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1. ABSTRACT

The screw pull-out test has been developed to provide a simple, inexpensive, method of assessing the compressive strength of both building mortar and masonry units. It is a simple test, requiring only the insertion and withdrawal of a helically threaded tie from the test material. The test determines the compressive strength of the material being tested by using a graph to relate the load required to shear a cylinder of the test material out of the material, with the tie, the pull-out load, to the compressive strength. The test results suggest that the screw pull-out method is a viable method of determining the compressive strength of a range of masonry materials with strengths ranging up to 10 MPa.

2. INTRODUCTION

There are currently few widely accepted and effective in-situ tests for assessing the strength of masonry materials, and the screw pull-out test has been developed as a simple and inexpensive method of filling this gap: it provides a practical means for assessing the compressive strength of building mortar and weaker masonry units. This method uses the shear strength of the test material, measured by the load required to shear a small cylinder from the test material with a helical tie, and equates this to the compressive strength. This "pull-out" load is then related to the compressive strength of the material by calibration against standard test methods for mortar and units.

A 6mm diameter helically threaded stainless steel tie is used in these tests. The small diameter of the tie allows this method to be used in standard 10mm mortar joints. As a result, it can be used on site, causing minimal, and easily restored, damage. Tests already carried out on bricks and blocks have shown that the holes drilled in the material for a pull-out test do not significantly affect the strength of a masonry unit, and it is therefore possible to calibrate directly between helix and unit tests for individual units.

Keywords: Masonry; Materials; In-situ testing

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A report on the initial tests carried out using this method, essentially limited to tests on masonry units, was presented at the 3rd International Masonry Conference, in October 1992; a second paper, based on improved tests carried out on a range of mortars, was presented at the Autumn meeting of the British Masonry Society in Stoke-on-Trent, UK, in November 1993. In total, a wide range of test materials have been tested: autoclaved aerated concrete (AAC) blocks; lightweight, medium density and high density concrete blocks; a range of brick types and strengths, and a wide range of mortar mixes. The results showed that the method appeared to be suitable for testing materials of strengths ranging up to 10 MPa; with stronger materials, the method did not provide satisfactory results.

Essentially there were two problems with stronger materials: firstly, the mode of failure differed from that found in the weaker units - rather than failing in shear, the material failed in compression under the thread of the tie; secondly, at higher pull-out loads, it was found that the gripper used to hold the tie and stop it turning during a test, actually cut into the tie. These two factors combined to set the upper limit on the material strength for which the test was suitable.

An attempt was made to improve the design of the gripper, although this was not totally successful: the load at which damage was caused to the gripper was increased to about 3kN, but this was not enough to reach the loads required to test some of the stronger materials. A second redesigned gripper device has therefore been developed to try to extend the load to higher levels. The results of the tests on the new gripper are reported here, along with the results of a further series of tests on AAC blocks.

3. TEST PROCEDURE

The screw pull-out test measures the shear strength of a small cylinder of the test material by finding the load required to withdraw a 6mm stainless steel helical wall-tie from the material being tested: the peak load reached during a test is known as the pull-out load. On site, the pull-out tests are carried out using a standard proof loading device; for the calibration tests, though, all testing was carried out in a universal testing machine. Whatever the means of testing, however, a gripper device is attached to the tie and the load applied through it; the gripper secures the helix and prevents it from turning, and unscrewing from the test material, during a test.

With the exception of AAC units, where the tie was driven directly into the test material, the same test procedure was followed for all materials tested: holes were drilled into the test material 5mm deeper than the intended insertion depth, using a rotary-hammer drill with a 4.5 mm masonry bit, and a helical tie was then carefully hammered into it to a depth of 30 to 50mm. For this operation, the ties were fitted into a sleeved device that allowed the tie to rotate during insertion, allowing the tie to cut a thread in the material. The gripper was then screwed onto the end of the tie, and the load increased on the tie until the test material failed. The pull-out load was recorded.

It should be noted that the mode of failure is such as to make minor variations diameter of the pre-drilled hole unimportant. Except in cases where the hole is large enough to allow the mode of failure to change, allowing compression failure of the test material
rather than shear failure, its size does not matter: the hole is there only to aid insertion.

