Materials and Structures / Matériaux et Constructions, Vol. **37**, August-September 2004, pp 497-501

RILEM TC 177-MDT: 'Masonry durability and on-site testing'

RILEM Recommendation MDT. D.5 – In-situ stress - strain behaviour tests based on the flat jack

The texts presented hereunder are drafts for general consideration. Comments should be sent to the Chairperson Prof. Luigia Binda, Dipartmento di Ingegneria Strutturale, Politechnico di Milano, Piazza Leonardo da Vinci, 32, I-20133 Milano, Italy; Fax (+39) 02 23994220, Email: luigia.binda@polimi.it, by 28 February 2005.

TC Membership – Chairperson: Luigia Binda, Italy; **Secretary**: Bob de Vekey, United Kingdom; **Members**: Giulia Baronio, Italy; Vlatko Bosiljkov, Slovenia; Norman J. Bright, UK; Geoff Edgell, UK; Mike Forde, UK; Caspar Groot, the Netherlands; Elizabeth Laycock, UK; Christiane Maierhofer, Germany; Paul Maurenbrecher, Canada; Claudio Modena, Italy; Adrian Page, Australia; Felicita Pires, Portugal; Mike Schuller, USA; Robert Thomas, USA; Miha Tomazevic, Slovenia.

0. SUMMARY

There is an enduring interest in the durability of masonry acting as a composite material especially because a very large proportion of the world's heritage buildings and civil engineering structures are predominantly constructed from this material. There is a continuing need for information on the best way to maintain a state of good preservation of masonry and on sympathetic techniques for repair and reinstatement of deteriorated masonry.

In order to evaluate materials for use in both new and old structures, laboratory accelerated durability tests are necessary. Equally, a range of in-situ, non-destructive or semi-invasive tests are required to evaluate the status and condition of structures in the field and allow quality control of repair systems.

1. SCOPE

This recommendation specifies a method of in-situ determination of the local stress-strain behaviour as a function of stress in built masonry by using flat jacks reacting against the main body of masonry to apply a force to a small specimen volume. Guidance is given on the principles involved, the preparation for the test, the apparatus, the method of test, the method of calculation and the contents of the test report.

2. SPECIMENS (SIZE, SHAPE AND NUMBERS)

Some replication (repeat determinations) may be required. The level of replication required will depend on the level of variability and the ratio of the measured value of stress (Sm) to the predicted stress capacity (Sd). The designer / engineer should use his/her knowledge of the structural form of the building element and its relationship to the overall structure to decide on the appropriate replication rate.

The size and shape (and position) of the specimen (area of masonry) is determined by the form of the masonry and the type of jack used and some guidance on the choice of suitable specimen position / jack type and size is given in section 5 and in the guidelines.

3. PRINCIPLES OF THE TEST

The testing technique is based on the use of two flat jacks on a common oil supply to apply a stress field to a volume of masonry between them. Quite clearly the jacks have to react against the rest of the structure in order to exert a force and the level of applied stress will be limited by the ambient stress field in the structure increased to an extent by load spreading. The jacks will also need to be pre-calibrated in the way described in Test MDT.D.4.

Because the masonry in the test volume will still be physically linked (bonded) to the rest of the wall at its edges and may be linked at its rear in multiple leaf walls, there will be an inherent uncertainty which cannot normally be resolved. In multiple leaf walls the measurement should only be ascribed to the leaf or leaves tested and not to others which may be in different materials. The value of Young's modulus measured by this technique together with measured or calculated strain data is probably sufficiently accurate for estimating stresses due to expansion, movement or differential movement in masonry structures. The test may, in some cases, be used as a proof test for compressive strength but is not recommended as a reliable technique.

4. CONDITIONS OF TESTING

Ambient conditions should be adopted but it is inadvisable to carry out such work in strong sunlight, heavy rain or any other conditions likely to cause serious fluctuations in the state of the specimens or the instrumentation during the test duration.

5. APPARATUS

The following equipment is required:

1 Slot cutting equipment: This may be an abrasive cutting machine for harder materials or a drill which is used to 'stitch drill' softer materials such as mortars plus a file to smooth the cut.

2 Equipment such as vacuum cleaners, blowers, brushes etc. to clean the slot.

3 Strain measuring equipment such as a transducer or a mechanical meter which can measure over attached reference points. (NOTE fixed measuring devices are feasible for this test but are not practical for stress tests done in the same area of the masonry).

