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Stress state laboratory verification in masonry structures according to the *flat jack* method

Laboratoryjna weryfikacji stanu naprężenia w konstrukcji murowej według metody *flat jack*

Abstract

In the article, the value of compressive stress defined according to the *flat jack* method with a theoretical value of the stress was compared. The test was performed in a laboratory using part of the 38 cm thick masonry wall according to the procedure described in the ASTM C1196 – 14a Standard. Significant correspondence between the obtained results confirms that this diagnostic method is useful in Polish conditions as well as it allows one to estimate approximately how accurate it is.

Keywords: semi-destructive tests, flat jack, masonry structure, stress state

Streszczenie

W artykule dokonano porównania wartości naprężenia ściskającego określonego według metody *flat jack* z wartością teoretyczną tego naprężenia. Test wykonano w laboratorium na fragmencie ściany murowej o grubości 38 cm według procedury opisanej w normie ASTM C1196 – 14a. Uzyskana duża zgodność wyników potwierdza przydatność metody diagnostycznej w warunkach polskich, jak również pozwala na orientacyjne oszacowanie jej dokładności.

Keywords: semi-destructive tests, flat jack, masonry structure, stress state

1. Standard adopted as basis for tests according to the flat jack method (FJ)

As part of a typical diagnostic procedure of historic masonry structures, tests according to the flat jack method cannot be missing. This method is the basis for evaluating the existing masonry structures in the United States as well as in the countries of Western and Southern Europe [1]. Unfortunately, in Poland, this method is known mainly from foreign literature and several domestic items (for example [2, 3]) and so far, it has been applied only by the author of the article to diagnose the existing buildings (for example, a historic building of the Municipal Theatre in Gliwice, Poland).

The simplest test using pressure flat jack, which is determining a level of compressive stress, is carried out in three steps. First of all, the length of the measurement base on the surface tested is read, and then, the joint located between these bases is removed; in order to do this, the most indicated solution is to use a circular saw. Thereby, the slot formed is smooth enough. As step two, mortar, which is removed, is replaced by a thin (3–8 mm) flat jack made of two smooth leaktight metal sheets joined together with tubes to fill the flat jack with a liquid medium, to vent it and to bleed it (pressure reduction). To make the flat jack thickness better match the width of the joint, a compensating insert is used and the pressure flat jack is preliminarily pumped so that the pressure value reaches half of the expected target value. The last step is to increase the pressure inside the flat jack using an external hydraulic pump and, at the same time, the length of the measurement bases is monitored. The test ends when each of the bases reaches the length at least equal to the initial value.

The procedure described above is founded by the American ASTM C1196 Standard [4] and by the European RILEM MDT.D.4. Instruction [5]. However, verification of the stress state does not exhaust all the flat jacks possibilities; they are also used to determine the stress – strain relationship (Young's modulus) according to ASTM C1197 [6] or RILEM MDT.D.5. [7] or the masonry mortar joint shear strength index according to ASTM C1531 [8].

2. Laboratory verification of the forced stress state

2.1. The purpose of the tests

In practice, to make the diagnosis, several shapes of pressure flat jacks are used, depending on the country where the tests are carried out, on the dimensions of masonry components and the values tested. In European studies, rectangular and oval-rectangular flat jacks are most commonly used. The purpose of this article is to assess how reliable this method is by comparing the value of the forced compressive stress to the value of this stress when using the most popular flat jack, i.e. the oval-rectangular. The methodology described in the introduction, i.e. methodology being in full compliance with the current ASTM C1196 Standard [4], was used in the testing. The main advantage is conducting tests using the 1:1 scale member, which, in contrast to the only existing domestic tests [9], will allow the author to obtain results similar to those that can in fact be expected.

2.2. Test bench description and equipment used

The subject of the tests was a wall sized 168 × 38 × 150 cm made of solid bricks (250 × 120 × 60 mm) bonded with lime-cement mortar. In order to maintain a reproduction of the actual conditions as well as possible, the masonry work was carried out by qualified masons using spacing strips to obtain a constant thickness of joint equal to 10–12 mm. To distribute the load more evenly on the whole width of the wall, the area tested was located below the half of its height. In addition, on the side tested as well as on the opposite side, 5 measurement bases were positioned to assess whether or not the wall was unevenly deformed. To record displacements in the area tested, 28 measurement bases in 7 columns (A to G) with 5 cm spacing were mounted on it (5, 10, 15 and 30 cm long). The bed joint designed for tests was placed right through the middle of all measurement bases. This condition is presented in Fig. 1 in detail.

