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THIN STAINLESS STEEL FLAT-JACKS: CALIBRATION AND TRIALS FOR MEASUREMENT OF IN-SITU STRESS and ELASTICITY of MASONRY

by R.C.de Vekey

SUMMARY

The flat jack is a flat flexible envelope which is filled with hydraulic fluid and can be pressurised using a pump and used to generate small movements in structures and apply substantial forces. Suitable arrangements allow the measurement of compressive stress in members and the local stress strain behaviour with minimal, easily reparable damage of the masonry. The BRE version is described and some calibration work and application trials are discussed. The work indicates that for most purposes provided the 'jack effective area' has been measured for each individual size and the hole size is allowed for, all the calibration data for a range of wall sections and materials fits a common curve and can be used interchangeably.

INTRODUCTION

There are numerous situations where it is advantageous, or even essential, to know the state of stress existing in a structure. One way of measuring such stresses is to use a flat-jack. Such jacks have often been used to determine the stresses in rock formations, and are made from steel sheet, welded and filled with hydraulic fluid.

The use of a flat-jack as a method of assessing the in-situ vertical stresses in masonry walls has been suggested by a number of researchers, including Rossi 1982, Sacchi Landriani and Talierco 1986, and Noland et al 1990. Recently a RILEM international

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standard recommendation for their use has been published - RILEM 1994. The principle used is to measure an accurate vertical length in an area of masonry, cut a slot within the measured length (whereupon the slot will close by a small amount) and then use the jack to restore the original length. The jack force can then be relate to the stress field across the slot. In an alternative arrangement two jacks can be inserted and can be used to generate a stress field in the masonry between them and measure elastic modulus.

A small thin stainless steel flat-jack design is currently being developed at BRE. These are commonly just larger than bed face dimension of a brick and about 5mm thick but much smaller area jacks have also been produced. They have an angled inlet tube to allow their use both in 'stretcher' and 'header' mode and their relative thinness allows installation in most mortar joints.

APPARATUS

The BRE flat-jack is shown in Figure 1. Essentially it consists of two thin, stainless steel membranes welded over a rigid, rectangular steel frame, with oil filling the space between them. Dimensions of some jacks are given in Table 1.

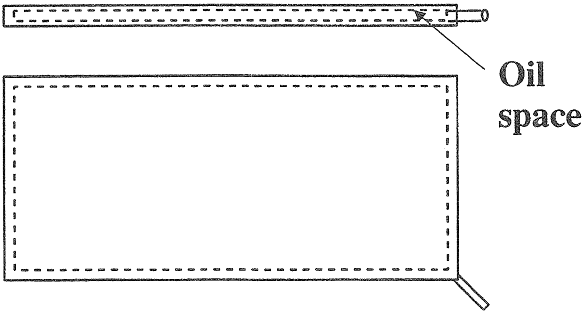

Fig.1. BRE style Flat Jack

Table 1. Dimensions of flat jacks

Type	Dimensions	Gross plan area	Effective area
1	125 x 251 x 5	31375	23584
2	112 x 225 x 5	25200	18380
(3)	two of type 2	50400	36760
4	113 x 226 x 8	25538	20047
5	70 x 105 x 5	7350	4286

An oil feed connector is fixed rigidly to one corner of the frame at 135 degrees to each side, to allow the jack to be used against a header or a stretcher.

An oil pressure gauge and a hand pump are connected to the jack, and these, together with a pack of stainless steel shims and a Demec strain gauge and points, comprise the essential apparatus.

For calibration trials a uniform stress field was set up in test walls by loading in an Amsler 1000 tonne capacity compression test machine.

CALIBRATION OF JACK EFFECTIVE AREA

A flat jack operates, in principle, like a normal cylindrical jack in that the force exerted is the product of the oil pressure and the 'area' of the jack. However, because the edge of the jack exerts a restraining force by diaphragm action and a slight fixity its effective area is not as much as the actual face area. This effective area was measured by clamping each jack, at the normal operating distension, between two very rigid steel plates in a compression test machine. The test machine was then zeroed and a curve plotted of jack oil pressure versus indicated load on the test machine. Figure 2 give calibration curves for a range of sizes.