4 A pair of flat diaphragm jacks of nominally the same size with an overall thickness which allow insertion into a cut slots or cleaned-out mortar joints.

5 Steel shims with the same plan area and shape to pack around the jacks to ensure an accurate fit to the slots.

6 A hydraulic pump and high pressure flexible connecting tubes with quick change connectors.

7 An accurate pressure meter.

8 Measuring devices to measure the area of the cut slots *i.e.* by measuring the depth and the width of a rectangular cut slot.

The flat jack is commonly rectangular with a ratio between the sides of 1: 2 or sector -shaped to fit slots sawn with an abrasive cutting wheel and with a thickness of between 5 and 10mm. Typical jacks are shown in Figs. 1 a, b, c, d, e. The jacks in Figs. 1c and d are adopted when an electric eccentric circular saw is used.

Referring to Fig. 1e, for optimum accuracy the dimension A shall be equal to or greater than 1.5 times the length of a masonry unit (l_u) if the unit length is more than 200 mm or 2 times the length of masonry unit l_u if the unit length is equal to or less than 200 mm. Dimension B shall be equal to or greater than the thickness (t_u) of the masonry unit. Other (particularly smaller) sizes of jacks may be used but will only give accurate results if the geometrical efficiency factor K_e has been determined and is used to correct the measured values.

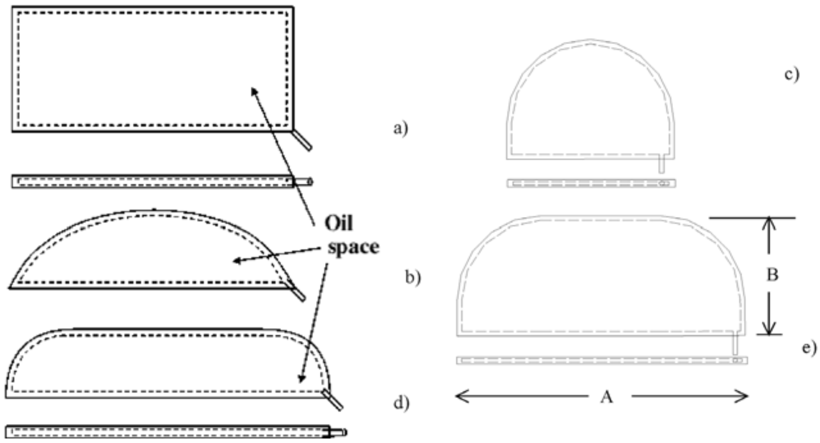

Fig. 1 - Typical flat jack shapes.

The jack must be pre-calibrated to measure its own pressure / force / deflection characteristic in a grade-A test machine. The jack, which must be able to support a pressure of at least 6N/mm², is made of steel sheets, with a thickness of 0.5 - 1 mm, formed into a bladder and provided with an inlet/outlet port. Particular care should be taken in welding the edge of the jack. The mechanical or electrical strain gauge should have as high a sensitivity and precision as possible. A sensitivity of approximately 0.0025 mm is normally sufficient. The measurement reference points are INVAR discs with a conical seat, which are glued to the masonry symmetrically such that the strain can be measured using mechanical gauge extensometers over 75-90% of the specimen height. Brackets should be attached for mounting electrical displacement measuring devices (*e.g.* Linear Variable Differential Transformers, LVDTs). The oil pressure is measured by means of a pressure gauge or a pressure transducer cell.

6. PRECALIBRATION PROCEDURE FOR INDIVIDUAL JACKS

A procedure is described fully in Test MDT.D.4.

7. PROCEDURE

The test sequence is as follows:

1 Choose a representative piece of masonry then glue the metal reference points at the correct gauge length for the strain measuring instrument or attach LVDTs. The instrument should be selected to give a measurement (Gauge length) over 75-90% of the distance between the two jack planes. A number of replicate measuring positions (pairs of points or LVDTs) should be used and their results averaged. Four are recommended as in Fig. 2.

