A REVIEW OF THE TECHNIQUES TO DETERMINE THE TENSILE FLEXURAL STRENGTH OF MASONRY

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ABSTRACT

In general, codes of practice assume that masonry behaves elastically when subjected to transverse lateral loading. To predict the lateral load capacity of wall panels, the tensile flexural and bond strength of masonry is required. A number of tests exist which enable this property to be determined in practice, but the results from this are not equal, as would be expected from a theoretical analysis. To examine this, a review of the methods employed and the type of small specimen used in the testing is carried out.

INTRODUCTION

In this paper, the tensile flexural strength of masonry is defined as the ultimate tensile strength of bonded masonry bent about an axis parallel to its bed joints. The bond strength is a measure of the direct tensile strength between the mortar bed and a unit. When determined experimentally, the two properties have different values\(^{(1,2,3)}\), although they are related\(^{(1,2,3)}\). In this paper the tensile flexural strength about an axis perpendicular to the bed joints will not be examined.

The tensile flexural strength of masonry as defined above affects the composite in a number of ways. The propagation of cracking due to the bending or shear of structural elements is partially controlled by the tensile flexural and bond strength, although the ultimate failure load of such elements also depends on other factors, in particular unit tensile flexural strength. Differential settlement in non-structural elements will cause cracking, the extent of which will again be influenced by the tensile flexural and bond strength of masonry. Obviously weak mortars will be more flexible and distribute cracks in a less noticeable manner, whereas stronger mortars will result in a brittle material which will be prone to visible cracking. The bond and tensile flexural strength are also important in limiting water penetration through mortar joints\(^{(4,5,6)}\). The tensile flexural and bond strength of masonry will influence unreinforced, reinforced and pre-stressed...
masonry in different ways and affect a wide combination of units and mortars used in the industry. These properties thus have a broad effect on the composite, influencing both its strength and durability.

This review attempts to examine and rationalise the testing techniques available for determining the tensile flexural and bond strength of masonry.

THE TENSILE FLEXURAL AND BOND STRENGTH OF MASONRY

Many researchers have looked into how the tensile flexural and bond strength of masonry have been measured, what factors affect these properties, and how the various tests used to measure them relate to each other. Clearly all these questions are important and need or have required clarification. However, what is of paramount importance is how the tensile flexural or bond strength is ultimately to be used in:

- designing the ultimate strength of structural masonry,
- evaluating serviceability aspects of masonry walls, for example how impermeable a wall is to rain penetration,
- controlling the quality of newly built masonry, and
- predicting the properties of existing masonry.

In the following sections these aspects are considered in more detail.

The Ultimate Strength of Masonry

In considering the strength of masonry elements, the tensile flexural strength of masonry will be critical in enabling predictions of the ultimate load capacity particularly of vertically spanning laterally loaded walls to be made although walls under high compression will be in no danger of collapse if the tensile flexural strengths are negligible. The influence of the tensile flexural strength of the masonry on the ultimate load carrying capacity of wall panels subject to combinations of direct loads and bending moments will depend on the ratio of these two forces. Where the bending component is proportionally larger, structural elements will be at greater risk of failure. With two way spanning panels, the tensile flexural strength as defined in this paper, will have an effect on the load carrying capacity of laterally loaded walls, but the tensile flexural strength about an axis perpendicular to the bed joints will also contribute to wall strength. So in the strength determination of masonry elements, the tensile flexural strength determined must represent the strength of masonry in walls.

Structural masonry subject to lateral loading comprises units bonded together with mortar. If the units are removed, a mortar lattice remains which has some residual lateral strength dependant on the mortar used. A soft weak mortar will provide little lateral resistance, whereas a stronger more brittle material would offer appreciable lateral restraint. Whilst the overall lattice would be subject to bending moments, the bed joints would be under torsion between each perpend joint and in a 100mm wide blockwork wall the perpends may be subject to buckling effects. In practice, the perpend joints in the mortar are laterally restrained by blocks so will not buckle, but torsional movement of the bed joints has been observed in tests on wallets so the perpend
effect contributes to the flexural resistance of vertically spanning walls. In these cases the bond between the bed joints and the mortar in the vicinity of the perpend joints has failed but the masonry has not reached ultimate load. This particular instance suggests that the tensile flexural strength of the masonry is a combination of the torsional resistance of the bed joints due to their intersection with the perpends, some resistance due to tensile flexural bond in the bed joints but away from the perpend/bed joint intersections, some effect from the mortar lattice and an effect due to all the materials acting together. The mechanism is complex. It is evident the influence of each factor will vary as the load on the wall changes and will depend on the mortar and units used in the wall. In determining the tensile flexural strength of masonry for these applications, an aspect of bond strength would be included in the overall tensile flexural strength of the masonry.

