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

RILEM Recommendation MDT. D. 4: In-situ stress 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.

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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 determining the local compressive stress levels in built masonry by monitoring the local state of strain. The method is not applicable to masonry in tension. 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 (slot) is determined by the jack type used and some guidance on the choice of jack type and size is given in section 5.

3. PRINCIPLES OF THE TEST

The testing technique is based on the release of the state of stress in a small area of the masonry by a plane cut perpendicular to the surface. The stress release allows the sides of the cut to close and the extent (level of strain) can be assessed by measurements between two points symmetrically positioned on either side of the cut. The flat jack is then inserted into the cut and the pressure is gradually increased until the previously measured closure is nullified and the state of strain is returned to the condition prevailing before the cut. In this condition the pressure in the jack is equal to the previously existing state of stress in the masonry provided that correction factors are applied which take into account: (1) the characteristics of the jack, (2) the efficiency of the particular test geometry and (3) the ratio between the area of the jack and that of the cut slot. It must be emphasized that the stress given will be the average stress over the area of the cut slot. If the stress field is completely uniform throughout the wall, *i.e.* the material is completely homogeneous and there is no eccentricity in the load then this stress will be representative of the overall compressive stress at that section of the wall. Most commonly the stress will be vertical and the slot horizontal but horizontal compressive stress can be measured. If any significant inhomogeneity or eccentricity is present then the stress may only represent the average stress level over the particular cut slot area.

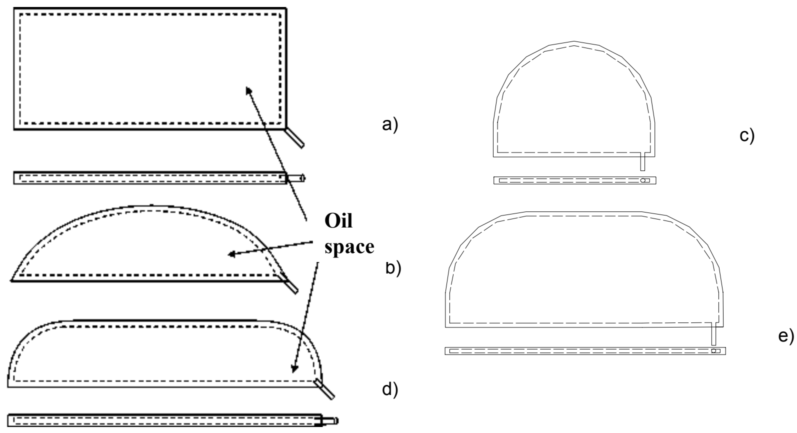

Fig. 1 - Typical flat jack shapes.

4. CONDITIONS OF TESTING

Ambient conditions should be adopted but it is inadvisable to carry out such work in intense 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 obstruct the cutting process and are thus impractical)
4 Flat diaphragm jacks with an overall thickness which allows insertion into a cut slot or a cleaned-out mortar joint.
5 Steel shims with the same plan area and shape to pack around the jack to ensure an accurate fit to the slot and to protect the faces of the jack from damage due to rough surfaces or holes in the masonry.
6 A hydraulic pump and high pressure flexible connecting tubes with quick change connectors.
7 An accurate pressure meter accurate to within 1 percent of full scale.
8 Measuring devices to measure the area of the cut slot.

The flat jack is normally 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. c) and d) are adopted when an electric eccentric circular saw is used.

For the most accurate determinations where the slot is made in the mortar joints, the area of the jack should be the same or greater than one of the units (bricks or blocks) in the masonry but smaller sizes can be used provided calibration data is available for the test arrangement.

When the elastic modulus test has to be made after a stress test the flat jack shape shall be as described in test MDT2.

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 strain gauge should have as high a sensitivity and precision as possible. A sensitivity of approximately 0.0025mm is normally sufficient. The measurement reference points are metal discs with a conical seat, which are glued to the masonry symmetrically about the cut. The oil pressure is measured by means of a pressure gauge or a pressure transducer cell.

6. PRECALIBRATION PROCEDURE FOR INDIVIDUAL JACKS

A flatjack has an inherent stiffness which resists expansion when the jack is pressurized due to the resistance to flexing of the metal, particularly at the edges and to diaphragm action (tension) in the steel sheet as it is expanded. Therefore, the fluid pressure in the flatjack is greater than the stress the flatjack applies to masonry. A flatjack must be calibrated to provide a conversion factor to relate internal fluid pressure to stress applied. The simplest way of expressing this calibration factor is as an effective area A_{je} which is the apparent area of the ram of a conventional cylindrical hydraulic jack of equivalent power to the flatjack.

