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FLEXURAL TENSILE STRENGTH OF STRUCTURAL CLAY TILE

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ABSTRACT

Structural clay tile was widely used in the first half of this century in masonry construction. Structural clay tile is distinguished by hollow units having parallel cores and thin webs and faceshells. It is typically unreinforced. Knowledge of the tensile bond strength is needed for evaluation of existing facilities. Tests were conducted to determine the flexural tensile strength of side constructed (horizontal cores) structural clay tile. The bed joint mortar is placed against a smooth extruded face, which leads to low initial rates of absorption (approximately 3-10 g/min/30in^2), and lower tensile bond strengths. Average laboratory flexural tensile strengths were 100 kPa for Type N masonry cement mortar, 135 kPa for Type S masonry cement mortar, and 170 kPa for both Type N and Type S Portland-cement lime mortar. These were all higher than values obtained from in-situ testing of a 1940's era wall, which showed a flexural tensile strength of 45 kPa. Both the laboratory and in-situ tests had high coefficients of variation (20-60%). Results of deformation measurements showed a shift of the neutral axis towards the tensile face, as has been observed by other researchers.

INTRODUCTION

Structural clay tile was first produced in the United States in about 1875, and was widely used for both load-bearing walls and partitions. Production of structural clay tile peaked in the 1920's, with over 4,000 tons produced annually. Since then production has rapidly dropped, and little new structural clay tile is being used. Much of the existing structural clay tile is in buildings that are in moderate to high seismic hazard areas (-, 1993). Unfortunately, little is known on the properties of structural clay tile masonry walls, which makes the seismic evaluation of these older buildings difficult, or impossible. A review of the physical properties of structural clay tile was given by Flanagan et al., 1993, and the results of prism testing using structural clay tile masonry units is given in Bennett et al, 1997. This paper presents the results of flexural bond strength testing. All of the testing was performed using side construction, or the cells of the tiles running horizontally.

DESCRIPTION OF SPECIMENS

The clay tile used in this study was a nominal 200 mm thick x 300 mm x 300 mm unit. The tile was manufactured in 1987, and mean dimensions are shown in Figure 1. Initial rates of absorption of the tile were 139 g/min/m^2 with the cells horizontal, and 274 g/min/m^2 with the cells vertical. Both initial rates of absorption were quite low, but the initial rate of absorption along the smooth extruded face was particularly low. The initial rate of absorption was approximately twice as high along the wire cut edge.

Two tile high specimens were constructed using 19 mm thick full bed joints, which is typical of most side construction. The specimens were allowed to air dry in the laboratory twenty-one days before testing. Five specimens each using four different mortar types were constructed. Type N and S masonry cement (MC) mortars, and Type N and S portland cement lime (PCL) mortars were used. The proportions for the mortar are given in Table 1, along with the compressive strengths of the mortars determined using 50 mm cubes. The sand used was a natural river sand, and water was added to obtain a workable mix. One of the Type N masonry cement specimens broke in handling prior to testing. No special care was used in the construction of the specimens, such as maintaining a certain flow and/or slump of the mortar, in an attempt to duplicate field construction conditions.

BOND WRENCH TESTING

The flexural tensile strength of the clay tile was determined using a large bond wrench, as shown in Figure 2. Results of the bond wrench testing are given in Table 2. Two things are notable about the results. The first is the increase in bond strength with the portland cement lime mortar over the masonry cement mortar, which is consistent with lime increasing the bond strength for other types of masonry units. The tensile bond strength increased with increasing mortar compressive strength with the masonry cement mortars, but not the portland cement lime mortars. There was not a statistically significant difference between the tensile bond strength of the Type N and Type S portland cement lime mortar. The second item of interest is the low bond strengths. The measured strengths were about 80% of the allowable tensile strengths given in ACI 530 (MSJC, 1995) for solid units, and about 30% greater than the allowable stresses given for hollow units. Presumably, the solid unit values would be more appropriate, since a full solid bed joint is used. The low tensile bond strengths are most likely due to the smooth extruded face, and the low initial rate of absorption.