A kit that was complete and suitable for a high-pressure flat jack, consisting of five components shown in Fig. 2, was used for testing. The pressure flat jack was made of two metal sheets 0.8 mm thick each. To make sure the readouts are highly stable, all screw connections were sealed with Teflon tape wound up to the conical threads.

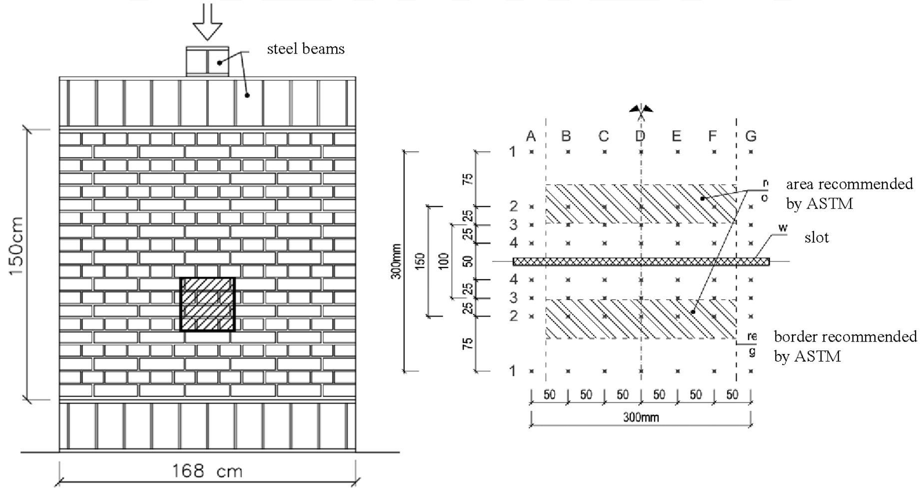

Fig. 1. Brickwall tested with marked measurement area (on the left) and picture of measurement bases made in this area (on the right)

The slot was made using a specialised peripheral-driven saw (Fig. 3) in dry cutting mode, which allowed to eliminate the wall moisture disturbances. The tests were conducted in the following sequence:

1. Measurement No. 1a of control bases located peripherally.
2. Wall load with known value of force – 980 kN.
3. Measurement No. 2a of control bases located peripherally in order to evaluate disturbances (e.g. possible eccentricities).

4. Measurement No. 1b of bases in the area of direct impact of the flat jack.
5. Tempering cutting – slot creation – Fig. 3.
6. Measurement No. 2b of bases in the area of direct impact of the flat jack.
7. Flat jack installation and preliminary pumping (in order to improve adhesion).
8. Measurement are taken No. 3b of bases in the area of direct impact of the flat jack by a predefined value of oil pressure until all the bases return to the length as in the 1b measurement – achieving the value of compensating pressure.

Fig. 2. Flat jack kit used to evaluate stress level – from the left: hydraulic hand pump, manometer, flexible hose, stopcock, oval-rectangular flat jack

Fig. 3. High precision slot cutting using the RING type circular saw and designer stand (on the left) and view of the wall during the flat jack test (on the right)

2.3. Determining the oil compensation pressure – p_{teor}

Readouts in vertical sections A and G proved to be impossible due to the collision of measuring devices with tubes transporting oil to/from the flat jack (in addition, they were located beyond the area recommended by [4] that has been shaded with lines in Fig. 1).

The other results recorded during the test were divided into 4 groups according to the length of the measurement base and are presented in sequence in graphs 1 to 4. The relative level of base length return to the input value shown in graphs shows for which value of oil pressure (the so-called theoretical pressure, p_{teor}) the distance between the measuring points returns the value before sawing (ordinate 100% – compensation pressure). Due to the fact that the bases' return speed to their input length was differentiated, the interval of the compensation pressure value obtained was marked with vertical arrows. The detailed values of compensation pressure are shown in Table 1. For each of the bases and between them, the results were highly convergent – the standard deviation and the variation coefficient for (5; 10; 15; 30) cm bases amounted to, respectively: (0.10; 0.07; 0.08; 0.05) MPa and (4.5; 3.4; 3.7; 2.4)%.