The Serviceability of Masonry

Typical serviceability failures related to the tensile flexural and bond strength of masonry include the cracking and bulging of walls and the penetration of rain through walls. Whilst these failures do not pose any danger to life they are none the less important and result in much litigation. The cracking and bulging of walls is related to their tensile flexural strength a part of which will be bond strength. The mechanism will be much the same as that described in the previous section. But in the case of rain penetration, the effect of bond alone may be more important. If the wall is not subject to significant lateral loading then debonding in the vicinity of the perpend/bed joint intersection will not occur to reduce the resistance of the wall to rain penetration. Walls subject to significant lateral loads will debond in the vicinity of the perpend/bed joint intersection and this will reduce their resistance to rain penetration.

The Quality Control of New Masonry

Clients in the construction industry are increasingly aware of the need to maintain high standards. The quality of concrete in compression is monitored using cubes tested at 28 days. In the UK no such quality test exists for masonry in tension, although in Australia the bond wrench is recommended for site use. Using a tensile flexural or bond strength test to monitor the quality of newly built masonry would provide clients with an indication of quality related to both the strength and durability of masonry.

The Properties of Existing Masonry

Serviceability defects in structural masonry are common. Some useful information for designers on the condition of masonry which would enable judgements on the likelihood of future defects to be made, could be obtained from a knowledge of the tensile flexural or bond strength of the material. Research to determine these properties on site are currently being developed.

The above discussions confirm the need for wall designers and owners to have a knowledge of the tensile flexural and bond strength of masonry. Recommending tests appropriate to specific applications is essential. In order to enable considered opinions on appropriate tests to be made, a summary of the current tests used to determine the tensile flexural and bond strength of masonry follows.
THE TENSILE FLEXURAL AND BOND STRENGTH TESTS IN USE

Masonry structures constructed in the first half of this century and earlier, relied only on the compressive strength of the material. However, in recent decades, there has been an increasing use of the tensile flexural strength of masonry in the design of masonry and a number of tests have developed to measure this property. In addition, tests to determine the bond strength of masonry are available. A summary of the more common tests follows in which they are briefly described, and their advantages and disadvantages discussed. Appropriate uses of the tests are considered in a later section.

The B-Wallette Test

Wallettes of various formats have been tested and recommended by a number of researchers. The wallette test described in this paper is in Appendix A of BS5628:Part 1. For brickwork, small wallette specimens 2 units wide and ten high are constructed in stretcher bond and for blockwork, specimens one and a half units wide and five high are built, and cured under polythene for 28 days when they are tested to failure in the vertical orientation under four point loading. The test only requires the ultimate load to be recorded, so no knowledge of the deformational characteristics of the masonry are required. At least eight replicate specimens need to be tested. With blockwork specimens code requires units be pre soaked for five or six minutes then drained for about half an hour before specimens are constructed and with brick wallettes docking of units with high suction rates is allowed. The test and specimen formats are shown in figure 1.

Advantages

The specimens are built as a wall which would include all the elements of actual masonry which could contribute to it’s lateral resistance. These have been previously discussed and include the effects of bond strength, the perpend effect and the composite action of masonry. Consequently a measure of the tensile flexural strength of masonry which is representative of actual masonry strength is obtained.

Disadvantages

The test specimens are relatively large and need to be constructed in a laboratory as on site building would usually necessitate transporting sets of specimens to a testing laboratory. Constructing specimens in a laboratory would not replicate site workmanship. The blockwork specimen is not symmetrical and exhibits some torsion when tested. The test determines the strength of the weakest of a set of joints between the load lines.

