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Evaluation of Flat Jack Test Method Effectiveness for Masonry Structural Investigations

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***Abstract* – Flat jack testing method is one of the most commonly used techniques for the structural assessment of existing masonry structures. Single and double flat jack are commonly adopted to evaluate the acting normal stress, or the compressive behaviour of masonry material. Test procedures are codified by international standards (e.g. A.S.T.M D4729-87; C1196-04; C1197-04, R.I.L.E.M TC 177–MDT D.4; R.I.L.E.M. TC 177–MDT D.5), which provide the preliminary calibration of an experimental coefficient (k_m), which determination influences significantly the reliability of the test. This paper presents the result of an experimental study on the calibration of k_m coefficient for flat jacks. The problem is investigated by several tests carried out at DISMAT Laboratory in Canicattì (Italy). Different types of flat jacks made by different manufacturers are considered, and two calibration methods are adopted in order to relate the pressure values of the flat jack with those of the hydraulic press and obtaining the coefficient k_m. Results of this investigation highlighted the influence of materials used and production technology for the flat jacks for obtaining reliable results from the tests on masonry structures.**

I. INTRODUCTION

Flat jack testing method is one of the most commonly used techniques for structural investigations for existing masonry structures. Both methods, single and double flat jack are useful: the single flat jack addressed to evaluate the acting normal stress, the double flat jacks to evaluate the mechanical parameters of the behaviour in compression of masonry material, with particular reference to the elasticity modulus.

In particular the single flat jack allow to measure the stress in a small area of the structure by a plane cut made in general in correspondence of a mortar bed joint. The flat jack is then inserted in the cut and then loaded with a pressure gradually increasing applied by a hydraulic pump until the state of strain is equal to the previously existing condition before the cut. The necessary pressure to restore the initial distance between the two cutting edges allows to obtain the measure of the acting normal stress. If more results on compressive behaviour of masonry are required, a second cut is made parallel to the first one and a second jack is inserted. Therefore, the portion of masonry between the two cuts is loaded by simulating an uniaxial compression stress. The pressure is applied with subsequent increments until the point of nonlinearity is highlighted in the load-strain curve to avoid damage in the structure. Sometime, it is possible to go beyond this load level, when it is possible to destroy the masonry portion between the two jacks.

In both cases, technical specifications of the flat jack, are needing to obtain the stress measure from the applied pressure. In particular, the recorded pressure should be multiplied for two coefficients: the calibration coefficient of the flat jack, that should be determined in laboratory, and the ratio between the area of the flat jack and the area of the cut. The measured stress is finally provided by the following expression:

$$\sigma = k_m \cdot k_a \cdot p \qquad (1)$$

where k_m is a coefficient which depends on the features of the jack adopted, k_a is equal to the ratio between the area of the flat jack and the area of the cut and *p* is the pressure applied by the jack. The reliability of the obtained results depends on the quality of the tests, especially in presence of weak masonry or irregular masonry, in the cases of low values of compressive stresses (low buildings), in the cases of multi-faceted masonry or masonry walls subjected to eccentric loads, or in the presence of consolidation, and so on. The test procedure is codified in American Code A.S.T.M.[1]-[3], in European Code R.I.L.E.M.[4][5], and also in Italian ReLUIS Recommendations[6][7]. In the present study attention is paid on the calibration of the coefficient of the flat jack which determination influences significantly the reliability of the test. The problem is investigated by different tests carried out by DISMAT Laboratory in Canicattì (Italy), by using two types of flat jacks made by different manufacturers, and adopting two calibration methods to obtain the k_m coefficient of the flat jack, in order to relate the jack pressure values with those of the hydraulic press. Results of this investigation highlighted the influence of materials used and production technology for the flat jacks into obtain reliable results from the tests on masonry structures.

a)

b)