Calibrate flatjacks in an accurately calibrated compression machine of at least 10 tonnes capacity.

Place a 50 mm thick steel bearing plate on the lower platen of the compression machine. The bearing plate shall be of sufficient size to completely cover the flatjack being calibrated. Place the flatjack on the lower bearing plate such that the edge of the flatjack with the inlet/outlet ports is coincident with the edge of the bearing plate. For flatjacks without an edge frame, place steel spacers around the other edges of the flatjack. The thickness of the spacers shall be equal to approximately 1.33 times the combined thickness of the two steel sheets used in fabrication. (For flatjacks with an edge frame this will provide a spacer.) Place the upper 2 in. (50 mm) thick bearing plate on top of the shims and flatjack, and align it to be directly above the lower bearing plate. Position the bearing plate / flatjack / shim assembly on the lower platen such that the centroid of the area of the flatjack is within 6 mm of the axis of thrust of the test machine.

Raise the moveable platen such that the non- moveable platen is in contact with the top bearing plate. Apply a pre-load sufficient to provide full contact between the bearing plates and the spacers, equivalent to 0.05N/mm² over the gross area of the flatjack. The distance between platens must be held constant during the calibration procedure. Fix the displacement of the test machine at this point if using a displacement controllable machine. If not, attach displacement gauges (mechanical or electrical) such that the initial distance between platens can be held constant when using a force-control test machine.

Pressurize and depressurize the flatjack three cycles with the maximum pressure in the flatjack not to exceed 7 N/mm² nor the stress applied to the flatjack by the compression machine to exceed 7N/mm² based on the gross area of the flatjack.

Increase the pressure in the flatjack in 0.5 N/mm² (5 bar) increments up to 7 N/mm² (70 bar) while holding the distance between platens constant. At each increment, record flatjack hydraulic pressure and force measured by the test machine.

Plot the test machine load on the vertical axis against the jack pressure on the horizontal axis. The slope of the regression line: - load (N) / Pressure (N/mm²) gives the effective area of the jack (mm²).

$$A_{je} = W / p$$

where A_{je} is the effective area, W is the indicated load and p is the pressure.

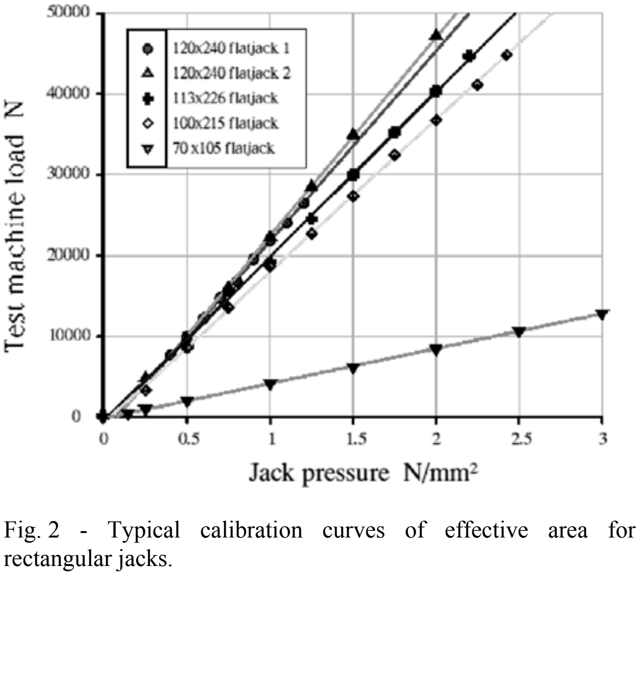

Fig. 2 - Typical calibration curves of effective area for rectangular jacks.

Table 1 - Effective area of some examples of rectangular flat jacks

Type	Depth mm	Length mm	Thickness mm	Gross plan area A_{jg}- mm²	Effective area A_{je} - mm²	Ratio of A_{je}/A_{jg}
1	125	251	5	31375	23584	0.75
2	112	225	5	25200	18380	0.73
Two of type 2	112	450	5	50400	36760	0.73
4	113	226	8	25538	20047	0.78
5	70	105	5	7350	4286	0.58

Recalibrate flatjacks after five uses or when distortion appears excessive.