One final note on these results. The student who constructed the bond wrench tested seven specimens which were made with a premixed, packaged mortar obtained from a local building supply store. The average tensile bond strength obtained from these tests was 136 kPa (coefficient of variation of 37%), which is reasonably consistent with the results given in Table 2.

COMPARISON TO IN-SITU TESTS

Bond wrench tests were performed on an existing 200 mm structural clay tile wall (Hardin, 1991). This wall had been previously tested out-of-plane with an airbag (Fricke et al, 1992). Although the tested specimens appeared to be undamaged, it is possible that there was damage from the airbag test. The wall was constructed in the early 1940's using running bond. To test the flexural tensile strengths of the wall, the course of tile above the tile to be tested was removed. The head joints were sawed so that the tile to be tested was separated from adjacent tiles. The average tensile bond strength from 25 in-situ tests was 66kPa, with a coefficient of variation of 60%. Tensile bond strengths ranged from 15kPa to 186kPa. An additional two tiles were found to have grooved surfaces after testing. The tensile bond strength for these two specimens was 218 kPa and 227 kPa. Overall, the in-situ tests resulted in tensile bond strengths of about half that measured in the laboratory for smooth faced tile. The grooved surface increased the tensile bond strength a little over three times that of the smooth face.

The bond strengths obtained from the in-situ tests were similar to an additional series of tests performed in the laboratory using Type N masonry cement mortar. Six additional laboratory bond wrench tests were performed, with bed joint deflections being measured on some of the specimens during testing. The average tensile bond strength from these tests was 56 kPa, with a coefficient of variation of 65%. It is unclear why this set of laboratory tests resulted in lower tensile bond strengths than the first test series.

COMPARISON TO OTHER RESULTS

Although no other data was found for bond wrench testing of structural clay tile specimens, some other data is cited for comparison. Johnson and Matthys (1973) tested wallettes similar to the bond wrench specimens, but tested according to ASTM E149. Type S portland cement lime mortar was used, and the units had an average initial rate of absorption of 527 $g/min/m^2$ on the smooth extruded face. Testing was performed for both side construction and end construction, but only the side construction results are examined herein. The average modulus of rupture for three 200 mm specimens was 326 kPa on the gross area with a coefficient of variation of 34% (note that gross area and net area results in the original paper are assumed to be reversed). The average modulus of rupture for 100 mm units was 546 kPa and the average modulus of rupture for 150 mm units was 514 kPa.

Johnson and Matthys (1973) also tested 1.2m x 2.4m walls. Average gross area modulus of rupture values were 900 kPa for 100 mm units, 444 kPa for 150 mm units, and 394 kPa for 200 mm units. The walls were tested in the vertical position using an air bag, and it is unclear whether the wall weight was accounted for in calculating the modulus of rupture.

Modulus of rupture values reported by Johnson and Matthys (1973) were thus about three times the tensile bond strengths obtained from these tests. Some of the enhancement of the Johnson and Matthys' strength was probably due to their units having an initial rate of absorption almost four times as great as the units used for this series of test.

Plummer (1962) presents results of crossed brick couplet tests in which the smooth die skin face of the brick was used. A summary of the results is given in Table 3, which are the average of six tests. Values for the initial rate of absorption are for the wire cut edges, with no values given for the initial rate of absorption along the smooth face. Based on the ratio of initial rates of absorption measured on the structural clay tile, initial rates of absorption on the smooth die skin face would be about half those on the wire cut edges. The mortar for these tests was 1 part cement, ½ part lime, and 4 ½ parts sand. The cross couplet results averaged approximately twice the results currently measured with the bond wrench. Part of the enhanced strength could be due to the care used in the construction of the crossed couplet specimens.