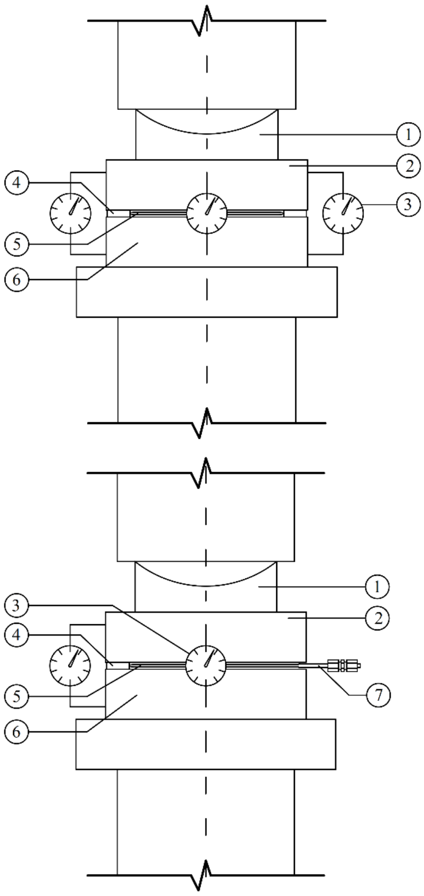
Fig. 1. Types of tested flat jacks. a) Jack B1; Jack C1.

II. EXPERIMENTAL PROGRAMME

The current experimental study provides the calibration of two kinds of flat jacks, commonly adopted for in-situ testing. The target is to assess the coefficient k_m by relating the pressure induced in the jack and the external force recorded by a load cell in a testing machine. The first type of jack, namely B series (Fig.1a), had semi-circular shape, sizes 350x260x4 mm and it was made with steel foils having thickness equal to 0.8 mm. The nominal area of this series of jack is equal to 77506 mm^2. The second type of flat jack (C series) had a similar shape, but sizes were 345x260x6 mm, and it was made with 2 mm thick foils of steel. Nominal area of the jack is in this case equal to 76045 mm^2. For each kind of flat jack, three specimens were considered, each one made by the same producer, for an overall number of six jacks.

A. Test set-up and instruments

Test set-up is that shown in Fig.2. A force-controlled testing machine with spherical swivels is adopted. The flat jack is introduced between the plates of the machine, which relative distance is kept constant. Three Linear Voltage Displacement Transducers (LVDTs) are arranged to monitor the displacements during the test, two on the sides and one in the front of the flat jack, allowing to check the uniformity of displacements. A load cell is also introduced between a swivel and the steel plate to check the load level. Oil is pumped inside the flat jack by a hydraulic pump, connected to two digital pressure transducers. LVDTs, load cell and pressure transducer are connected to a data acquisition unit, which allows storing data that can be managed by a PC, as shown by Fig.3.



a)

b)

Fig. 2. Test set-up. a) Front view; b) Lateral view.

Fig. 3. Test on a flat jack.

B. Testing procedure

Both procedures provided by ASTM and RILEM are followed to find the k_m coefficient. Both technical codes provide to perform three load cycles with constant increases of pressure up to a maximum value of pressure is reached equal to 95% of the maximum service load prescribed by the producer. In particular, in the present study a value of 60 bar was adopted as maximum value for both series of jacks. Each specimen was loaded making difference between low and high pressures. In the first case, the pressure was kept between 2 and 6 bar with increments equal to 1 bar, while in the second range, pressure was maintained between 12 and 60 bar with increments equal to 6 bar. Test is performed by inducing an established value of pressure in the flat jack. Afterwards, load is applied from the testing machine in order to keep the distance between the plates equal to 1.33 times the thickness of the jack. In this way, the jack is working as in inverse manner to his common service conditions. At each step, the value of pressure in the transducer is recorded and related to the corresponding load value measured by the load cell. The ratio between load and pressure values represents the effective area of the flat jack, according to the RILEM procedure. Similarly, the ratio between the pressure value multiplied by the nominal area of the jack and the load given by the load cell represents the k_m coefficient, according to the procedure provided in the ASTM code. In the following, results are presented in terms of RILEM or ASTM representation, and they are not all reported for the sake of brevity.