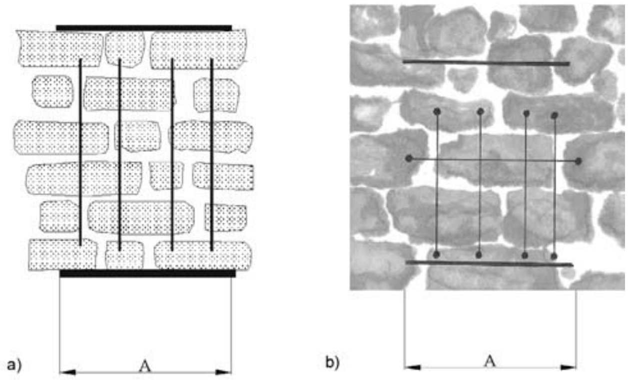

Fig. 2 - Double flat jack test in a) handmade brick masonry and b) irregular stone masonry.

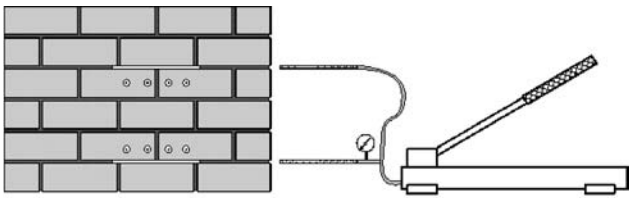

Fig. 3 - Typical test layout for a test of modern, accurately shaped, brickwork.

2 The cuts are then made taking care to disturb the surrounding masonry as little as possible. Slots shall be parallel, vertically aligned and separated by at least 5 courses of masonry in case of unit height equal to or less than 100 mm (brick masonry) or 3 courses of masonry in case of unit height equal to or greater than 100 mm (stone masonry). In any case the distance between the slots shall be between the length A and 1.5 times the length A of the flatjack but also not less than 2.5 times the average dimension B of the jack.

3 The area of the cuts is normally determined by measuring the surface width and taking depth measurements every 10-20mm and summing the area of the strips.

4 The jacks are then inserted and packed tightly into the cut slots using shims (thin steel sheets) as necessary. If the masonry has any internal voids over any part of the slot area, *e.g.* caused by unfilled frogs, perforations in the bricks or vertical joints in the slot area it is very important to use an overwide slot and pack with shims to protect the jack membrane from local swelling.

5 After the zero strain measurement has been taken, the pressure is then increased in increments of about 10% or less of the expected maximum and the strain is monitored after a short dwell at each increment. Both jack pressure and strain should be recorded at each increment. The ratio of the increase of jack pressure (dp) to the strain increment de_m should be monitored and the test should be stopped when the ratio starts dropping rapidly to avoid damage to the masonry. Furthermore it should be remembered that the measured stresses should not exceed the limit values of the carrying capacity of the jack declared by the producer or experimentally measured.

6 Depressurise and remove the jacks and repoint with a matching mortar if restoration is required.

8. TEST RESULTS (CALCULATION)

The stress in the masonry between the jacks f_m is given by the relation:

$$f_m = K_e \cdot p \cdot A_{slot}/A_{je}$$

where A_{slot} is the average of the area of the two slots; A_{je} is the average of the effective area of the two flat jacks and p is the hydraulic pressure in the jack lines. In absence of calibration data the default value of the geometrical efficiency factor K_e should be taken as 1.

The tangent modulus of elasticity, E_t, at any given level of stress is given by the relation:

$$E_t = df_m/de_m$$

where df_m is the increment of stress and de_m is the increment of strain at the chosen stress level.

The secant modulus of elasticity, E_s, at any given level of stress is given by the relation:

$$E_s = f_m/e_m$$

where f_m is the cumulative stress and e_m is the cumulative strain increment from zero.

This procedure is likely to overestimate the elastic modulus and a more accurate value will be obtained by multiplying the results by the geometrical efficiency factor K_e appropriate to the masonry type and jack size and position (see MDT.D.4) and allowing for confinement by adjacent masonry.

9. TEST REPORT

1 A reference to this RILEM standard.

2 A description of the site, building and masonry together with existing relevant information such as the environmental conditions, specification of the units or mortar, drawings and data derived from ancillary tests such as mortar analysis or pull-out.

3 The date of construction of the masonry if known.

4 A description of the units including a sketch showing the dimensions, and shape, pattern and size of holes and the properties of the units including body material, strength and, where appropriate, water absorption, IRS, density if available.

