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The Effect of Height-to-Width Ratio on the Strength of Concrete-Backed Stone Masonry Prisms

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Abstract

This experimental investigation is intended to study the strength and behavior of concrete-backed stone masonry prisms built with different kinds of stones, ranging from soft to very hard. Large number of prisms with constant thickness, width, and mortar joint thickness were tested under concentric loads. Four types of concrete and mortar mixes were used in order to study the change of the materials strength on the compressive strength of the prisms. Two types of stone with a width-to-height ratio of 1 and 2 were used in constructing the prisms, one with regular thickness of 50 mm and the other with irregular thickness ranging from 30 to 110 mm. The height-to-width ratios adopted for the tested prisms were 1.6, 2.15, 2.7 and 3.25 used with three, four, five and six course height prisms respectively.
The test results indicated that the prism's height-to-width ratio is not significant in reducing of the ultimate compressive strength of the prisms.

Keywords: Concrete-backed stone masonry, Compressive strength, Mortar, Stone

1. Introduction

Until 1990's, load-bearing walls made from concrete-backed stone masonry, were the main method used in constructing external walls of low-rise buildings in Jordan. This method is still widely used to construct, one, two-story and even higher buildings in Jordan and other Middle Eastern countries where buildings are constructed from the assemblage of three materials namely stone, mortar and concrete. The usual wall thickness for buildings rising up to three or four stories is between 300 – 350 mm with 200 × 400 mm strengthening corner columns reinforced by six vertical bars and confined by 8 mm ties each 200 mm. Between corners, other similar or even smaller strengthening columns were kept at a distance of about four meters from each other[1][2].
A previous study carried on concrete-backed stone masonry prisms [2] studied the effect of the height-to-width ratio on the ultimate compressive strength, and concluded that the height to width ratio has a significant effect on the ultimate compressive strength of the prisms. Three types of prism heights were investigated; one, two, and three course height prisms with height to width ratios of 0.5, 1.05 and 1.6 respectively. The thicknesses of the tested prisms were 250 mm.
The current investigation aims to study the effect of the height-to-width ratio on the ultimate compressive strength of concrete-backed masonry prisms with a thickness of 250 mm and height to width ratios of 1.6, 2.15, 2.7 and 3.25. These ratios are for three, four, five and six course height prisms respectively.

2. Materials

2.1 Stones

Six different types of limestone, brought from different quarries, were used in the construction of the prisms. According to ASTM C 568-89 (1992)[5] limestone may be classified into three categories. These are *I (Low-Density*), for limestone having a density ranging from 1760 through 2160 kg/m^3; *II (Medium-Density)* for limestone having a density ranging from 2160 kg/m^3 and not greater than 2560 kg/m^3 and *III (High-Density)* for limestone having a density greater than 2560 kg/m^3. At least one type of each category was chosen to be included among the constructed prisms.
Two groups of stones with a breadth of 200 mm and a height of 100 mm were adopted in this investigation. The thickness of the first group was regular of 50 mm, and the other group thickness was irregular thickness ranging from 30 to 110 mm.

2.2 Mortar

Two mortar mixes with 1:3 and 1:4 (cement : sand) proportions batched by volume and mixed with water to a desired workability, were used in constructing all the prisms. Three 102 × 102 × 102 mm cubes were casted with each batch, cured in a water tank and tested in compression after 28 days.

2.3 Concrete

Two medium strength mixes with 1:2:4 and 1:2:5 (cement : sand : aggregate) proportions batched by volume were used in constructing all the prisms. The water content was adjusted to provide concrete of medium slump. With each batch of concrete more than three 102 × 102 × 102 mm cubes were casted then cured in water and tested in compression after 28 days. Ordinary Portland Cement was used in all mixes.

3. Experimental Program

3.1 Prisms Construction

An Experienced mason built more than 16 prisms for each type of stones using 10 mm horizontal mortar joints. The prisms were divided into two groups: A and B. All prisms in group A were constructed using stones with regular thickness of 50 mm. The prisms of group B were constructed using stones with irregular thicknesses having dimensions ranging from 30 to 110 mm. After 24, hours, the mortar was cured for 4 days by wetting it with water twice a day. After that, the built stones were put over a sheet of plywood and surrounded from three sides by wooden forms. The concrete was placed in about 100 mm layers, each layer was hand compacted 40 times using steel rod commonly used for compacting concrete cubes. The prisms were cured for 14 days by wetting it with water for about half an hour twice a day.
Figure 1a,b shows different types of prisms during construction.

(a)

(b)
Figure 1a,b: Different types of prisms under construction.