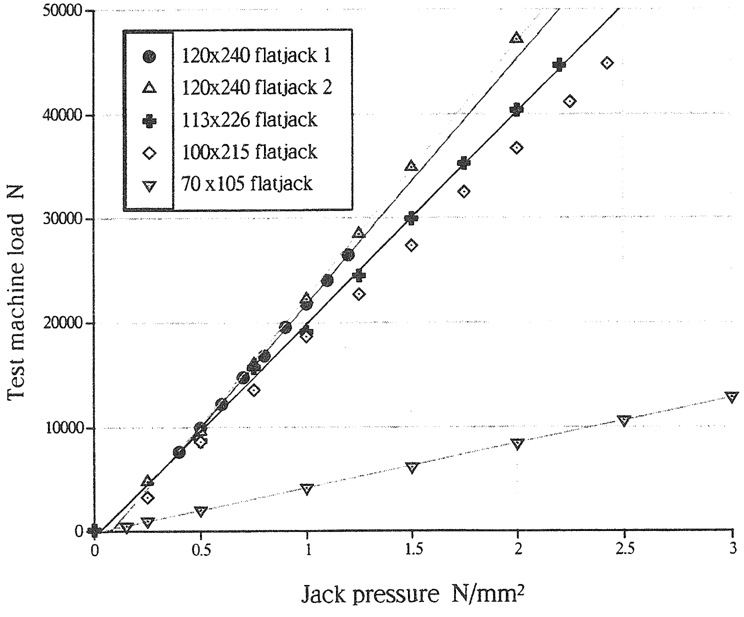

Fig. 2. Calibration curves for effective area.

There is either some initial slight curvature due to bedding-in and increase of the contact surface or a slight zero error on the gauge then an almost perfect straight line. The tangent slope of the pressure over the load give the effective area of the jack. Table 1 gives the effective area for four sizes of jack plotted in Figure 2.

Because the edge of the jack is rigid, as it swells the diaphragm action increases slightly so the effective area changes very slightly. Thus for very accurate work the calibration should be carried out at different distentions and plotted as a calibration curve. Figure 3 shows that there is a significant variability of the effective area with distension thus the jacks are calibrated at around the middle of the operating range of distension to minimise the error in normal use since it is very difficult to measure the jack distension while in situ.

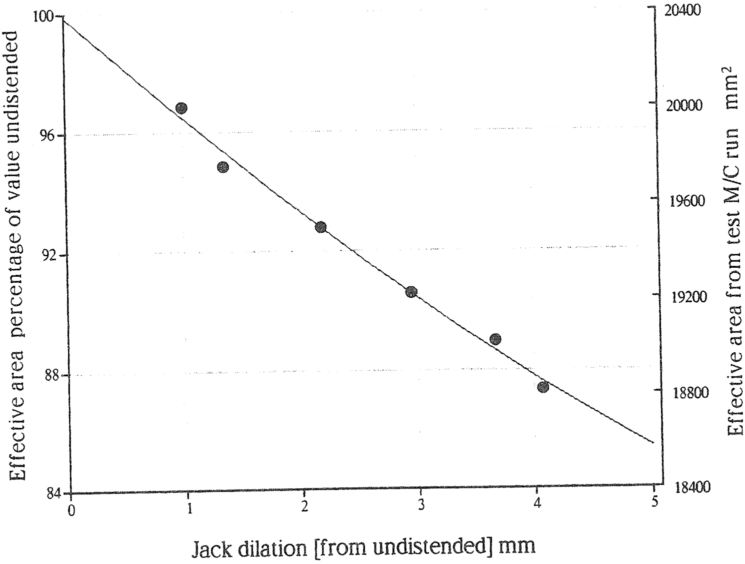

Fig. 3. Effective area versus distension for a typical jack.

CALIBRATION SPECIMENS

Calibration was carried out using storey-height walls around 2 - 2.3m high and 2m long. A total of 4 walls have been used and their dimensions and characteristics are given in Table 2.

Table 2. Characteristics of calibration walls

Wall / bond	Dimensions m	Plan area mm^2	Unit str. N/mm^2	Mortar designation.
Stock 1½ B. stack	0.353 x 2.083 x 1.99	735818	9.3 †	(iv)
Fletton 1 B. flemish	0.215 x 1.854 x 2.39	398533	24.4 †	(iii)
Fletton ½ B. stretcher	0.103 x 1.854 x 2.0	190962	23.2 †	(iii)
Block stretcher	0.136 x 2.034 x 2.29	276670	12.04 ‡	(iii)

† Tests in accordance with BS3921 ‡ Tests in accordance with BS2028

GENERAL DESCRIPTION OF TESTS

To avoid edge effects, tests were generally confined to the central third of the wall. This was not always possible in the blockwork wall.