5 The position of each measurement or photographic reference for each position.

6 The values of the calibration factor (effective area A_{je} and, if available, masonry format calibration factor K_e) for the flatjack used.
7 Computed stress - strain curve for each position and any values of tangent or secant modulus together with the stress level.
8 The date of the test.

10. BIBLIOGRAPHY

[1] Rossi, P.P., 'Analysis of mechanical characteristics of brick masonry tested by means of non-destructive in-situ tests', Paper presented at the 6th International Brick Masonry Conference, Rome, 1982.

[2] Sacchi Landriani, G. and Taliercio, A., 'Numerical analysis of the flat jack test on masonry walls', *Journal of Theoretical and Applied Mechanics* **5** (3) (1986).

[3] Noland, J.L., Atkinson, R.H. and Schuller, M.P., 'A review of the flat-jack method for nondestructive evaluation', Proceedings of Non-destructive Evaluation of Civil Structures and Materials, Colorado, October 1990.

[4] ASTM C 1197-91, 'Standard test method for in-situ measurement of masonry deformability properties using the flatjack method'.

[5] RILEM Technical Recommendations for the Testing and Use of Construction Materials, LUM.D.3 'In-situ strength/elasticity tests based on the flat jack' (E & FN Spon, London, 1994) 503-508.

[6] Building Research Establishment - Digest 409, 'Masonry and concrete structures: measuring in-situ strength and elasticity using flat jacks' (1995).

[7] de Vekey, R.C., 'Thin stainless steel flat-jacks: calibration and trials for measurement of in-situ stress and elasticity of masonry', Proc 7th Canadian Masonry Symposium, Hamilton, Vol. 2 (1995) 1174-1183.

[8] EN 1052–1, 'Methods of test for masonry. Part 1 - Determination of compressive strength' (1998).

11. GUIDELINES

11.1 Difficulty in measurement interpretation

Difficulties or impossibility in applying the double flat jack test can be found in the case of low rise buildings (one or two story high) due to the lack of stress restraint by the upper masonry caused by the low stresses acting on it. Fig. 4 shows one of these cases: the continuation of the test was impossible due to the failure of the upper part of the masonry.

11.2 Problems due to the masonry characteristics

11.2.1 Thick joints

In the case of thick mortar joints (*e.g.* byzantine joints), the choice of the cutting position for both single and double flat-jack is very difficult. When the joints are more than 2 cm thick, the best choice should be cutting partly through a brick (or stone).

11.2.2 Regular masonry with thin joints

Care should be taken in cutting operations when the joints are particularly thin and/or the wall is of high historic importance. When the thickness of the joint is less than 4 mm in order to avoid spoiling the stones, the circular saw instead of the drill should be used for cutting. When the joint is not excessively thin, the test can be carried out as for the brick masonry.

11.2.3 Irregular stone masonry

When a very irregular stone masonry has to be tested the cutting cannot be made only through the joints due to their softness and irregularity, but must pass partly through the stones. [Guidelines reference 6]. In that case the choice of the test position is very important, since the high inhomogeneity of the masonry can influence the results, as shown in Fig. 5. The presence of a non-symmetric and non-homogeneous distribution of the stones caused a non uniform distribution of stresses during the test, with higher concentration of stresses at the location of LVDT 4. The result was an apparent higher stiffness of the specimen measured at the location of LVDTs 1, 2 and 3. The test, in fact, was considered not valid. Furthermore, also in the case of the double jack, it is very difficult that symmetric values are measured.

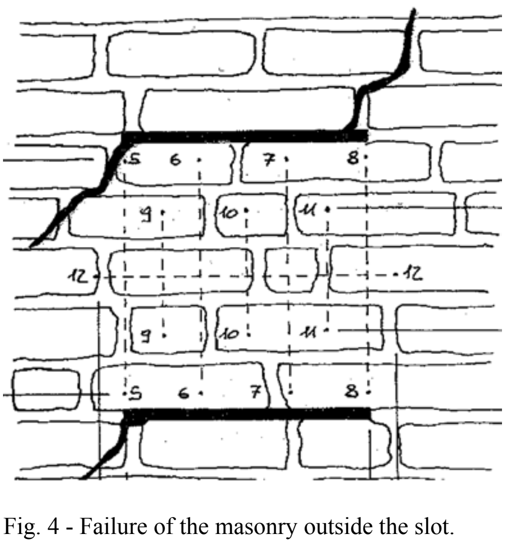

Fig. 4 - Failure of the masonry outside the slot.