III. RESULTS

A. Load cycles

Figures 4 and 5 show some results in graphical form for specimens of B series. In particular, graphs of Figure 4 a,b plot the load recorded by the testing machine as a function of the corresponding load measured by the pressure transducer in the jack, for low and high pressures respectively. It should be reminded that the slope of this curve represents the k_m coefficient, according to the ASTM procedure, and an ideal jack -only theoretical case- should show a linear trend with slope equal to 45°. The three load cycles are shown in both cases, highlighting as the behaviour is substantially different on the basis of the pressure range. In fact, the trend of the function represented seems to be almost linear for high pressures, with points almost coincident for the three load cycles. Differently, load values recorded for the three cycles are slightly different for low pressures, and the load applied by the machine tends to be a non-linear function of the pressure recorded in the jack. Similar results are achieved for specimens B2 and B3. In particular Fig.5 shows the load recorded by the testing machine as a function of the pressure read by the transducer, for specimen B2. It is worth to note that the slope in these curves represents the effective area of the jack, according to the RILEM code. Also in this case, load cycles for low values of pressure (Fig.5a) are not coincident, and a non-linear trend is recorded again, with increasing values of load for successive cycles. A marked linear trend is achieved for high pressures (Fig.5b), meaning that the effective area of the jack can be considered constant and only a function of the range of working pressure.

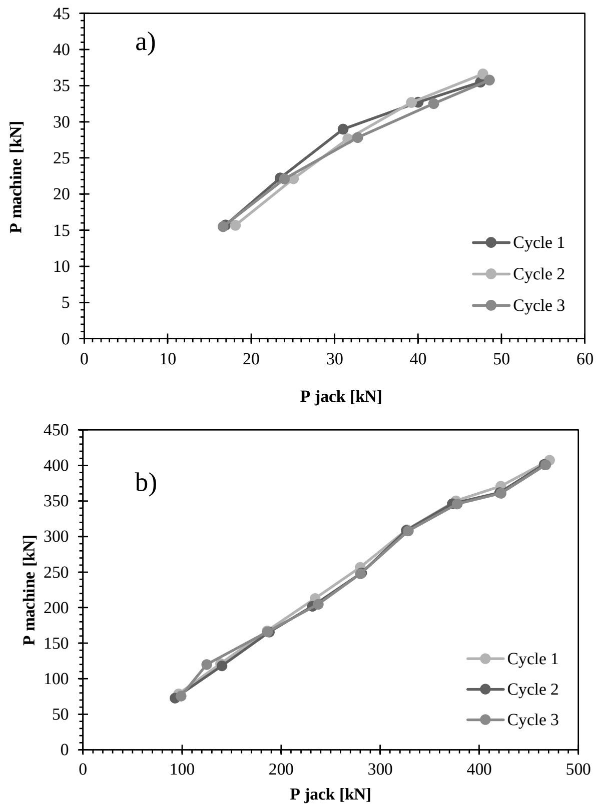


Fig. 4. Results for specimen B1. a) Low pressure; b) High pressure.

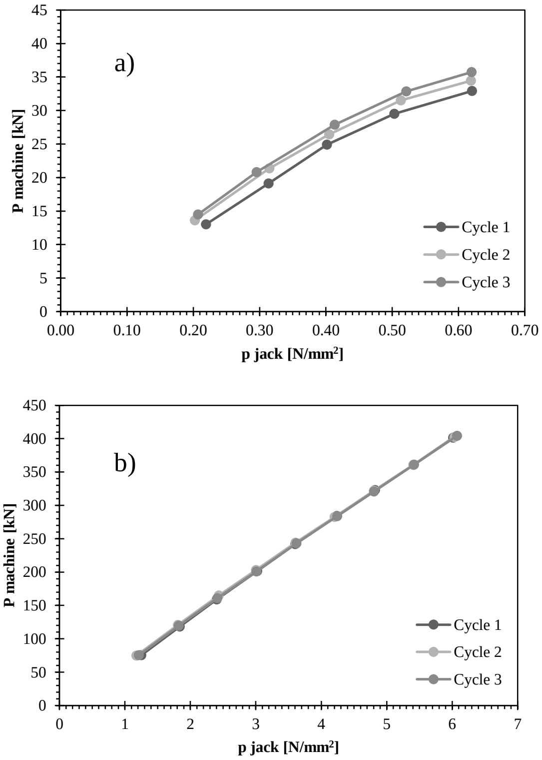


Fig. 5. Results for specimen B2. a) Low pressure; b) High pressure.

