had three bond beams located at the third, sixth and ninth courses with a 15 M rebar at the third course while group D similar to group C but having reinforcement of one 10 M rebars located at third course and another 10 M rebar at the sixth course The horizontally bars were bent 90o around the outermost vertical rebars of the walls and were tied with thin wires to the three vertical rebars. The upper course was grouted in all the walls to form a rigid top for the wall to allow for the transfer of the horizontal load from the upper steel beam to the wall as a uniform load, Figure 1 shows the different configurations of the tested walls.

The walls were built in two phases, the first phase included the walls of groups A and B, and the aim of this phase was to check the effect of the horizontal reinforcement on the shear resistance of the walls. While the second phase included groups C and D to examine the effect of distributing the reinforcement along the height of the walls.

For each of the two phases, the construction of the walls took place in three days. In each day, two walls were built one from each of the two groups of the same phase so the walls are exposed to the same conditions and that can create more reliable results in the comparison of the two groups.

2.1Material Properties:

All the walls were all built in face-shell bedding using type S mortar by the same experienced mason. Standard concrete blocks of nominal dimensions of 400*200*200 mms with two hollow cells in each block were used. These concrete masonry units had an average compressive strength of 30 MPa. As each wall was constructed, the mortar was sampled and six 50 mm mortar cubes formed. Three of these mortar cubes were tested at 7 days of age and three at 28 days. For each grouted wall, six cylinders were sampled during the casting of the grout, with again three being tested 7 days and three 28 days after casting. The average compressive strength for the mortar cubes was 18.7 MPa and the average compressive strength of the grout was 23.8 MPa.

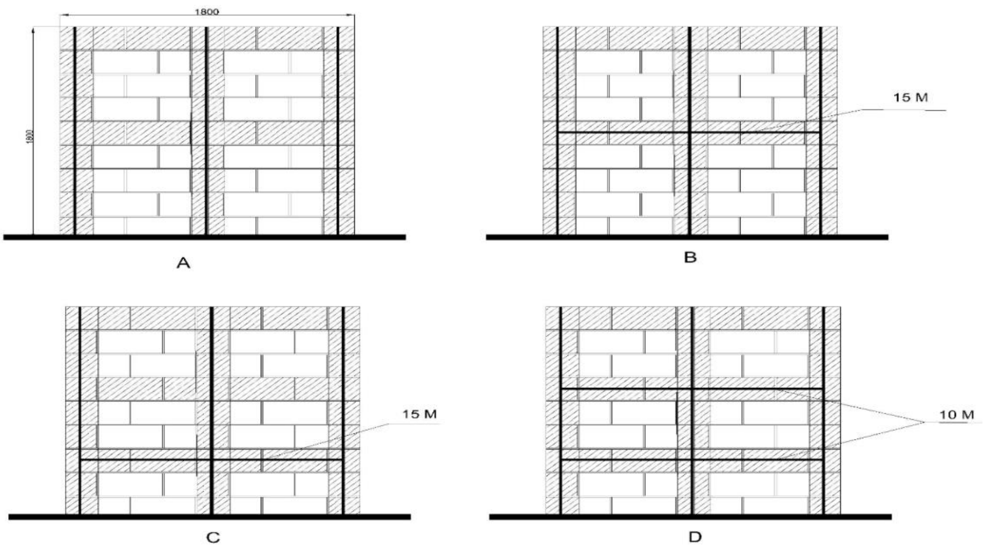

Fig 1: Different types of tested walls.

2.2Testing setup and instrumentation:

The walls were subjected to bi-axial monotonic loading, where the vertical load was first applied by two vertical actuators of capacity 1.5 Mega Newton each and 250 mm stroke. The load was applied at a rate of 1 kN/sec until the desired level of stress (0.5 MPa based on the net area of the wall) was achieved then the two actuators were placed in force control mode to maintain the same level of axial stress during the whole experiment.

For the racking load, a 500 kN actuator was used with a stroke of 150mm to apply the load and the load was transferred from the actuator to the beam by means of two steel arms (HSS 200x100x10) which were connected to a steel beam (W450x140) placed on top of the wall. A steel rod which acted as a pin connection between the arms and the middle of the top beam. The beam had a welded bead pattern on the bottom flange at the wall connection to increase the friction at the interface and increase the bond between the walls and the steel beam while transferring the horizontal force to the wall. The steel beam was mortared to the wall using quick set mortar. Figure 2 shows the mechanism used to apply the vertical and horizontal loads.

The horizontal load was applied at 0.05 mm/sec until the walls cracked and the ultimate load dropped to 80% of its value which was considered to be the end point of the experiment.