Before either the slot was cut, or loading was started, Demec points were glued to the bricks spanning the proposed cut, using a Demec gauge with a gauge length of 100 or 150mm. These gauges have a sensitivity of respectively 16 and 10.8 µstrain per division. Normally three or four Demec spans were used on each face, crossing the expected position of the cut near to the centre but mortar joints were avoided. The readings were averaged. As a general control a further set of permanent measuring points were installed to monitor the overall strains on the working face in some cases.

The slots were cut such that the jack bore on one whole brick and two half bricks or, in the case of blocks, on two half blocks. A typical relationship between cut and array is shown in Figure 4.

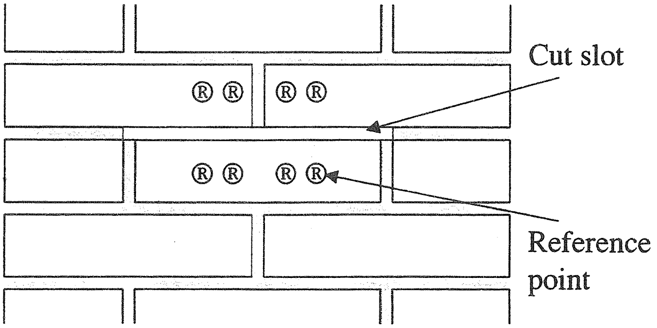

Fig. 4. Positions of demec points in elation to a slot position

Before the flat-jack was installed, a check was made to ensure that the cut slot was both smooth and free from any small pieces of mortar or brick. This was to ensure that the stress on the surfaces of the flat-jack would be uniform and that the membranes of the flat-jack would not be liable to puncturing by the debris.

Installation of the flat-jack itself was carried out very carefully, to avoid any damage to the membranes. Metal shims of various thicknesses were used as packing between the jack and the cut surfaces to obtain a good fit and reduce to a minimum the expansion of the jack.

Cutting techniques

Slots may be cut using angle grinders, stitch drilling and power chiselling or a combination of two or more techniques. Angle grinders probably give the fastest cutting but tend to be very dusty without extraction equipment. Holes cut only by this method inevitably have semicircular ends and the depth is limited to the free radius of the cutting disc. Hand held equipment is usually limited to a maximum of 125mm. Stitch drilling is slower, gives a rougher hole and can be very difficult to control at depth but can penetrate much deeper. Power chiselling can be quite effective in friable mortars and for trimming holes partly cut by other techniques but is difficult in hard or dense mortars because the hammer action only works going inwards and there is a tendency to jam. A combination of stitch-drilling and power chiselling or abrasive sawing and power chiselling can be very effective in a range of materials and can produce quite accurate rectangular holes. Hand filing is usually necessary for a final trim.

Test procedure

The safe gross load capacity of the walls was estimated in accordance with the UK Code of Practice BS5628 ignoring partial factors of safety. This gave a design ultimate strength for each wall. In test the walls were normally restricted to 70% of their estimated failure stress and only used after a 5 minute proof-load application to check stability and that there was no visible or audible signs of distress.

The test procedure for each calibration run was as follows:

1. The wall was placed in the Amsler test machine, and the Length (Demec) readings were taken;
2. A test load was then applied to the wall and the reference Demec readings taken: these were later to be the target readings for the analysis;
3. The slot was then cut in the wall in the appropriate position, and the Demec readings taken;
4. The flat-jack was placed in position and packed with steel shims to locate it securely and to ensure that the pressure was transmitted evenly across the bed;
5. Pressure was then gradually applied to the wall in increments by the flat-jack, until the Demec gauge readings were restored to the reference value.

For stress strain measurements a section of wall is selected and demec gauges attached then slots are cut above and below this section and matched twin jacks connected to a common hydraulic supply are placed in the slots.