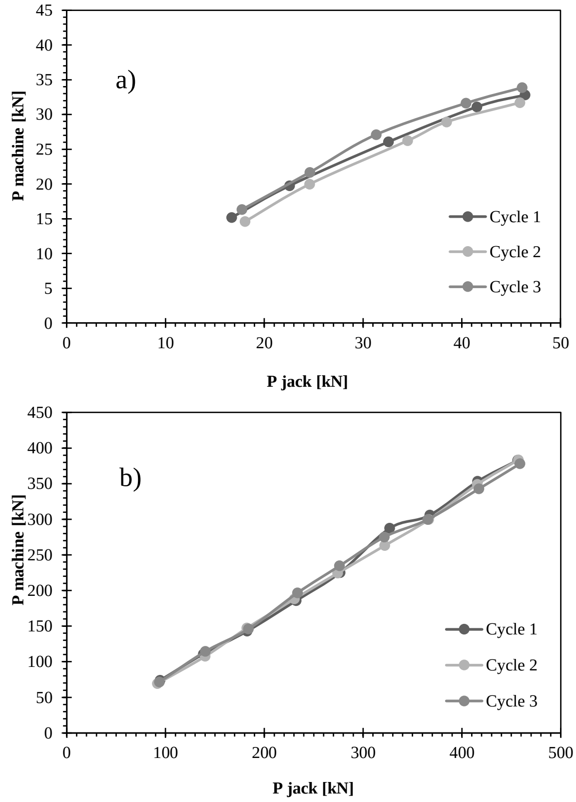


Fig. 6. Results for specimen C1. a) Low pressure; b) High pressure.

Results for flat jack B3 are similar to those obtained for specimens B1 and B2 and they are not shown here for the sake of brevity. Specimens of C-series shows a similar behaviour, but with quite different slopes of recorded curves. As an example, Figure 6 shows data obtained for specimen C1. It is evident as a larger scatter between the three load cycles is achieved for low pressure values and data recorded assumes an irregular trend, particularly for specimen C3, which response is shown in Fig.7. Moreover, it is observed as the slope of curves shown in Figs.6 and 7 is substantially lower than 45°, expecting a low value of k_m. Results for specimen C2 are similar to other obtained for other specimens of C-series and they are not here reported for the sake of conciseness.

B. K_m coefficient and effective area for tested flat jacks

Results shown in the previous section allow calculating the k_m coefficient as the slope of the curve representing the relationship between the load measured by the machine and the pressure induced in the jack multiplied for the nominal area. This calculation is made for each specimen tested and for each load cycle, making difference between low and high pressure, as described above. In particular, a value is determined as the angular coefficient of the regression line able to fit experimental data for a single load cycle. Finally, the k_m coefficient is evaluated as the average value between the three cycles.

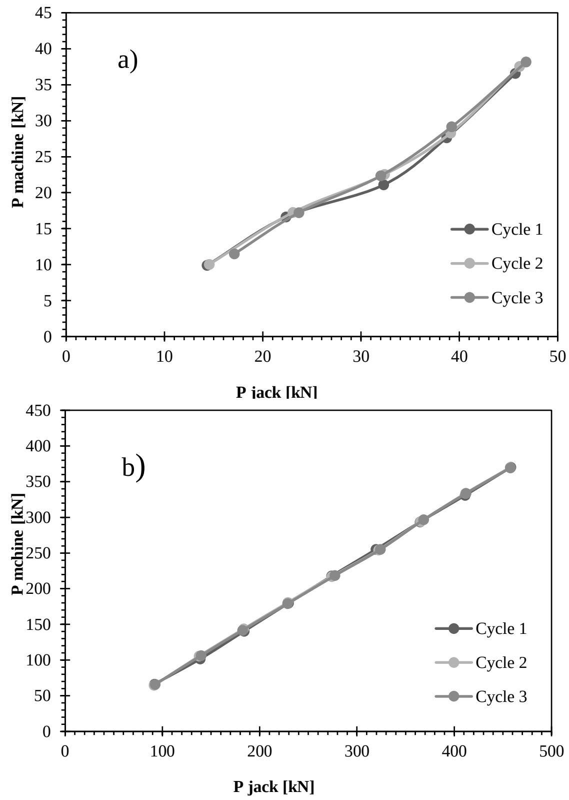


Fig. 7. Results for specimen C3. a) Low pressure; b) High pressure.