MEASUREMENT OF BED JOINT DEFORMATIONS

Bed joint deformations were measured near the tensile and compressive face of some of the supplemental laboratory specimens described in the section on comparison to in-situ tests. Typical results are shown in Figure 3. No attempt has been made to reduce this data in terms of tension and compression moduli. It is simply noted that the tensile deformations are much greater than the compression deformations, particularly as the ultimate load is approached. In other words, the neutral axis is shifting towards the compression face. Fried et al (1988) noted a similar neutral axis shift in the testing of masonry joints. Fried et al (1988) comment that one of the implications of this is that bond wrench results could be influenced by the lever arm used, but not enough data is available.

CONCLUSIONS

There is a dearth of knowledge on the flexural tensile strength of structural clay tile masonry. However, the knowledge of the tensile bond strength is needed for the evaluation of existing structures, particularly in moderate and high seismic regions. The measured tensile bond strength from laboratory and in situ tests is given, along with other relevant data from the literature.

As with other tensile bond strength testing, there was large variation in results. The average tensile bond strength from all the bond wrench testing (both laboratory series and in-situ tests) was 100 kPa. This is somewhat lower than modulii of rupture values reported by Johnson and Matthys (1973) and tensile bond strengths from cross couplet brick tests reported by Plummer (1962). Without a knowledge of mortar type and/or mix, using a tensile bond strength of 100 kPa for structural clay tile in side construction is probably appropriate. This would be an ultimate tensile bond strength, and not an allowable.

ACKNOWLEDGMENTS

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REFERENCES

- (1993). Proceedings, National Workshop on Unreinforced Hollow Clay Tile. Center for Natural Phenomena Engineering, Martin Marietta Energy Systems, Inc., Oak Ridge, TN, ES/CNPE 93/1.

Bennett, R.M., Boyd, K.A., and Flanagan, R.D. (1997). "Compressive Properties of Structural Clay Tile Prisms." Journal of Structural Engineering, ASCE, 123(7), 920-926.

Flanagan, R.D., Bennett, R.M., and Butala, M.B. (1993). "Properties of Structural Clay Load-Bearing Wall Tile." Sixth North American Masonry Conference, Philadelphia, PA, 87-98.

Fricke, K.E., Jones, W.D., and Huff, T.E. (1992). "In Situ Lateral Load Testing of an Unreinforced Hollow Clay Tile Wall." Proceedings, 6th Canadian Masonry Symposium, 519-530.

Fried, A., Anderson, C., and Smith D. (1988). "Predicting the Transverse Lateral Strength of Masonry Walls." Proceedings, 8th International Brick and Block Masonry Conference, 1171-1183.

Hardin, E.J. (1991). Bond Wrench Testing at Building 9207 at the Y-12 Plant. Center for Natural Phenomena Engineering, Martin Marietta Energy Systems, Inc., Oak Ridge, TN, Y/EN-4592.

Johnson, F.B., and Matthys, J.H. (1973). "Structural Strength of Hollow Clay Tile Assemblages." Journal of the Structural Division, ASCE, 99(ST2), 259-275.

Masonry Standards Joint Committee (1995). Building Code Requirements for Masonry Structures, ACI 530-95/ASCE 5-95/TMS 402-95.

Plummer, H.C. (1962). Brick and Tile Engineering. Brick Institute of America.

Table 1. Mortar Properties

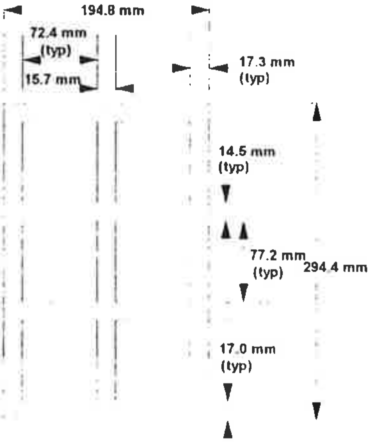
Mortar Type	Proportions					Aggregate to Cementious Material Ratio	Compressive Strength (MPa)
	Masonry Cement		Portland Cement	Lime	Sand		
	Type N	Type S					
Type N MC	1				2 1/2	2.5	9.36
Type S MC		1			2 1/2	2.5	13.56
Type N PCL			1	7/8	4 3/4	2.53	6.69
Type S PCL			1	3/8	3 1/2	2.55	11.43