3.2 Strain Measurement

In order to study the stress-strain relationship near failure, some prisms were fitted with demec points having gauge length of 50 mm for measuring the vertical and horizontal strains. The demec points were glued on the center of the stone face of the prism intermediate course. Demec points were also glued on the mortar joint around the intermediate course of the prism and on the concrete back face. Two displacement measurements were glued on the stone face, and the back face of some prisms to measure the change of length of the stonework namely the stone and the mortar from one side and the concrete on the opposite side of the prism. Figure 2 shows strain and displacement measurements mounted on a five-course prism

Figure 2: A five-course height prism with strain and displacement measurements

4. Testing Procedure

4.1 Stone Specimens

Water absorption and specific gravity tests were carried on in accordance of ASTM C 97[3]. For determining the compressive strength 100 × 100 × 100 mm cubes were tested by axial compression in accordance ASTM C 170 [4].

4.2 Masonry Prisms

All specimens were tested by axial compression using 1.3MN and 750 KN capacity hydraulic testing machines at a loading rate of 10 N/mm^2 per minute in accordance with BS 6073: Part1: 1981[6]. For prisms with strain measurements, initial readings were taken at zero load. The load then was applied until a stress of 0.5 N/mm^2 was reached, and the first set of reading were taken. The next set readings were at small increments until failure.

5. Results and Discussion

Table 1 gives the results of compressive strength, water absorption and specific gravity for the six types of stones used in constructing the prisms. The table gives different strength values ranging from 30 N/mm^2 for type 1 to 79 N/mm^2 for type 6. The results show that the decrease of stone absorption has great significance in increasing the compressive strength of stones [2][7].

Table 2 and 3gives the results of the compressive strength for prisms with height-to-width ratios of 1.6, 2.15, 2.7 and 3.25 these ratios are for three, four, five and six course height prisms respectively. The results in table 2 are for prisms built with mortar mix of 1:4 (cement: sand) and concrete mix of 1:2:5 (cement: sand: aggregate) while the results in Table 3 are for prisms built with mortar mix of 1:3 (cement : sand) and concrete mix of 1: 2 : 4 (cement: sand: aggregate).

The results show that the compressive strengths for Group A prisms are slightly higher than the compressive strength for group B for the same prism height. It also shows that the height-to-width ratio is not significant in reducing the ultimate compressive strength. The main factor affecting the reduction of the ultimate strength of the prism is the strength and the rigidity of each of the three materials. The mode of failure for most of the prisms was as a result of longitudinal cracks along the stones and through the mortar joints and ended with two or more separated blocks.

Table 4 and 5 gives the results of strain readings obtained from some important places of the prism. The results show that when failure occurred the strain on the stone face was small compared with mortar joint and concrete back face strains.

Figure 4 shows a five course prism built from hard stones after failure. The dominate mode of failure for very hard stone was by one or two longitudinal cracks. Longitudinal cracks were also noticed on the other three concrete sides. After the failure happened, crushed, and split stones are removed, one longitudinal crack was noticed along the position where small wooden wedge was placed to assist in building the prism. Figure 5 shows a longitudinal crack passing through the position where the small wooden wedges were placed.

Table 1: Some important properties for stone samples

Type of Stone	Compressive Strength (N/mm^2)	Water absorption (%)	Specific Gravity
1	30	4.24	2.56
2	36.5	4.07	2.02
3	46.2	4.86	2.52
4	63	1.03	2.53
5	69	2.89	2.52
6	79	1.2	2.61

Table 2: Compressive strength for prisms with different (height-to-width ratios) for concrete mixes of 1:2:5 and mortar mixes of 1: 4.

Type of Stone	Average Compressive Strength (N/mm^2)							
	Group A (stones with regular thickness of 50 mm)				Group B (stones with irregular thickness 30-110 mm)			
	Three course high	Four course high	Five course high	Six course high	Three course high	Four course high	Five course high	Six course high
1	*	10.1	9.5	7.6	*	7.6	9.8	8.5
2	*	8.0	9.5	*	*	7.9	9.8	*
3	*	8.3	8.8	*	*	8.4	8.7	*
4	*	7.0	9	14	*	6.8	10.2	10.4
5	*	13	12	12.4	*	13.1	11.2	11
6	*	*	*	*	*	*	*	*

Note: The average compressive strength of mortar and concrete used in building this type of prisms were 19.7 N/mm^2 and 13.75 N/mm^2 respectively.

* Not Tested.

Table 3: Compressive strength for prisms with different (height-to-width ratios) for concrete mixes of 1:2:4 and mortar mixes of 1: 3.