7. PROCEDURE

The test sequence is as follows:

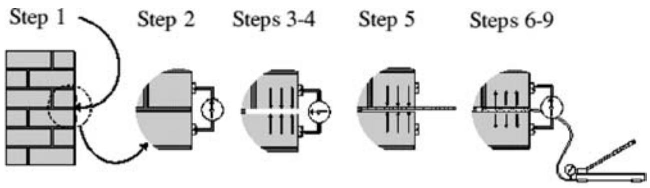

Fig. 3 - Schematic diagram of the important steps in the procedure.

1 Choose a representative piece of masonry then glue the metal reference points either side of the selected cut line and

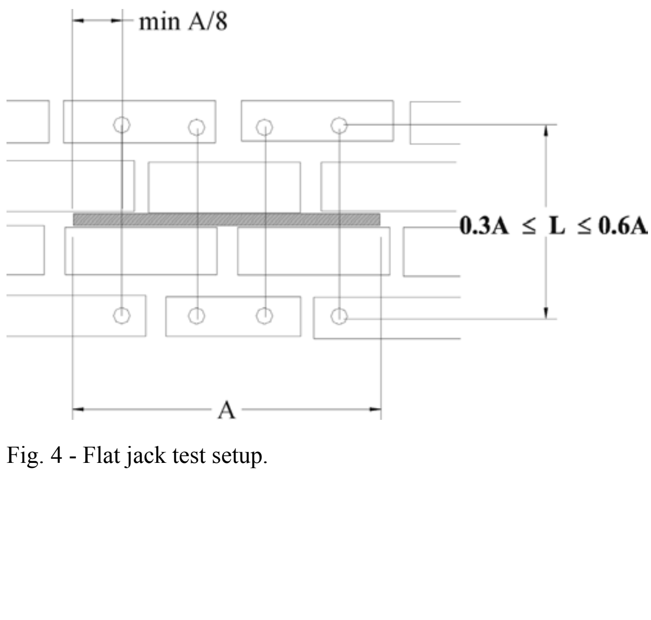

Fig. 4 - Flat jack test setup.

equidistant from it. Four pairs of points are recommended. The recommended minimum gauge length L shall be 0.3 times the length A, where A is the length of the jack as shown in Fig. 4. The recommended maximum gauge length L shall be the length A of the flat jack. The first and last gages shall be located not less than 1/8 of dimension A inward toward the centre of the slot from each end.

Where possible the cut for insertion of the jack should be made into a layer of mortar**.** In the case of irregular stone masonry the cut may have to be made partly or wholly within the stone course as shown in Fig. 5.

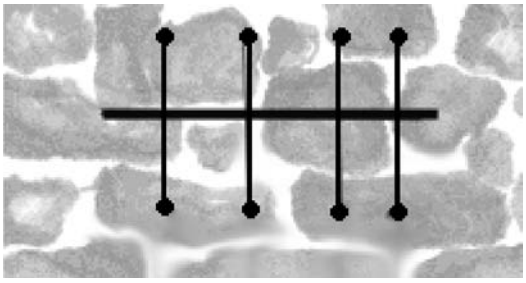

Fig. 5 - Single flat jack cut through the stones in case of irregular mortar joint.

1 When the glue has set, a set of initial reference measurements are taken with the removable strain gauge.
2 The cut is then made taking care to disturb the surrounding masonry as little as possible.
3 After cutting and cleaning, a second set of measurements are taken with the removable strain gauge in order to assess the closure of the cut.
4 The area of a perfect rectangular cut may be assessed by measuring the overall length and depth and using their product. For non-rectangular slots the area is determined by measuring the surface width and taking depth measurements every 10-20mm and summing the area of the strips.
5 The jack is then inserted and packed tightly into the cut slot 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, irregularity of stones 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.
6 Apply an initial pressure of half the estimated maximum pressure to seat the jack and shims then depressurise.
7 The pressure is then increased in increments of about *1/8th* of the expected maximum, but normally not less than 0.5 bar and the strain is monitored after a short dwell at each increment.
8 The test is stopped when the strain is returned to the state measured before the cut was made with no single deviation exceeding 10% of the other gauges. However, the reliability of glued reference points is not 100% and it is acceptable to reject one gauge measurement out of the set of four if it is clearly no longer functional and giving irrational readings. At this point the pressure value (p) required to restore the original masonry conditions, is registered. The time taken for the pressurisation should be approximately the same as the time required for making the cut and preparing the test after strain measurements are stable. This means that the creep deformation will be symmetrical and balance itself out. Fig. 3 shows the phases of the test.
9 Ideally a repetition of steps 8 and 9 should be carried out to verify the jack pressure but this may be affected by the creep factor.
10 Depressurise and then remove the jack and repoint with a matching mortar if restoration is required. It may be easier to remove the shims first to ease the jack especially where the stress measured was high (> 2N/mm^2).