4. EFFECT OF THE TEST METHOD

A series of tests was carried out to assess the pull-out test method and the effect, if any, it had on the compressive strength of masonry units.

Clearly, the effect on the compressive strength of the units tested using this method would be most obvious in a single-frog clay brick, as they have a small volume. Tests were carried out on twenty single-frog clay bricks: these were sampled at random from the same batch, and were then divided into two groups of 10 bricks. One group was tested for pull-out load, with six tests being performed on each brick, and both sets tested for compressive strength. At the 95% confidence level, the pull-out tests did not affect the compressive strength. We therefore concluded that the pull-out tests did not have any adverse effect on the compressive strength of units.

A series of tests was carried out on two types of AAC blocks, to check that the pull-out load is proportional to the depth of insertion. The results of the tests, carried out using depths of insertion of 25mm, 50mm and 75mm, are shown in Table 1; a plot of the pull-out load against embedment depth is shown in Figure 1. It is clear from the results that the pull-out load is proportional to the depth of insertion of the tie.

A further series of tests was also carried out on artificial aggregate blocks and AAC blocks to assess the affect of testing at pull-out depths of 30mm, 40mm and 50mm. The results showed that the coefficient of variation of the results is reduced with increasing depth of insertion of the tie. This can be attributed to a number of factors:

1. the deeper the tie is inserted, the more homogeneous the material becomes, so any surface effect is reduced;
2. the greater the depth of insertion, the smaller the overall effect of any error in the measurement of the depth of insertion: if the ties are inserted with the same accuracy, a larger percentage error will occur with a small embedment depth;
3. as the depth of hole is increased, more material is tested, and the effect of any localised density variation is reduced.

5. GRIPPER PROBLEMS

During the tests on the stronger masonry units it was noticed that some of the ties suffered localised failure on the thread under action of the gripper: the tie, however, was still pulled out of the brick. The gripper used in these tests, the "original" gripper, is shown in Figure 2. This localised failure was caused by the gripper cutting into the tie at greater loads: as the load increased, the tie cut in deeper, increasing the resistance of the
gripper to turning. This started to occur at a load of around 1.5 kN, which corresponded to a material strength of around 10 MPa. Once the load was large enough for the gripper to strip part of the metal off the thread, which in practice meant removing approximately 0.5 mm of material from each side of the tie, the load stopped increasing. This phenomenon was observed, to an extent, in all the materials tested except AAC.

An improved gripper, shown in Figure 3, was developed to stop this happening. This new gripper used ball bearings touching the surface of the tie between the threads to grip the tie. This both changed the location at which the loads were applied to the tie, and reduced the localised stresses on the tie, allowing testing to be carried out at higher loads. This new device gripped the tie better and more than doubled the load that could be applied to a tie before it failed. However, the localised stresses applied to the tie were sufficient to cause the tie to unravel before the pull-out load was reached in the stronger materials.

A second improved gripper has therefore been developed. This uses a different method to fix the tie during a pull-out test: the tie is threaded into a nylon cone, some 40mm long, and the cone is then inserted into a holder which fits into the proof loading device. The advantage of this system is that the tie is restrained over the whole length of the thread, and so the stress at any point on the tie's surface is low. Once the test tie is inserted, the plastic gripper is then placed inside a steel holder, and the tie loaded. The nylon cone is made by casting nylon into a mould around a tie which has been covered with a coating some 2 microns thick. Once the cone has been cast the tie can be removed, and uncoated ties can be screwed into the gripper and used in a test. This gripper system is shown in Figure 4.

Unfortunately, tests carried out using this system have shown that it does not perform as well as had been hoped; at loads of around 1 kN, the tie is pulled out of the gripper. Rather than being ripped out, the material is drawn out of the gripper, which is unaffected by the action. However, the tie is irreparably damaged: as the tie is loaded, it is slowly drawn out of the gripper. During loading, the number of turns of the thread on the tie between the gripper and the test material stays constant, and so, as the gap...
between the gripper and the test material increases, the pitch of the thread increases. A tie that has been tested and failed in this way is shown in Figure 5, alongside an untested tie.