Values of k_m coefficient determined are summarized in Table 1. It is worth to note as lower values are associated to specimens of C-series. Moreover, larger dispersion of data is observed for C-series specimens. In all cases, the coefficient of the jack is greater for high values of pressure, highlighting as the reliability and the accuracy of the measure performed by flat jack technique depend from the stress state in the observed masonry wall.

These considerations are more evident by observing histograms reported in Fig. 8 and 9. They represent the k_m coefficient for all specimens and for each cycle.

Table 1. Values of k_m.

Flat jack series	Specimen no.	Low pressure	High pressure
B	1	0.8146	0.8889
	2	0.7766	0.8616
	3	0.8124	0.8679
C	1	0.7665	0.8301
	2	0.7256	0.8199
	3	0.7503	0.7989

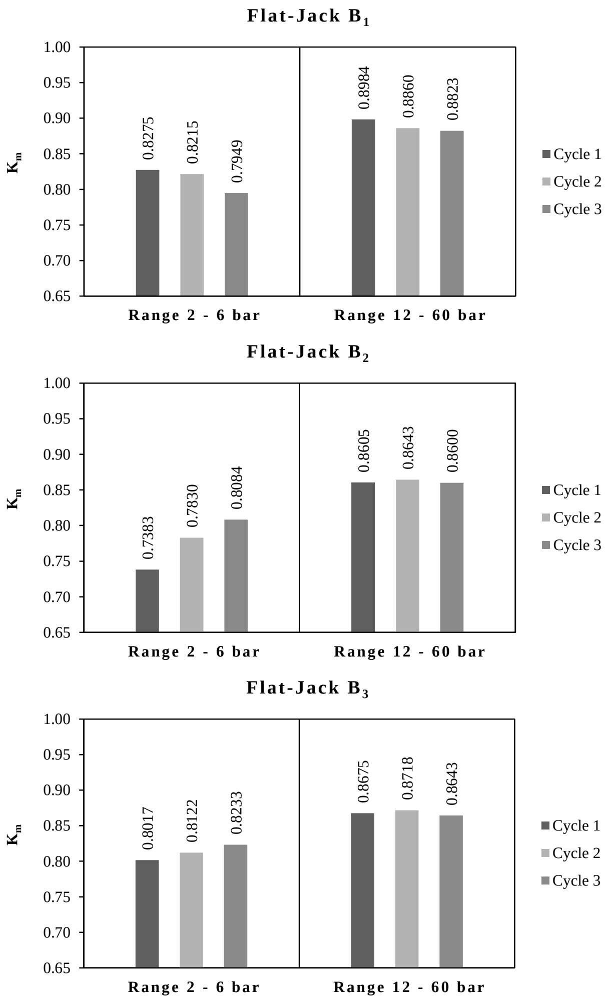


Fig. 8. k_m coefficient for the B-series of flat jacks.