RESULTS AND DISCUSSION

Stress measurement calibration

The results of the tests are shown as the points on Figure 5. This summarises the results of 17 determinations in four types of wall using four types of jack. The regression line is based on 16 data points for the larger jack sizes. One experimental determination with the small jack in the concrete block wall was obviously not in the main data group and has been omitted from the regression analysis. Figure 6 repeats figure 5 but includes the 95% confidence bands.

This data has been subject to a simple linear regression with a force through zero and gave the following results:

Correlation coefficient R = 0.998
Ratio of stress in wall to corrected jack stress (Flatjack efficiency factor K_e) = 0.828
Standard error of estimate = 0.0137
Students t for the regression = 60.3
Lower 95% confidence interval of ratio of Flatjack efficiency factor K_e = 0.800
Upper 95% confidence interval of ratio of Flatjack efficiency factor K_e = 0.857

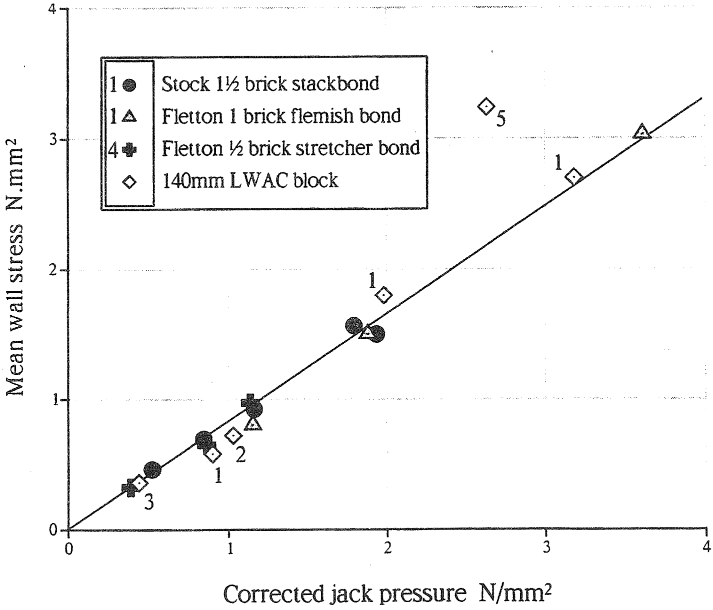

Fig. 5. Plot of corrected jack pressure versus applied wall stress. Numbers refer to jack types given in Table 1.

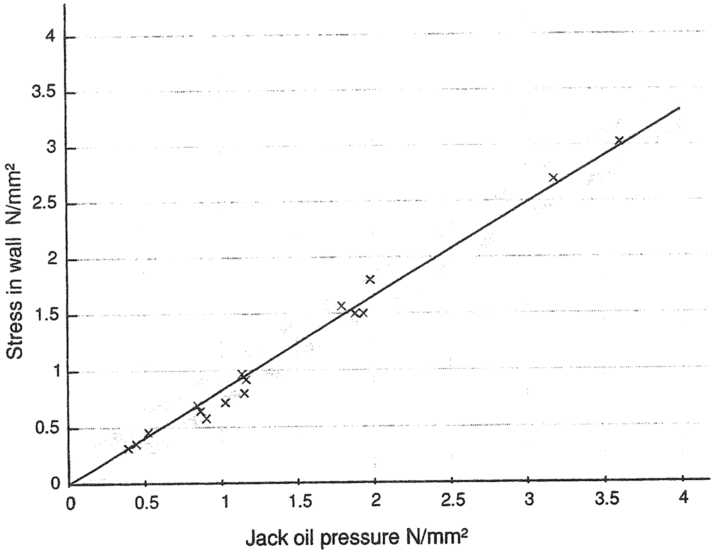

Fig. 6. Plot of corrected jack pressure versus applied wall stress showing 95% confidence bands.

Thus the restoring stress value (S_r) at the testing point is given by the relation:

$$S_r = K_e \cdot K_a \cdot p$$

Where: K_e is the efficiency factor determined by means of a calibration runs and K_a is given by the ratio between the effective area of the flat jack and the area of the cut ($K_a = A_{Je}/A_C$). p is the oil pressure which restores the original strain condition.

For the larger jacks tested in this programme, where the jack size is 50% to 100% of the bedface area of the units a common value for K_e of 0.828 can be assumed. This includes one case, No 3 on Figure 5, where two jacks attached to the same oil supply were used in one slot to load the whole bed face of a block.

