1. ABSTRACT

Two different non-destructive in-situ techniques to determine the compressive strength of masonry mortars are compared and cross calibrated. Both methods act on small cylindrical regions of mortar: the PNT-G method determines the energy spent to make a hole of prescribed dimensions; the HELIX method measures the force required to extract a helical device tapped to a prescribed depth. The two techniques are compared using different mortars in sets of 6-unit stack bonded prisms and mutually verified against the results of the cube and prism compressive strength of the mortars.

2. INTRODUCTION

Non-destructive in-situ mechanical measurements of compressive strength in mortars are crucial for an estimation of static performance of masonry walls. Most tests currently used to evaluate the constituents and performance of built masonry are based on chemical analysis of mortars, sonic or ultrasonic tests or semi-destructive tests (flat-jack, bond-wrench, pull-out etc). [1] [2]. Apart from the pendulum rebound hammer, which has limited application for quality control of pointing mortar, the only methods that are available to assess in-situ strength characteristics of mortar are the Helix pull-out method [3] and the PNT-G penetrometric method [4]. The first one measures the force required to extract a helical device that has been self tapped into the mortar to a prescribed depth; the second one determines the energy spent to make a hole of prescribed dimensions. The knowledge of the mortar mechanical properties is required to assess the static response of the masonry. In fact, in most cases, the mortar is the weakest component in masonry compared to the resistance of the units, moreover it is more difficult to extract non-disturbed specimens of mortar than to take away bricks or blocks. On the other hand, mortar in-situ tests will be acceptable only if they are easy to do, are highly repeatable and if they involve a very low level of destructivity. Only in these circumstances is it possible to do sufficient numbers of replicate measurements to allow a statistically significant result to be attained.

Keywords: Masonry, Materials, In-situ testing.

1 Masonry Str. Sect., Building Research Establishment, Watford, UK, Email: devekeyb@brush.bre.co.uk
2 Department of Structural Engineering, University of Pisa, Italy, Email: sassum@docenti.ing.unipi.it
3: DESCRIPTION OF PNT-G AND HELIX METHODS

3.1. Helix method.

Positions along the mortar beds were selected randomly and, at each position, a 4.5mm diameter by 35mm depth hole was drilled in the middle of the thickness of the mortar bed. Holes which were significantly off-centre and too close to the unit or where the drill had dropped into an obvious air void before reaching at least 30mm depth were rejected and alternative positions were substituted until at least ten positions had been prepared. A helical tie was mounted into the driving tool, placed with its tip in a prepared hole then hammered firmly but not violently into each hole so that 30mm of the full diameter part of the tie was screwed into the mortar. After installation of the tie, a gripper was screwed onto the end, a proof loading device was attached to the gripper and the assembly rotated to screw down the tie and take up any slack until the reaction frame was in contact with the masonry surface. The arrangement is shown in fig 1a. The load applied to the tie was then increased steadily until failure. The peak load reached during a test was held by the dead needle on the dial and recorded as the pull-out load. The mortar strength was estimated by reference to a calibration curve shown in fig 2 which was based on previous calibration trials.

3.2. PNT-G method.

The test consists of a penetrometric trial in the mortar using a 12V DC drill powered by a cadmium-tungsten battery and connected to a self-calibrating energy counter together with an acoustic signalling apparatus (fig. 1b). The instrument measures the energy spent to make a hole in the mortar joint of 4mm diameter and 5mm depth, discounting the transitional effect at the beginning of the test and the self-dissipating energy. The acoustic gear emits a tone at both the start (upon completion of self-calibration) and the end (the reaching of the prescribed hole depth) of each trial. Each energy units measurement, with the help of an appropriate calibration curve (fig. 3), gives an in-situ non-destructive estimation of the characteristic simple compression strength of the mortar. The instrument is properly calibrated to evaluate the resistance of mortars, formulated from weak medium and strong sand, whose collapse values do not exceed 10 N/mm². In this case the energy spent to make the prescribed hole is done only to break the connections of the grains without destroying them. However it is possible to calibrate the PNT-G also for other cases. Its efficiency in the determination of the strength of masonry has been also verified through a group of comparative tests with flat-jack measurements [5].