Type of Stone	Average Compressive Strength (N/mm^2)							
	Group A (stones with regular thickness of 50 mm)				Group B (stones with irregular thickness 30-110 mm)			
	Three course high	Four course high	Five course high	Six course high	Three course high	Four course high	Five course high	Six course high
1	13.7	14.7	11.0	10.8	12.9	13.8	12.4	12.4
2	14.2	*	12.4	11.8	11.3	*	13.6	11
3	13.6	19.8	17.3	12.4	11.4	15.8	*	16.1
4	13.3	17.4	*	14	13.2	14.8	12.5	*
5	17.4	*	16	*	15.8	15.3	15.8	*
6	14.7	14.8	22	14	14.2	21	25	14.2

Note: The average compressive strength of mortar and concrete used in building this type of prisms were 25.4 N/mm^2 and 20.8 N/mm^2 respectively.
* Not Tested.

Table 4: Strain readings obtained near failure for a six- course height prism*

The location where the stain was taken	Method used		
	Demec mechanical strain gauge, 50 mm length		Measuring the change of length over 0.67 to 0.75 of the prism height
	Vertical Strain	Horizontal Strain	Vertical Strain
Stone Face	9.9×10^{-4}	36.6×10^{-4}**	0.0026
Mortar Joint	107×10^{-4}	24.7×10^{-4}	
Concrete (Prism back side)	17.6×10^{-4}	3.6×10^{-4}	0.0027

*Built from stones with regular thickness with mortar mix (1: 3) and concrete mix (1: 2: 4).
** High strain was obtained because of a longitudinal crack passes through the horizontal strain gauge.

Table 5: Strain readings obtained near failure for a six-course height prism*

The location where the stain was taken	Method used		
	Demec mechanical strain gauge, 50 mm length		Measuring the change of length over 0.67 to 0.75 of the prism height
	Vertical Strain	Horizontal Strain	Vertical Strain
Stone Face	11.7×10^{-4}	4.36×10^{-4}	0.0030
Mortar Joint	94.8×10^{-4}	10.2×10^{-4}	
Concrete (Prism back side)	23.7×10^{-4}	11.6×10^{-4}	0.0029

***Built from stones with irregular thickness with mortar mix (1: 3) and concrete mix (1: 2: 4).

Figure 3: Typical compressive failure mode (hard stone).

Figure 5: A typical longitudinal crack passing through the position where the wooden wedges were placed (broken stones were removed after failure)

6. Conclusions

Based on the results obtained from this investigation the following conclusions can be drawn:

1- Tests carried out on large number of concrete-backed stone masonry prisms having height-to-width ratio ranging from 1.6 (three course height) to 3.25 (six course height) tested under concentric loads show that the height-to-width ratio is not significant in decreasing the ultimate compressive strength of the prism. This conclusion is for prisms built from three materials (stone, mortar and concrete) that have same compressive strength.

2- The failure mode for prisms having different height-to-width ratio are the same when prisms built from the same materials (stone, mortar and concrete) that have the same compressive strength. Different compressive strengths especially for stones will change the failure mode. For very hard stones, one or more longitudinal cracks along the mortar joint can be observed across the stone face.

References

[1] M. A. Abdel-Halim, M. R. Basoul, and R. A. Abdel-Karim, Structural Evaluation of Concrete-Backed Stone Masonry, Structural Journal, Sep.-Oct. 1989, 608-614.

[2] N. M. Abdel-Qader, Compressive Strength of Concrete-Backed Stone Masonry Prisms, The 6th International Conference on Concrete Technology for Developing Countries, Al-Balqa' Applied University, Vol. 2, 21-24 October 2002, pp. 595-604.

[3] ASTM C 97-90, Standard Tests for Absorption and Bulk Specific Gravity of Dimension Stone, Vol. 04.80, 1992.

[4] ASTM C 170-90, Standard Test Method for Compressive Strength of Dimension Stone, Vol. 04.80, 1992.

[5] ASTM C 568-89, Standard Specification for Limestone Dimension Stone, Vol. 04.08, 1992.

[6] BS: 6073: Part 1: 1981, Precast Concrete Masonry Units, BS 6073: Part 1 and 2, 1981.

[7] Nart Mawloud Naghoj, Nafi Abdel Rahman Yousef and Omar Nawaf Maitah, Mechanical Properties of Natural Building Stone: Jordanian Building Limestone as an Example, Jordan Journal of Earth and Environmental Sciences, Vol. 3, No. 1. June 2010, 37-48.

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