![Figure 5: Mode of failure of tie in second redesigned gripper](image)

The tie seemed to fail in the way it did due to the friction between the tie and the nylon in the gripper not being high enough to prevent the tie being pulled out of the gripper. As there does not seem to be any way to increase the co-efficient of friction between the tie and the nylon, the second improved gripper does not seem to be viable.

6. SCREW PULL-OUT TESTS

6.1 Masonry Units

The pull-out tests on masonry units were carried out in their stretcher faces. In practice, the number of tests carried out in each individual unit varied depending on the size of the unit. In addition, the depth to which the tie was inserted into the units also varied: in most of the unit types 30mm was used, although 50mm was used with some of the weakest AAC units, to ensure that a reasonable pull-out load was reached.

During testing, each unit was used to provide 3 test results per stretcher face, although some of the blocks were only tested in one face. In the weaker AAC blocks, the depth of insertion of the tie was increased to 50mm. For each unit the pull-out test was carried out first, followed by tests to determine the density, the water-absorption and then the compressive strength.

6.2 Mortars

The test programme used to calibrate the screw pull-out test in mortars used 6 mortar mixes and four unit types, covering a range of water absorptions. The tests were carried out in nominally 10mm mortar beds, cast between two bricks in a couplet. Six pull-out tests were carried out on each specimen, three per stretcher face. The couplets were lightly precompressed both before and during a test as it was felt that the insertion of the tie into unloaded couplets could cause some of them to break.
Details and properties of the six mortar mixes used, with the proportions of cement, lime and sand used, by volume, are shown in Table 2. The sand used in the tests complied with the requirements of a Type S sand, as defined in BS1200 (3); the cement was an Ordinary Portland Cement, complying with the relevant British Standard; and a bagged hydraulic lime was used. Sufficient water was added to the materials to give equal workability to all the mortars. A grading curve for the sand, produced following a wet sieving analysis, is shown in Figure 6.

Five couplets and three 100mm mortar cubes were made for each test mortar and unit type. All the specimens, including the cubes, were cured under polythene sheeting, and testing of both the couplets and the cubes was carried out 28 days after the specimens were manufactured. The pull-out testing took place on an Instron universal testing machine.

A scattergram showing the results for all the pull-out tests carried out on medium strength masonry units is shown in Figure 7. It is clear from the diagram that the results for materials with a compressive strength in excess of 10 MPa show a poor relationship between the compressive strength of the material and the pull-out load. They clearly show that for these units either the test method needs to be refined or some other method needs to be devised to apply the load to the tie, thereby ensuring that the same mode of failure occurs whenever the material strength.

7.1 Masonry Units

A scattergram showing the results for all the pull-out tests carried out on lower strength masonry units is shown in Figure 8. It shows that the results for materials with a compressive strength in excess of 5 MPa show a poor relationship between the compressive strength of the material and the pull-out load. They clearly show that for these units either the test method needs to be refined or some other method needs to be devised to apply the load to the tie, thereby ensuring that the same mode of failure occurs whenever the material strength.

Figure 6: Wet sieving analysis of sand used in the mortar tests
Figure 7: Scattergram of results for medium strength masonry units
Figure 8: Scattergram of lower strength masonry unit tests
Figure 9: Scattergram of mortar test results
The results of the tests on AAC units and units with a compressive strength of less than 10MPa were more promising, as may be seen in Figure 8. As the AAC blocks have strengths ranging up to around 10 MPa, the screw pull-out method seems to be suitable for determining the compressive strength of AAC units in-situ.

7.2 Mortar Tests

As every combination of the 4 brick types and 6 mortars was tested, there were 24 sets of results. Each set of data was given an identification reflecting the combination of its constituents: for example, a 1:½:4½ mortar mix used in an engineering brick couplet was labelled as E1. Unfortunately, some of the couplets split before all six tests had been completed on them; in addition, different numbers of specimens of each type were made. As a result, the numbers of test results available for each combination of mortar and brick varied considerably.

A scattergram showing pull-out load plotted against compressive cube strength of the mortar for all the results of the pull-out tests is shown in Figure 9.