8. TEST RESULTS (CALCULATION)

The restoring stress value (Sr) at the testing point is given by the relation:

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

where: K_e is a dimensionless geometrical efficiency constant which takes into account the position of the slot in relation to the mortar joints, the relative size of the jack and the units and the geometrical characteristics of the jack. (This constant is determined by means of a calibration test on masonry subjected to a known stress field within a compression testing machine); A_{slot} is the area of the slot; A_{je} is the effective area of the flat jack and p is the pressure which restores the original strain condition.
Where calibration data is not available to determine K_e then it may be taken to be 1. In this case the stress value will be overestimated but this will normally be on the safe side.

For typical European brick units with plan dimensions of around 200–300 mm by 75–125 mm, where the jack is the same dimension as the unit and is placed in a bed joint, the value of K_e is normally around 0.83. Values for other situations are available from the bibliographical references.

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 masonry 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 and the relaxation strain for each individual determination at this position.
6 The restoring force required to nullify the relaxation closure strain for each position.
7 The values of the calibration factor (effective area $A_{je)}$ for the flatjack used and the appropriate geometrical efficiency factor K_e.
8 Computed mean stress for each position
9 The date of the test.

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11. GUIDELINES

Some comments, warnings and suggestions are given in the following with special attention to irregular or weak masonry.

11.1 Irregular or weak masonry

The reliable determination of the equilibrium pressure is a fundamental requirement for the test, regardless the details of the type of application. Conflicting information, regarding the interpretation of the effect of the concentration of stresses and/or of inelastic deformations or of very low stresses usually requires significant amount of subjective judgement, which may compromise the reliability of the entire procedure [Guidelines Reference 3].

Due to the inhomogeneity of the masonry and to the cutting operation, variation in the stress field is caused during and after the cutting of the slot. Once the cut has been carried out, the values of the displacements measured at the reference points are not constant; they tend to be greater in the centre of the cut due to the new distribution of stresses. Three potential deformation patterns assumed by the edges of the cut are represented in Fig. 6 [Guidelines Reference 2].

Therefore there will be a concentration of tensile stresses at the middle of the slot and the greatest values of compressive stresses beyond its end. In the middle of the slot the situation of unloading by cutting and successive loading by the flat jack is represented in Fig. 7. Obviously in the case of cracking due to the tensile stresses generated at the top of the slot (Fig. 6c) or consequent rigid movements of the upper parts of the slot, the situation of Fig. 8 can be obtained. On the contrary, the corners and the lateral parts of the cut are under compression increasing after the cut has been made. Therefore the situation at the ends of the cut is such that higher stresses have to be applied to recover the relaxation displacement and to

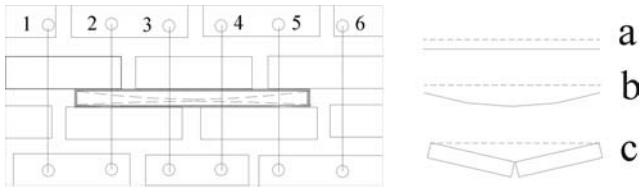

Fig. 6 - Deformation of the edges of the cut [Ronca, 1996].

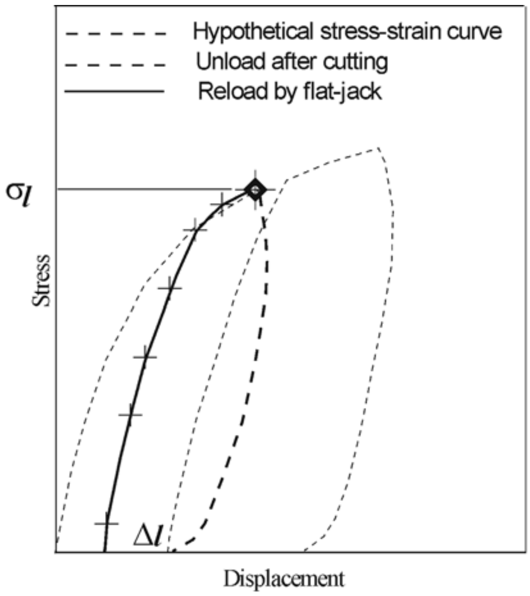

Fig.7 - Stress displacement in the middle of the slot.