Stress-strain measurements

A limited number of stress strain measurements have been made which are depicted in Figure 7. It is less easy to calibrate these measurements absolutely without cutting out the sections of masonry and repeating the measurements in a test machine but the whole wall test of the block wall gives an approximate comparison.

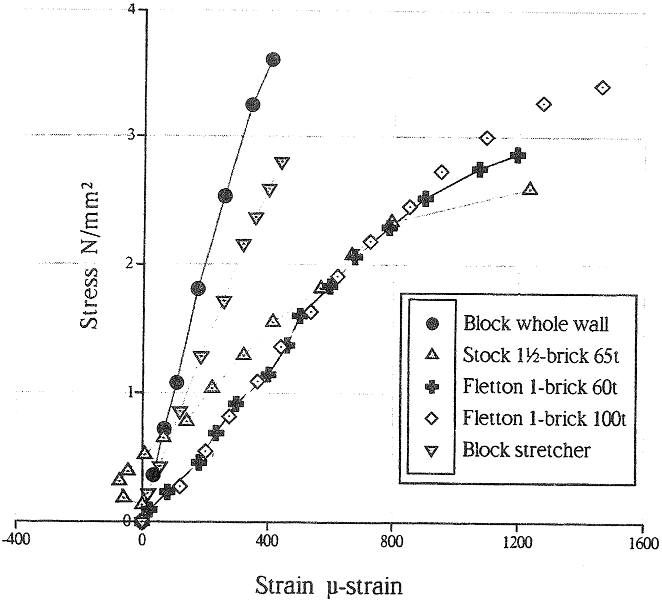

Fig. 7. Stress-strain measurements with two jacks on some of the walls.

Applications

To date the equipment has only been used for a limited number of site projects and these have been of a confidential commercial nature but it is hoped to expand usage for investigation of historically significant buildings and civil engineering structures in the coming year.

CONCLUSIONS

1. This technique is now maturing into a reliable and widely accepted method for obtaining structural data on existing buildings with minimal damage.

2. Whichever technique is used for cutting slots it is preferable to form an approximately rectangular shape for this type of jack to avoid introducing eccentricity and to keep the slot to the minimum size possible. It is not advisable to use power chisels or hammer drills to go right through a wall from one side because substantial damage is likely to the blind face.

3. It is reasonable to use a common efficiency factor for a wide range of wall

formats and bonds and for different jacks and hole sizes provided the area of the jack is a significant proportion of the bed face area of the units and the individual jack effective area is predetermined. This works for jacks going right through stretcher bond walls and going only half or a third through multi-wythe bonded walls with a uniform stress field and for pairs of jacks working in tandem.

4. Very small steel jacks, in relation to the bed area of the units probably do not share the same efficiency factor. They are attractive since they cause less damage and could be used for testing smaller masonry sections such as slender columns. It would be useful to improve the calibration data on them.

5. Theoretically jacks made from lower modulus material should have better accuracy and probably could attain an efficiency factor approaching 1. This concept has been developed, in the form of synthetic rubber jacks, and reported by Hughes and Pritchard 1994.

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ABOUT BUILDING DATING AND THE EVALUATION OF MASONRY'S STRENGTH IN PALAZZO PIANCIANI, SPOLETO, ITALY

Romualdo Montagna[1]

ABSTRACT

It is common knowledge that restoring a building involves not only the physical rebuilding of its parts, but also the identification and conservation of the peculiarities of each building as a first stage. Therefore, the process leading to the identification of the main features becomes important and a chief part of the restoration project.

There are two fundamental aspects in this process: the dating of each part of the building, and the evaluation of the actual strength of building components (masonry, foundations, floors, etc.). Dating the building entails an evaluation of the way it stands, whilst the knowledge of forces leads to an evaluation of the level and the type of intervention required. Obviously, the more information we obtained on the actual stress, the better the restoration project we were able to conceive.

In the case of Palazzo Pianciani, for example, direct shear test on the masonry, both in its present-day state and following fluid-mortar consolidation, let us to opt for no mortar injection into the masonry, thus saving about US $1.55 million compared to a diagnostic cost of US $50,000.

The paper shows the results on an 18th-century building and what this method can offer to the designer in order to optimize restoration work.

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