8. ANALYSIS OF RESULTS

8.1 General

Scattergrams of the results showing the mean pull-out strength for each test plotted against the compressive strength of the material are shown in Figure 7, for the medium strength masonry units, and in Figure 9, for the mortar tests. In Figure 9, all the individual results are shown plotted against the cube strength of the mortar mix, which was taken to be the compressive strength for that mix; in Figure 7, each solid point represents the mean of three pull-out loads taken in each individual unit, plotted against the measured compressive strength of that block. Some of the AAC tests were carried out at depths of insertion of 50mm: as the pull-out load is proportional to depth, these have been adjusted to a 30mm depth. It is particularly obvious, in Figure 7, that the pull-out forces levelled out for materials with a compressive strength greater than around 10 MPa.

8.2 Mortar Analysis

The scattergram in Figure 9, shows the results of all six mortars, plotting pull-out load against compressive cube strength. It is clear that the results for Mortar F, a 1:3 mix, are no higher than those for Mortar E, despite the considerable increase in the compressive strength of Mortar F. It therefore seems likely that the mode of failure of the mortar in this set of tests was not the same as in the other tests. As these results are so different, the Mortar F results have been ignored in the analysis of the data.

The mortar results were analysed using the Analysis of Variance technique, which uses the f-test (4). In total, 20 sets of test data were analysed, representing every combination of the four bricks and five mortars.

The results of the analysis of the data showed that, at the 99% confidence level, both the
mortar mix ratio and the brick type significantly affected the pull-out value. In addition, they showed that there was a significant amount of interaction between the brick and the mix ratio effects. This might be expected, as the properties of a mortar are known to be affected by the rate of removal of water from it as it is curing.

Looking at the data more closely showed that almost all of the mortars performed significantly differently at the 99% confidence level. It was harder to distinguish between some, however: for the solid unfrogged clay brick and the perforated clay brick, the 1:1:6 and 1:8 plasticiser mortars, Mortars C and D, gave results that were not significantly different, even at the 95% confidence level.

We also assessed the data to determine the minimum number of pieces of data required to provide results that are significantly different. Separate files were set up taking the first 5, 10, 15 and 20 pieces of data from each of the data files. The results of the analysis showed that 25 of the 36 results were significantly different with 5 pieces of data, 29 with 10, and 30 with 15 and 20 pieces of data. It therefore seems reasonable to assume that, for the data tested, 10 tests are sufficient.

The mortar cube tests showed that Mortars C and D had compression strengths of 3.35 and 2.86 MPa, respectively. Not surprisingly, the analyses of these mortars showed that, with the exception of Brick 2, only two of the results were significantly different at the 95% confidence level. It would therefore appear that the screw pull-out test method is unlikely to be able to distinguish between the compressive strengths of materials where the ratio of their cube strengths is not less than 0.85, or greater than 1.17.

9. DISCUSSION

The results of the tests carried out on to assess the screw pull-out test have shown that the method provides a practical way of assessing the compressive strength of weaker masonry materials. However, the limitations placed on the system by both the gripper device and the change in mode of failure that occurs in stronger materials limits the use of the system to these weaker materials, and is likely to continue to do so.

It is possible that the use of smaller diameter ties may help to provide shear failures in some stronger materials. However, the apparent change in the mode of failure in stronger materials, from shear to compressive failure, is unlikely to be easy to overcome.

10. CONCLUSIONS

The screw pull-out test has been shown to be a viable method of assessing the compressive strength of weaker masonry materials. Whilst its unsuitability for assessing the strength of stronger materials might initially seem to be a major limitation, in practice the vast majority of masonry materials we are asked to assess lie at the weakest end of the spectrum: stronger materials normally perform perfectly adequately.

The analysis of the mortar test results showed that 10 pull-out tests should be sufficient to provide an indication of the strength of mortar in any single test location.
REFERENCES


2. Ferguson, W. A., "Proceedings of the Autumn Meeting of the British Masonry Society". Stoke, United Kingdom, 1993. (To be published)


Table 1: Results of tests carried out to assess the effect of embedment depth on pull-out load

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| Compressive Strength (N/mm²) | 3.0 | 3.2 | 3.1 | 3.1 | 4.4 | 4.3 | 4.3 | 4.4 |

Table 2: Properties of materials used in the mortar tests

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<td>Single frog clay</td>
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<th>Compressive Strength</th>
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<td>1 : 8 + plasticiser</td>
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1266