The Bond Wrench Test

The Bond Wrench test developed by Hughes and Szembery for use with brickwork, applies a vertical load usually at an eccentricity of 1000mm to a single masonry joint formed by laying two units in stack bond. In some cases, individual joints from stack bonded brick piers are tested in a specially designed bond wrench. Only the joint being tested is subject to any load, all others being unstressed. The joint in either case is subjected to mainly bending forces, although there will be a small component of direct load. The tensile flexural strength of the joint is determined
as the average strength of ten specimens. Specimens are constructed either as two high piers or stack bonded beams, cured under polythene and tested at 28 days. The test is now specified in ASTM C - 1072(26), where bricks and blocks up to 100mm wide may be tested, and in Appendix A of AS 3700(25). ASTM C 952(20) defines a test method to determine the bond strength of blockwork units in which the eccentricity of the vertical load from the centre line of the units being tested is 254mm, but unlike ASTM C 1072 blocks of variable width may be tested. These specimens will consequently be subject to more direct loading as a proportion of bending moment than the brick specimens. The test and specimen formats are shown in figure 1.

Advantages

Bond wrench testing of brickwork specimens requires few units and little mortar. The specimens can be constructed and tested on site, as most wrenches can fit into the boot of a motor car. Site testing involves proof loading specimens using a bucket into which sand is slowly poured or alternatively the testing can be carried out in a laboratory using hydraulic methods of loading and a load cell. Consequently site testing is cheap and easy to perform. In addition site tested specimens may be cured in a manner similar to the constructed masonry and so the derived bond strength will closely represent the actual ‘bond’ performance of the masonry.

Disadvantages

In the brickwork test only the bond strength of the masonry is determined and the relationship of this to masonry a strength is not certain. When testing blockwork specimens, a testing laboratory is required as the construction and curing of the specimens is rigorous. Also, both brick and blockwork specimens will be subject to torsion if the specimens are not loaded exactly vertically or if there is any warping of the specimen.

The Pier Test

Whilst the pier test is no longer the recommended method of determining the tensile flexural strength of masonry, it is still a recognised test in America(29) and in Australia the code does not expressly prohibit the use of horizontally spanning piers. The test may be carried out on site or in a laboratory. Both on site and in the laboratory, stack bonded beams are constructed in the vertical orientation and cured in an agreed manner for 28 days when they are moved to the horizontal orientation, simply supported and loaded as indicated in figure 1. On site the load is applied as a number of the units making up the member, whereas in the laboratory the loading would be applied hydraulically.

Advantages

The construction and curing of the small specimens is simple both in the laboratory and on site. The test only requires broom handles and plywood when carried out on site as noted on figure 3. In the laboratory a similar test set up to that indicated in figure 3 is possible but loading would be through an hydraulic jack.

Disadvantages
To obtain a representative sample of piers, about a hundred bricks or forty block units and corresponding mortar are required. Sufficient storage must be available during curing. Lifting equipment may be necessary to manoeuvre the specimens onto the testing apparatus at 28 days. In the brickwork test the flexural strength determined is the weakest of two joints which are under pure bending. The test only measures bond strength as there is no perpend effect.

Crossed Couplet

The test, specified in ASTM C952(28) provides an inexpensive means of determining the tensile bond strength of unit to mortar in a laboratory. The principle of the test is shown in figure 1.

Advantages

The test is closely regulated at all stages and only requires twenty units to make the ten small specimens specified. The manufacture, curing and testing of specimens is closely controlled. The test measures a direct tensile strength.

Disadvantages

Results from testing programmes indicate large strength variations between specimens. Recent research indicates torsional forces are set up during testing. The value of tensile strength determined still needs to be related to the actual strength of masonry.

Modified Pier Test

This is a laboratory test in which the joint between two adjacent units in a stack bonded pier are subjected to flexural loads. A stack bonded beam is mortared and clamped into a metal tube either side of a joint to be tested as indicated in figure 4, then four point loading as indicated in the figure is used to break the joint and enable the bond strength to be obtained. Figure 1 shows the layout of the test.