Fig 2: Load application mechanism.

The walls were fixed to the floors using four bolts from each side that tightened the base beam to the floor, and an impact gun was used to tighten the bolts to prevent the uplifting of the walls. Nine LSC's were used to monitor the displacements of the walls, where three were used to monitor the displacement along the height of the wall (bottom course, middle course and top course), one LSC was place to measure the sliding of the upper steel beam, one was used to measure the sliding of the lower steel beam, one was used to measure the vertical displacement of the top steel beam, another one was used to measure the displacement of the upper course of the wall, one LSC was used to measure the vertical displacement of the lower course to and the last LSC was used to measure the vertical displacement of the base steel beam, Figure 3 shows the instrumentation.

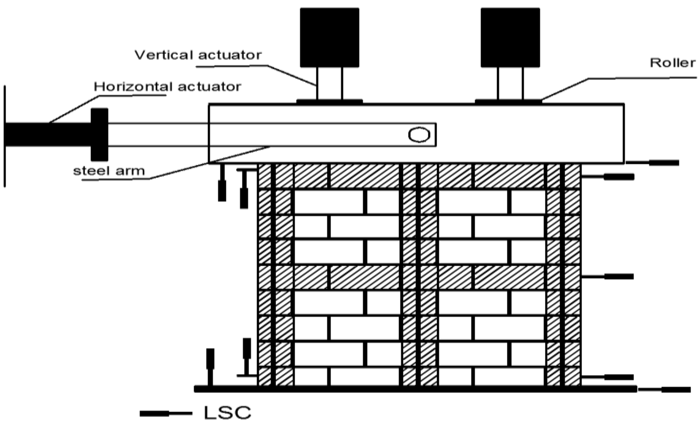

Fig 3: Instrumentation.

TABLE 1: Properties of the tested walls.

Wall		Horizontal Rft.	f mortar (MPa)	f grout (MPa)	Vmax (kN)	Max. displacement* (mm)
A	1	-	17.9	24.1	134.6	15.3
	2	-	20.0	24.6	133.0	12.6
	3	-	18.8	23.8	125.7	9.7
B	1	15 M @mid height	17.9	24.1	129.2	16.6
	2	15 M @mid height	20.0	24.6	142.2	10.3
	3	15 M @mid height	18.8	23.8	157.9	18.6
C	1	15 M @ 1/3 height	17.6	22.3	147.3	13.4
	2	15 M @ 1/3 height	19.1	24.3	145.4	16.3
	3	15 M @ 1/3 height	18.7	23.9	149.5	24.2
D	1	10 M @1/3 height + 10 M @2/3 height	17.6	22.3	138.6	12.9
	2	10 M @1/3 height + 10 M @2/3 height	19.1	24.3	151.5	13.7
	3	10 M @1/3 height + 10 M @2/3 height	18.7	23.9	151.8	19.8

*Maximum displacement was taken as the displacement just before the sudden drop in load.

3. RESULTS AND DISCUSSION

All the walls failed as intended in diagonal shear, the walls behaved similarly; where at the beginning of the test steel base beam starts to deform to a certain point and then the wall starts to pick up the load and starts cracking at the tension side of the wall. Figure 4 shows a typical load-displacement curve for the tested walls.

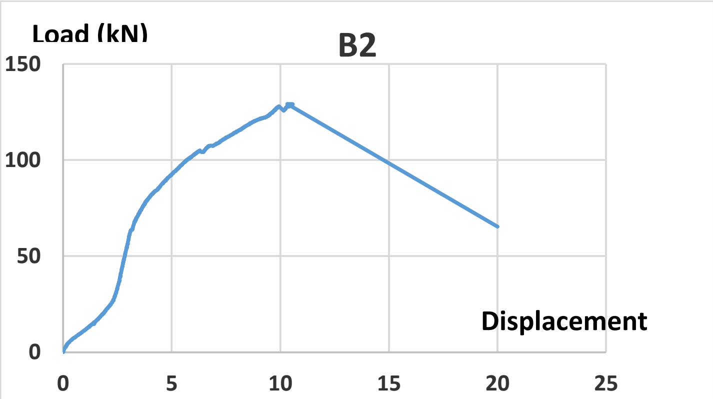

Fig 4: Load- Displacement curve.

For group A, the walls had and average shear resistance of 131.1 kN with a coefficient of variation 3.6%. All the three walls behaved in the exact same manner where the cracks started first at the lower part of the wall (under the bond beam) and by increasing the racking load the cracks increased until at a certain point the walls failed suddenly by a big diagonal crack leading to a complete failure of the walls Figure 5 shows the mode of failure of this group.