Table 2. Flexural Tensile Strengths from Bond Wrench Testing

Mortar Type	No. of Tests	Average Flexural Tensile Strength (kPa)	Coefficient of Variation (%)
Type N MC	4	101	47
Type S MC	5	135	21
Type N PCL	5	174	17
Type S PCL	5	167	26

Table 3. Tensile Bond Strengths for Smooth Die Skin Brick Faces (after Plummer, 1962)

Brick Designation	Initial Rate of Absorption ($g/min/m^2$)	Average Tensile Bond Strength (kPa)
A	500-1000	246
B	250-500	278
C	500-1000	214
D	250-500	202



200 mm Structural Clay Tile
Length = 293.1 mm
Weight = 138 N
Coring = 57.1 %
Net Area Vertical Cells = 24,600 mm^2
Net Area Horizontal Cells = 14,800 mm^2
Absorption:
5 hr. cold = 11.1%
24 hr. cold = 11.7%
1 hr. boil = 12.1%
5 hr. boil = 12.4%

Figure 1. Structural Clay Tile Units

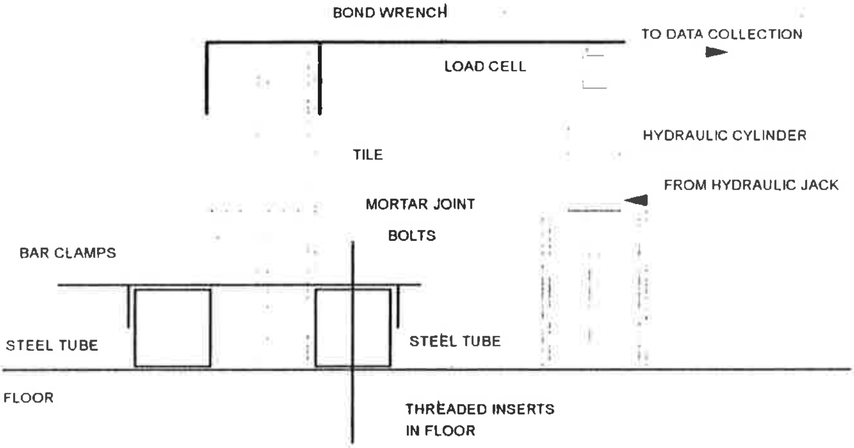


Figure 2. Bond Wrench Test Apparatus

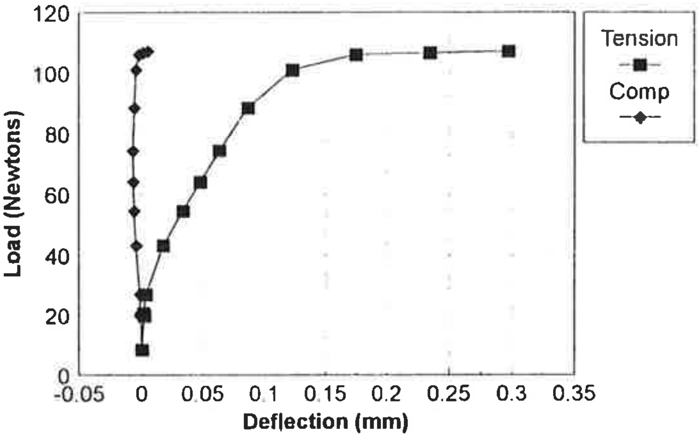


Figure 3. Bed Joint Deformations in Bond Wrench Testing