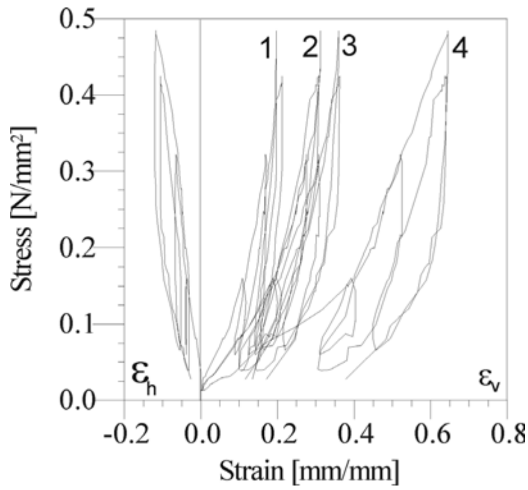

Fig. 5a - Stress strain behaviour.

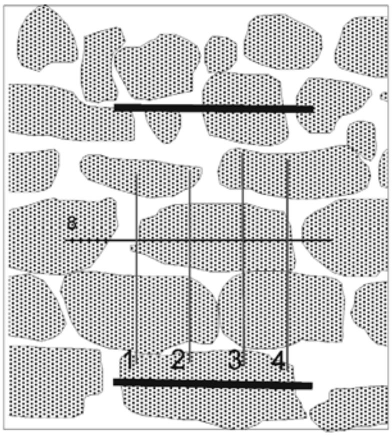

Fig. 5b - Test of an irregular stone masonry wall.

11.3 Efficiency of masonry repair

Two repair techniques of grout injection and deep repointing can essentially be controlled by carrying out double flat jack tests before and after repair.

The investigation can be made by leaving on site unloaded the flat jacks used to carry out the test before repairing. After repairing the test can be repeated and the stress-strain curves compared in order to detect the eventual increase in stiffness and, consequently, strength [Guidelines reference 2].

11.4 GUIDELINES REFERENCES

[1] ASTM C 1197, 'Standard test method for in-situ measurement of masonry deformability properties using the flat jack method' (1991).

[2] Bettio, C., Gelmi, A., Modena, C. and Rossi, P.P., 'Mechanical characterisation and strengthening of masonries from antique historic centres in the Trento province: preliminary report on the results of on site investigation, Conf. on "Murature, sicurezza, recupero", Trento, Italy (1993) 185-222 [in Italian].

[3] Binda, L., 'Characterisation of stone and brick masonries finalised to the choice of appropriate strengthening techniques', Milan Research Unit, Final Report for Contract CNR/GNDT (1999) [in Italian].

[4] Binda, L. and Anzani, A., 'The time-dependent behaviour of masonry prisms: an interpretation', *The Masonry Society Journal* **11** (2) (1993) 17-34.

[5] Binda, L., Gatti, G., Mangano, G., Poggi, C. and Sacchi Landriani, G., 'The collapse of the Civic Tower of Pavia: a survey of the materials and structure', *Masonry International* **6** (1) (1991) 11-20.

[6] Binda, L., Modena, C. and Baronio, G., 'Strengthening of masonries by injection technique', Proceedings of 6th NaMC, Vol. I, Philadelphia (1993) 1-14.

[7] Binda, L., Tiraboschi, C. and Tongini Folli, R., 'On site and laboratory investigation on materials and structure of the Bell Tower in Monza', 2nd Int. Conf. RILEM on Rehabilitation of structures, Highett, Australia, 1998, 542-556.

[8] Eurocode 6, 'Design of Masonry Structure'.

[9] Hilsdorf, H.K., 'Investigation into the failure mechanism of brick masonry loaded in axial compression', Proc. Int. Conf. on Masonry Structural System, Texas, 1969.

[10] Binda, L. and Tiraboschi, C., 'Flat-jack test as a slightly destructive technique for the diagnosis of brick and stone masonry structures', *Int. Journal for Restoration of Buildings and Monuments (Int. Zeitschrift für Bauinstandsetzen und Baudenkmalpflege, Zurich)* (1999) 449-472.