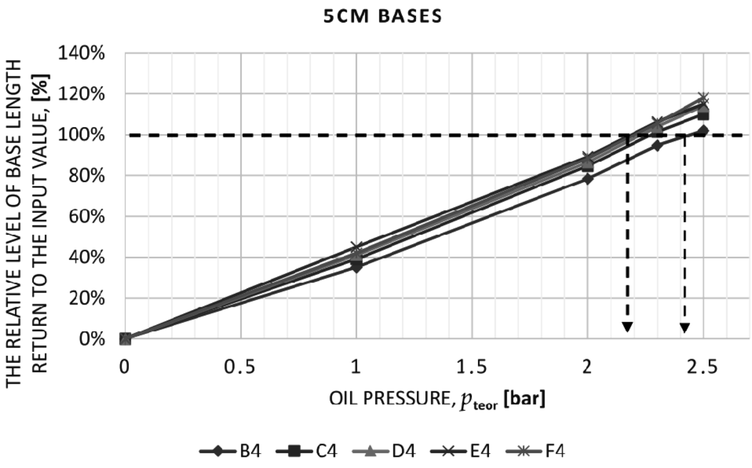

Fig. 4. 5 cm bases returning to the initial length in the theoretical pressure function

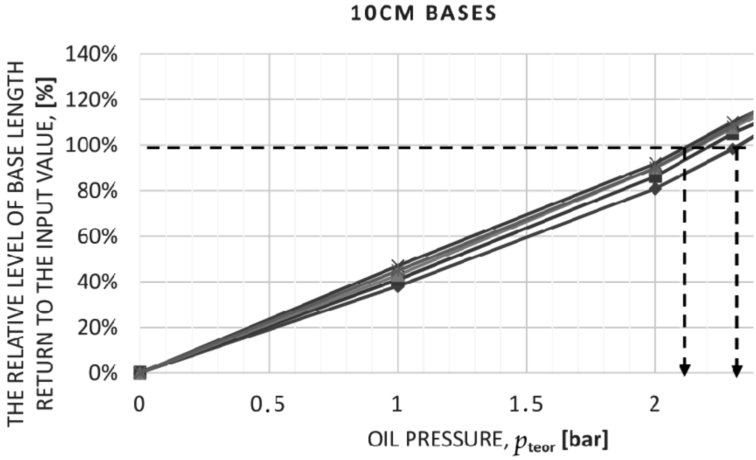

Fig. 5. 2. 10 cm bases returning to the initial length in the theoretical pressure function

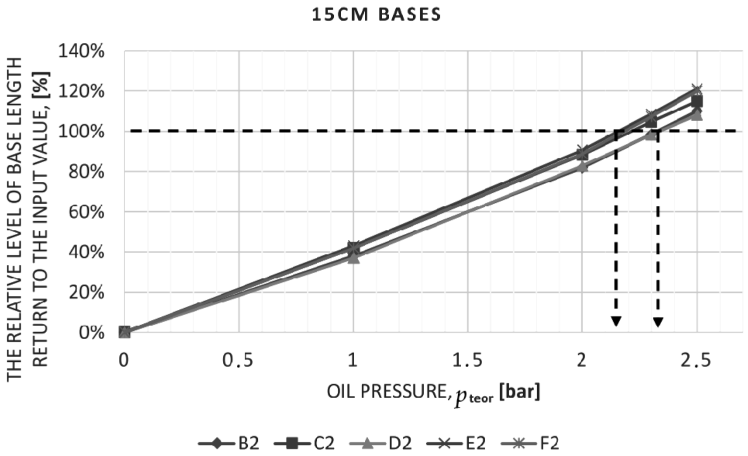

Fig. 6. 15 cm bases returning to the initial length in the theoretical pressure function