Advantages

In the test only a single joint is tested and less variability between results occurs than with the conventional bond wrench test. Reference (7) summarises other advantages of the test.

Disadvantages

The test is laboratory based and buttering in the specimens is time consuming. Only the bond strength of masonry is determined.

Other bond and tensile flexural tests.

van der Pluijm(8) in a research programme comparing methods of determining tensile flexural and bond strengths of masonry, examined five testing procedures. These included two formats of wallette, the bond wrench method of testing and a small four point bending test similar to the pier test as previously described. Then in addition, a tensile test with fully restrained platens and a
tensile test where the small specimens were glued to platens were used to determine the direct tensile strength of the masonry/mortar bond. The effectiveness of these tests will need to be demonstrated through further research to establish their importance.

USES OF THE TESTS

The table below indicates the property that each test measures, whether it is appropriate for site or laboratory use and the codes of practice which specify it.

<table>
<thead>
<tr>
<th>TEST TYPE</th>
<th>PROPERTY DETERMINED</th>
<th>SITE / LABORATORY APPLICATION</th>
<th>CODE OF PRACTICE</th>
</tr>
</thead>
<tbody>
<tr>
<td>B-Wallete</td>
<td>Tensile flexural strength</td>
<td>Laboratory</td>
<td>BS 5628:Part 1:1992(25)</td>
</tr>
<tr>
<td>Bond Wrench</td>
<td>Bond strength in flexure</td>
<td>Site and Laboratory</td>
<td>ASTM C 1072 - 92(26)</td>
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<td></td>
<td></td>
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<td>ASTM C 952 - 91(28)</td>
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<td></td>
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<td></td>
<td>AS 3700(27)</td>
</tr>
<tr>
<td>Pier test</td>
<td>Bond strength in flexure</td>
<td>Site and Laboratory</td>
<td>ASTM E 518 - 80(29)</td>
</tr>
<tr>
<td>Crossed Couplet</td>
<td>Direct tensile strength</td>
<td>Laboratory</td>
<td>ASTM C 952 - 91(28)</td>
</tr>
<tr>
<td>Modified pier test</td>
<td>Bond strength in flexure</td>
<td>Laboratory</td>
<td>N/A</td>
</tr>
</tbody>
</table>

DISCUSSION

Both the strength of masonry in flexure and its serviceability characteristics are important to structural designers. When determining the lateral load carrying capacity of panels, the flexural strength used must represent a strength which actually represents the existing strength in masonry if the design process is to remain rational and maintain credibility amongst designers. Thus the flexural strength must includes all aspects of masonry which affect strength including:

- the torsional resistance of the bed joints due to their intersection with the perpends,
- some resistance due to tensile flexural bond in the bed joints but away from the perpend/bed joint intersections,
- some effect from the mortar lattice and
- an effect due to all the materials acting together.

Of the small specimens examined, the wallette is the only one which includes all these aspects, but its reliability is still questionable as previously noted.
However to obtain a measure of the durability or quality characteristics of masonry, using a test which only measures bond strength would be acceptable. All the other tests measure either the tensile flexural bond or the direct tensile bond of mortar to units. To be of use to designers a bond strength test should be both a site and laboratory test. Determining a value of bond which represents the strength of all joints in a sample rather than the single weakest joint of a set, is of more use to designers. The pier test does not fit this criteria. In addition it is evident that the crossed coupel test although carried out under closely controlled conditions results in much variation between specimens and it is not a site test, so this test is also not appropriate. Also, as the modified pier test (currently under development) is a laboratory test, it too is unacceptable. So the only test which could be used as a measure of bond is the 'bond wrench' test. This test measures the strength of every joint in a set and can be used on site or in the laboratory.

RECOMMENDATIONS

1. The wallets test is recommended as a measure of Tensile Flexural Strength of Masonry.

2. Tests to relate wallette strengths to wall strengths would establish the exact relationship between the property in the small specimen and full sized walls.

3. Using the bond wrench to determine 'bond' in masonry is recommended.

REFERENCES


FIGURE 1