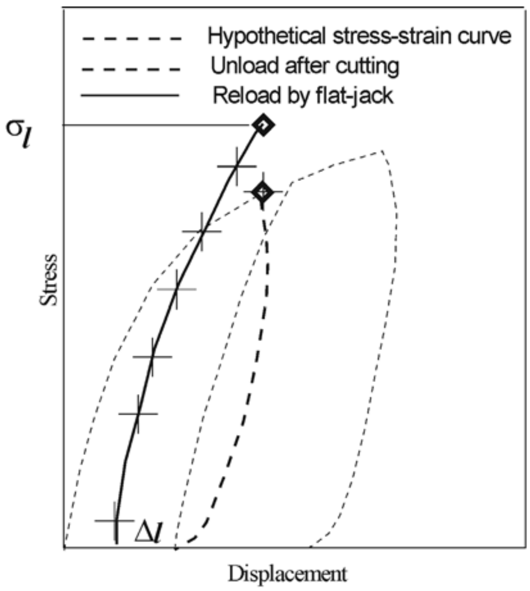

Fig. 8 - Stress-displacement in the middle of the slot in case of hinge formation or rigid displacement.

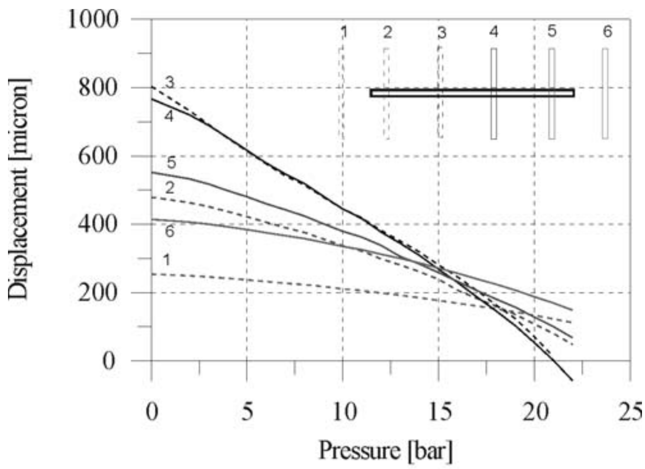

Fig. 9 - Pressure in the jack against measured displacements.

oppose the compressive stress [Guidelines Reference 2]. In any case the measurements carried out in the four chosen points will never give the same value and, after the flat jack has been inflated, very seldom will the original distance will be attained simultaneously in all of the four measuring points (Fig. 9) [Guidelines Reference 3].

11.2 Low values of the stresses

In the case of one or two floor buildings the values of the stress in the wall is very low (from less than 0.1 and 0.15 N/mm^2).

In this case the error of the measured value can easily be up to ±100% of the actual real stress. In this case the test will only be of use if the measured stress is much less than the likely stress capacity of the element (*i.e.* less by the size of the likely error or greater).

11.3 Traditional multiple leaf walls *e.g.* rubble-filled cavity walls

In the case of rubble-filled multiple leaf masonry the flat jack test can only be conveniently carried out on the leaf of the wall on the side from which the measurements have been made. No information of the state of stress in internal leafs is provided by this method. It is, however, possible to work on the remote leaves of walls with air cavities via a hole in the near leaf.

11.4 Wall under eccentric load

Two single jack tests can be carried out at the two faces of the wall. If different values are measured, the distribution of the stresses due to an eccentric load can be calculated.

When, after cutting, the distance of the reference points tends to increase, the presence of tensile stresses can be the cause; therefore, in that case the continuity of the wall should be quickly restored by filling the cut with mortar. The presence of cracks or signs of movements in the stones should discourage the user from carrying out the test in those positions. A technique for measuring eccentricity working from only one side of a wall has been reported by de Vekey [Guidelines Reference 5].

11.5 Wall subject to horizontal stresses

Horizontal stresses may occur due to expansion of confined clay brick masonry and could also occur due to foundation movement. A test procedure has been reported by de Vekey [Guidelines Reference 6].

GUIDELINES REFERENCES

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