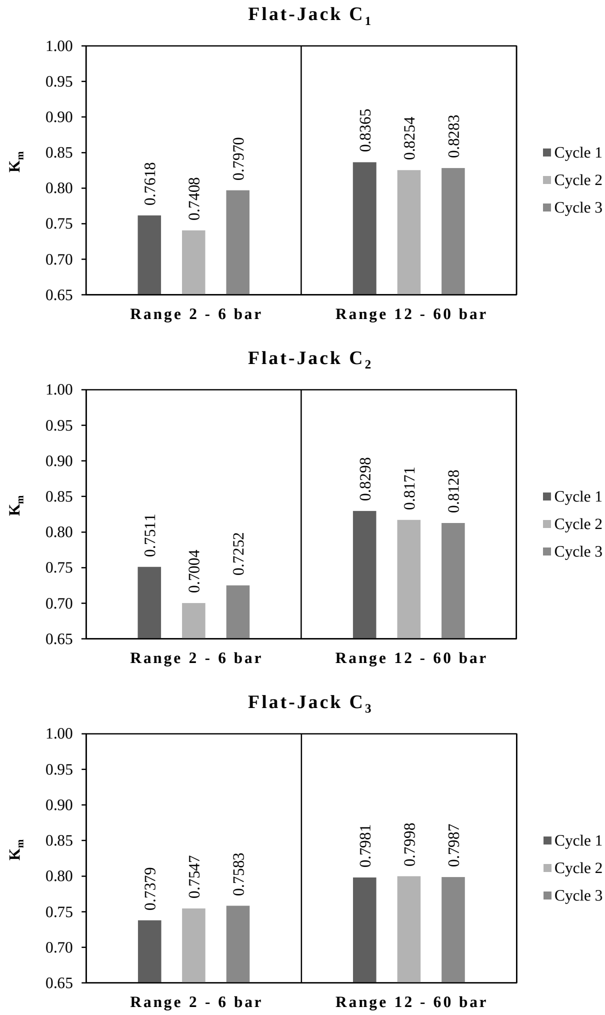


Fig. 9. k_m coefficient for the C-series of flat jacks.

It is graphically evident as, series C of specimens is characterized by lower values of k_m and larger scattering of results, especially for low pressure values. This fact can be explained considering that for this low range of pressure, oil pumped is not able to fulfill the inner core of the flat jack and large differences are observed.

Finally, Fig. 10 shows the comparison between the values of k_m calculated for each specimen as the average value between the three cycles, and already reported in Table 1. Dispersion of result is observed for each case. It is stressed as on the basis of results shown, the adoption of an average experimentally calibrated value, calculated as discussed above, could lead to errors lower than 4% for low pressure and 3% for an higher stress values, highlighting the fact that reliability of the test depends by the value of in-situ stress and by constructive features of the jack. It should be also reminded that errors can be achieved on the evaluation of the effective area. This fact is confirmed by results achieved in terms of effective area A_{eff}, the latter obtained as suggested in the RILEM code. In this way, the effective area is deduced as the slope of the regression line drawn to fit the relationship between the load deduced by the machine and the pressure recorded in the jack. Data obtained for each specimen are resumed in Table 2. It is confirmed that the two types of flat jack performed differently as higher values are obtained for series B and for higher pressure.

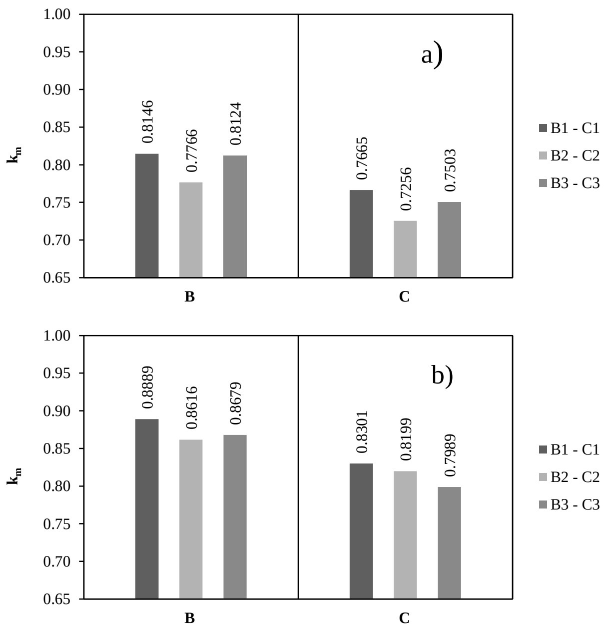


Fig. 10. Comparisons of k_m coefficient for the two series. a) low pressure; b) high pressure.

Table 2. Values of A_{eff} (values in [mm^2]).

Flat jack series	Specimen no.	Low pressure	High pressure
B	1	63147	68902
	2	60199	66799
	3	62974	67237
C	1	58313	63122
	2	55195	62349
	3	57072	60725

IV. CONCLUSIONS

This paper presented the results of an experimental investigation on the calibration of k_m coefficient for the flat jack testing technique. An experimental investigation was performed, by calibrating two kinds of flat jack, produced by different manufacturers. On the basis of results achieved and for the range of investigated variables, it was shown as the reliability of the flat jack method is strictly dependent by the value of pressure induced, consequently by the stress measured in-situ for single flat jack technique, or by the mechanical properties of investigated masonry for double flat jacks method. Generally, more accurate results are expected for higher values of stress. The absence of a proper calibration could lead to large errors, considering the sensitivity of k_m and A_{eff} from key parameters. Proposed calibration allows reducing the scattering of the k_m coefficient to 4% for low pressure and 3% for high pressure, confirming the need for a preliminary calibration between performing a test.

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