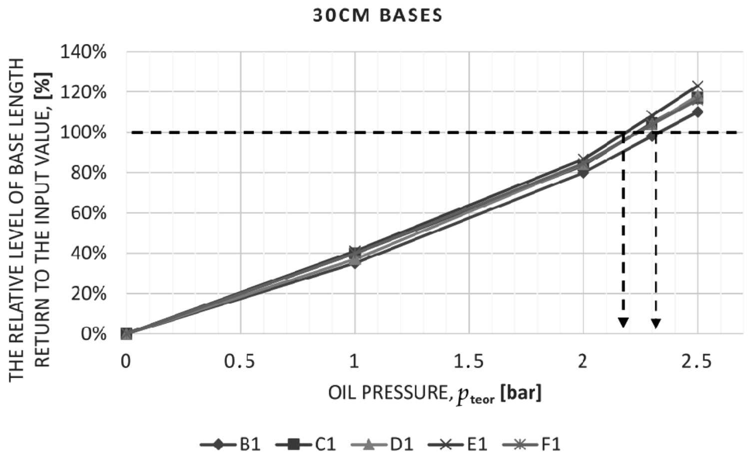

Fig. 7. 30 cm bases returning to the initial length in the theoretical pressure function

Table 1. The detailed values of the compensating pressure

Base	5 cm					10 cm				
Symbol	B4	C4	D4	E4	F4	B3	C3	D3	E3	F3
Comp. Pressure [MPa]	**2.44**	2.27	2.23	2.19	2.20	**2.32**	2.22	2.17	2.13	2.16
Base	15 cm					30 cm				
Symbol	B2	C2	D2	E2	F2	B1	C1	D1	E1	F1
Comp. Pressure [MPa]	**2.33**	2.21	2.33	2.16	2.18	**2.33**	2.23	2.24	2.18	2.24

2.4. Determining the correction coefficients – K_m, K_a

Unfortunately, the value of compensation pressure of oil cannot be directly identified with the value of the compression stress in the tested wall. This is due to the flat jack's own rigidity as well as due to the fact that it does not totally fill in the slot that was created after sawing (the surface of the flat jack is smaller than the cut-out). This is also why two correction coefficients should be entered, respectively: K_m, taking into account the reduction in flat jack's clamping to the wall and K_a, taking into account the flat jack's surface and slot's surface. Both coefficients take values from the (0;1] interval.

The K_m coefficient should be determined before the first flat jack test is made. In order to do this, a laboratory test should be performed by placing the flat jack between the plates of a testing machine, and then by a trial flat jack load with oil pressure until the maximum value is reached. What is obtained as a result is a relationship between the oil pressure in the flat jack and the resistance posed by the machine's plates when preventing flat jack from being deformed. The procedure should be repeated 3 times and, as a result, an average value should be taken. A detailed description of the procedure is described in [4].

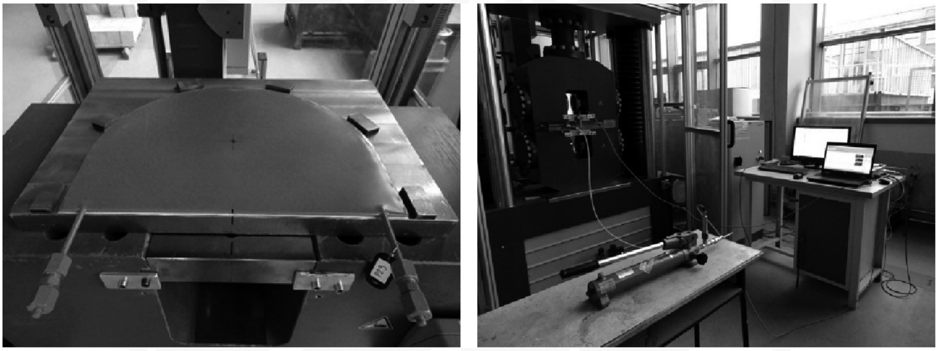

Fig. 8. Work station for determining the K_m coefficient

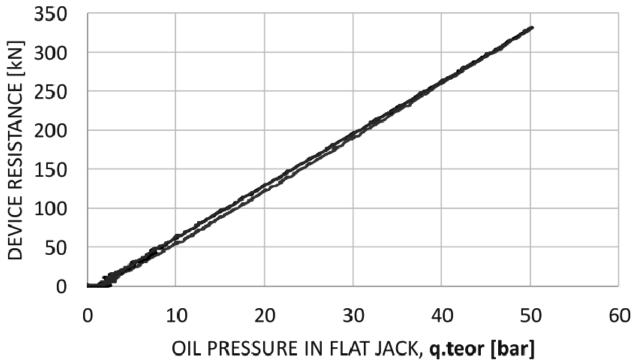

Fig. 9. The relationship between the device resistance and the oil pressure in the flat jack