For group B, the walls had and average shear resistance of 143.1 kN with a coefficient of variation 10.0%. Similar to the walls of group A, the walls of group B had initial cracks at the lower part of the walls then the vertical rebar at the tension side separated from the base steel beam followed by the formation of a wide diagonal crack and sudden drop in the load. For the walls of this group, a tension cracks appeared at side of the wall at tension side accompanied with an uplift of the walls which was characterized by a gap between the walls and the base beams. The gap increase with increasing the racking load till the first vertical rebar at the tension side separated from the base beam making a very high sound accordingly, the walls failed suddenly with a wide diagonal crack. Figure 6 shows uplift and the tension cracks at the side of the wall.

Fig 5: Failure mode of type A.

(a) **(b)**

Fig 6: Uplift (a) and tension cracks (b).

The walls of group C had the most consistent results among the four groups where the average shear resistance was 147.4 kN with a coefficient of variation of only 1%, while the average shear resistance of the walls of group D was 147.3 kN with a coefficient of variation of 5%. The mode of failure of these two groups was similar to that of group B. Both groups C and D had modes of failure similar to that of group B.

It was observed that the bond beams blocked the path of the cracks and prevented them from progressing, Figure 7 shows the effect of the bond beams on the crack patter where the crack either stops at the boundary and other set of cracks starts in case of reinforced beam or the crack reaches the beam then changes its angle to a more vertical one.

(a) Unreinforced bond beam **(b) Reinforced bond beam**

Fig 7: Effect of bond beams on the crack pattern.

4. STATISTICAL ANALYSIS

In order to verify the obtained conclusions statistical analysis methods were used, where T-test, ANOVA and Kruskal – Wallis methods were used for all the statistical methods used in this study, the level of significance was chosen to be 5%.

ANOVA was used to compare the results of the four groups, having number of groups of four and three data items in each group resulted in an eleven degrees of freedom and the value of critical F statistic is 4.07. Based on the obtained results, the calculated value of F statistic for these four groups is 1.78 which is less than the critical value that means there is no significant differences between the four sets of walls.

Since the data items of each group was three only so it was not possible to test the normality of the data within each group which is considered as requirement for the ANOVA test, consequently Kruskal – Wallis non-parametric test was used to confirm the obtained results and check the accuracy of the ANOVA results.

Using the Kruskal- Wallis method, the H statistic equals 5, while the calculated p-value is 0.1718, which means that the differences between the four sets of groups is not statistically significant, this confirms the results obtained from using ANOVA.

T- Test was used to examine the significance of the differences between each two sets of groups, when comparing groups A and B to check the effect of reinforcement, the result showed that there is no significant difference between the two groups which means that adding reinforcement to the wall did not affect the maximum shear resistance significantly, where there is an increase in shear resistance of the walls with adding the reinforcement but this difference in results is not statistically significant. Results of t-test methods are shown in table 2.

By comparing the results of groups C and D to check the effect of distributing the reinforcement, the results showed that there no significant differences between the two groups, that means that the distribution of reinforcement does not affect the maximum shear resistance of the walls but it might affect the crack patter only.

Adding a grouted beam to the walls resulted in a slight increase in the shear resistance of walls which can be observed when comparing the results of groups C and D to that of group B which already had an average higher resistance than group A. Adding the effect of adding reinforcement to the effect of adding an extra bond beam resulted in a significant increase in shear resistance that can be observed when comparing the shear resistance of both group C and group D to that of group A.

TABLE 2. T-test results.

	B	**C**	**D**
A	Difference between means = 12 P value = 0.242 **Not statistically significant.**	Difference between means = 13.4 P value = 0.033 **Statistically significant.**	Difference between means = 16.2 P value = 0.035 **Statistically significant.**
B	-	Difference between means = 4.3 P value = 0.635 **Not statistically significant.**	Difference between means = 1.95 P value = 0.879 **Not statistically significant.**
C	-	-	Difference between means = 0.1 P value = 0.983 **Not statistically significant.**

5. CONCLUSIONS

For the walls tested in this study, the use of horizontal rebars in a bond beam in concrete masonry walls did not affect the overall shear resistance of the walls significantly, it resulted in an increase in the resistance but when examining it statistically the results indicated that it was not significant. The existence of bond beams in the walls blocks the path of the cracks and changes its angel. The distribution of the reinforcement over the height of the wall did not affect the overall shear resistance of the walls as long as the same structural components of the walls are maintained. The use of three replicates at least from each wall configuration is very critical in obtaining reliable conclusions as the obtained results can be misleading which only can be verified by the statistical analysis methods that require at least three replicates of each specimen.

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