4. TEST PROGRAMME

A group of eight masonry specimens with same geometry were prepared (fig. 4) using coarse (C) or fine (F) sand and with the following four different ratios of binder (cement and lime) to sand:

A) 1 : 1/4 : 3
B) 1 : 1/2 : 4 1/2
C) 1 : 1 : 6
D) 1 : 3 : 12

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Each masonry specimen, lightly precompressed in an electrohydraulic apparatus to maintain its stability, was subjected to fifty PNT-G penetrometric tests and ten Helix pull-out tests, uniformly distributed over the five mortar joints of the wallettes. The measurements were reported on data schedules as in fig. 4. An estimation of the individual mortar compressive strength has then been deduced from the corresponding calibration curves for each specimen and the mean values and standard deviations have been calculated (tab. 1).

A large group of 70.7mm cubes and 40 x 40 x 160mm prisms has also been prepared from the mortar, in order to provide parallel cube and prism compression data to recheck the calibration curves: the characteristics cubic compression and prism compression strength has been calculated and is presented in tab. 2.

5. RESULTS AND DISCUSSION

The comparisons between the Helix and PNT-G compressive strengths and the corresponding cubic and prism compression limits (fig. 6) generate the following comments:

a) The PNT-G penetrometer gives its best performances for weak mortars (1 N/mm² < f < 3 N/mm²) or very weak mortars (f < 1 N/mm²) formulated with coarse sand.

b) The HELIX pull-out test shows best results for medium and strong mortars (3 N/mm² < f < 10 N/mm²).

c) Neither method is very accurate for very strong mortars (f > 10 N/mm²), but give reasonably reliable qualitative information. (Generally there is not likely to be a problem with high strength mortars so the qualitative result is adequate for most purposes).

From the trials it appears that the two instruments give reasonably equivalent results over the range of mortar strengths approximately from 2 to 6 N/mm², and less equivalent results over the range 0.5 - 12 N/mm²: The PNT-G is more applicable for the lower compressive strength values, while the HELIX is slightly better for higher values. Both methods show a fair level of variability, reflecting the variable nature of mortar, with the PNT-G giving overall a slightly lower variability at the chosen level of replication. So with their help it is possible to assess in-situ non destructive evaluations with good significance in a large number of practical situations.

6. CONCLUSIONS

- Both the PNT-G and the HELIX pull-out methods give substantially more reliable and accurate in-situ estimates for the strength of mortars than previously used techniques such as the Windsor Probe, the Schmidt hammer or attribution of strength on the basis of chemical analysis.

- The methods are simple and rapid and thus make it possible and economic to measure sufficient numbers of replicates to give a statistically acceptable result for what is accepted to be a highly variable material.
- The methods do not give perfect equivalence at this stage of their development but are in acceptable agreement over a fair range of strengths.

- The methods exhibit a similar level of variability.

- Both methods need their calibration data extended to cover a greater range of sand types and mortar formulations, particularly pure-lime sand and hydraulic-lime sand mortars.

- Both methods are likely to be prone to larger errors with sands containing a proportion of very large hard particles and should be evaluated for such materials.

REFERENCES


Fig. Helix pull-out (a) and PNT-G penetrometer (b)
Fig. 2: Helix calibration curve ($f_{hx}$: compressive strength [N/mm$^2$] - S: pull-out force [KN]).

Fig. 3: PNT-G calibration curve ($f_{pnt-g}$: compressive strength [N/mm$^2$] - U: work unit[0.006 J]).
Fig. 4: geometry of masonry specimen.

Fig. 5: typical data schedule.
### Tab. 1: Helix and PNT-G compressive strength values.

<table>
<thead>
<tr>
<th>Spec.</th>
<th>1 : 3 : 12</th>
<th>1 : 1 : 6</th>
<th>1 : 1/2 : 4 1/2</th>
<th>1 : 1/4 : 3</th>
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<tr>
<td></td>
<td>C</td>
<td>F</td>
<td>C</td>
<td>F</td>
</tr>
<tr>
<td>M hx</td>
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<td>0.31</td>
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<td>0.45</td>
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</tbody>
</table>

M: mean value [N/mm²]  
S: standard deviation [N/mm²]  
hx: Helix method compression strength  
pnt-g: PNT-G method compression strength

### Tab. 2: Cubic and Prism compressive strength values.

<table>
<thead>
<tr>
<th>Spec.</th>
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<th>1 : 1 : 6</th>
<th>1 : 1/2 : 4 1/2</th>
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<td>F</td>
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<td>0.254</td>
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</tr>
</tbody>
</table>

M: mean value [N/mm²]  
S: standard deviation [N/mm²]  
cc: cube compression strength  
p: prism compression strength
Fig. 6: compressive strength [N/mm²] comparison diagrams.