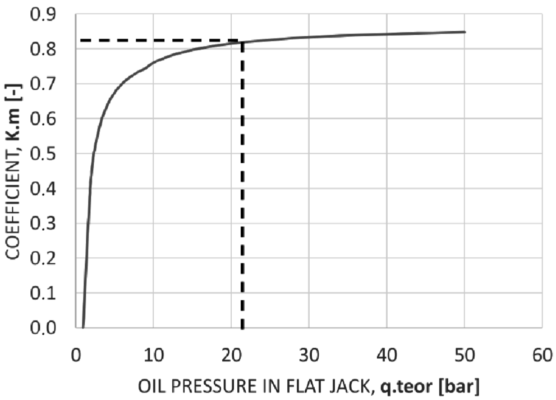

Fig. 10. The function of K_m coefficient

By analyzing the relationship between the oil pressure and the machine's resistance (graph 5), 3 specific intervals of oil pressure can be identified:

< 2 bars – flat jack's rigidity makes it impossible to transfer the load

[2;10] bars – measurement possible but poses a problem

> 10 bars – the most accurate measurement

Assuming that the resulting value of the test is the average value of the compensation pressure for the 15cm long base, the sought K_m (2.24 bar) coefficient = 0.82 (graph 6).

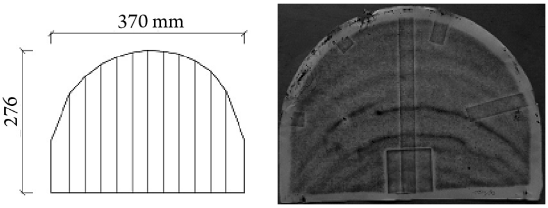

Fig. 11. The shape of the measured slot (on the left) and the flat jack active area (on the right)

To determine the value of K_a coefficient, the slot surface before testing was measured (864 cm²) (Fig. 4) and the flat jack surface before testing was measured to (779 cm²). The coefficient, which is the quotient of these values, was equal to 0.90.

In order to verify whether the flat jack adheres or not to the inner surface of the slot (whether or not the load is evenly distributed), carbon paper was placed. On the carbon paper, the flat jack's active area during loading was recorded (Fig. 4).

2.5. Comparison of the results obtained – evaluation of the method's reliability

When analysing the data contained in Table 2, almost no difference was observed in the average compensation pressure depending on the length of the measurement base. This means that, if a sufficient number of bases planned may not be applied according to standards adopted, other bases can be used.

Table 2. Verification of test results obtained

Base length	K_m coef.	K_a coef.	Avg. compensation pressure	Stress calculated	Average stress in the wall	Relative difference
[cm]	[–]	[–]	[MPa]	[MPa]	[MPa]	[%]
5	0.82	0.90	2.27	1.67	1.54	8.4
10			2.20	1.62		5.2
15			**2.24**	**1.65**		**7.1**
30			2.24	1.65		7.1

Ultimately, the pressure value evaluated according to the flat jack method was 1.65 MPa, while the average stress in the wall was 1.54 MPa. The difference is small, i.e. 7%, since deformation recorded on opposite sides of the wall is not homogeneous. The ratio of these deformations was 1.18, which would confirm that stresses on the tested side of the wall were higher.

3. Final conclusions

In terms of the methodology used in the article, the flat jack method is simple and effective way of conducting tests, which can be successfully used in diagnosing real objects in domestic conditions. However, you should bear in mind that, in order to make sure that the results are sufficiently reliable, professional equipment and extensive experience is necessary. The difference between the stress in theory and the stress measured was 7%. According to [2, 5, 10], this value does not normally exceed 15–20%, and we managed to demonstrate it. Previous domestic testing [9] produced small differences of about 1% as a result of using a very large surface flat jack compared to the size of the tested components, which is impossible in the case of on-site testing.

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