Analysis of Mechanical Characteristics of Brick Masonry by Means of non-destructive "in Situ" Tests

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SUMMARY

The paper presents a non-destructive in situ testing technique, based on the use of special flat-jacks which makes it possible to determine both the state of stress and the deformability characteristics of the masonry, without causing any alteration to the structures of the building. The results of a calibration test carried out at laboratory on a large masonry sample are also presented together with some recent examples of application.

1. FOREWORD

The static restoration of old buildings calls for a detailed knowledge of the mechanical characteristics of the material forming the structure.

The problem is especially difficult in the case of old brick masonry which presents courses with high mechanical properties alternating with courses of mortar having poorer characteristics. The determination of mechanical characteristics must obviously be carried out on samples which have to be representative, on the whole, of the mean total behaviour of the structure. These representative samples may be considerably large, depending on the structural characteristics of the masonry.

The absolute impossibilty of coring such large samples from the structures needs that special non-destructive tests be developed.

The simplest approach for the determination of physical and mechanical characteristics of the structure is given by geophysical testing methods. However, geophysical measurements can only give a qualitative evaluation of the mechanical behaviour of the structure, and in any case the results obtained by this technique has to be verified on the basis of the results of direct mechanical tests.

For this reason it is necessary to develop, in parallel to geophysical investigation, also non-destructive mechanical testing techniques which make it possible to test large-scale samples without causing any alteration to the structure.

In this connection, a significant contribution has recently been given by ISMES. A special testing technique by flat-jacks has been developed to determine "in situ" the deformability characteristics of large masonry samples, without removing or altering the samples themselves. This test also makes

it possible, in a first stage, to obtain another very important information on the mechanical behaviour of the structure: the measurement of the state of stress in the main structures of the building.

2. TESTING TECHNIQUE

The non-destructive mechanical test proposed for studying static problems related to brick masonry has been developed assuming as an example a technique already set up for tests in rock mechanics field.

The test is carried out in two separate phases:

2.1 Measurement of the state of stress (1st PHASE)

This determination is based on the stress release caused by a plane cutting, normal to the surface of the structure (Fig. 1). Stress release determines a closing of the cutting that can be noticed through convergency measurements between points symmetrical to the cutting. A special jack, less than 20 mm thick, is set inside the cutting. Inner pressure is gradually increased up to cancelling the previously measured convergency (Fig. 2). In this conditions, the pressure inside the jack is equal to the pre-existing state of stress in a direction normal to the plane of the cutting. The value obtained must be corrected taking into account the ratio between flat-jack and cutting surfaces.

In brick masonry, the plane cutting can easily be made at the mortar layer between two courses of bricks, after the mortar is removed by means of special tools.

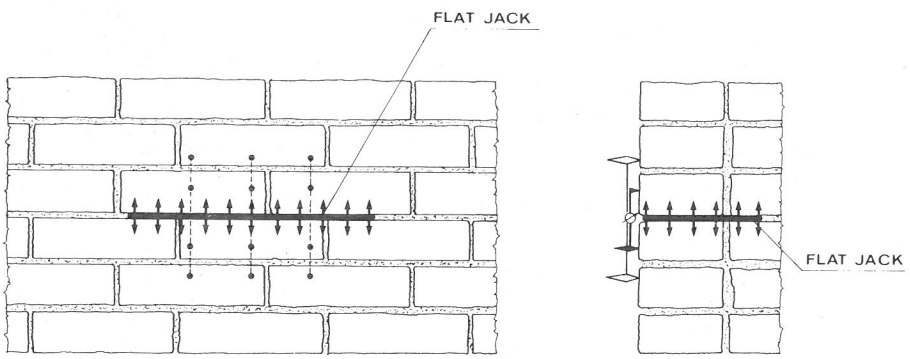

Fig. 1 Flat-jack test scheme.
1st PHASE: Determination of the state of stress.

2.2 Determination of the deformability characteristics (2nd PHASE)

In homogeneous isotropic material, the test described at point 2.1 can also be used to determine the deformability characteristics.

Fig. 2 Loading phase for the determination of the state of stress. The flat-jack is inserted into the cutting and the pressure is increased up to cancelling the release deformation. A 200 mm base mechanical strain-gauge is used.

In the case of brick masonry, which is a highly anysotropic material, it is advisable to introduce some changes in the testing technique. For this purpose, a second cutting is made, parallel to the first one, and a second jack is set in it. The two jacks delimit therefore a masonry sample of appreciable sizes (40 x 40 x 20 cm) on which they apply a uniaxial state of stress (Fig. 3).

Several measurement bases for mouvable mechanical strain-gauge installed on the sample free face make it possible to obtain a full picture of axial and transverse deformations of the sample (Fig. 4).

3. MAIN ADVANTAGES OF FLAT-JACK TEST

The testing technique proposed is certainly non-destructive because, after the test is completed, the jacks set in the masonry can easily be removed and the mortar layer restored to its original condition.

The results are quite reliable because the deformability characteristics are measured on an undisturbed sample which, for its large size, is certainly representative of the mean behaviour of the structure, as a whole.

Both instrumentation and loading equipment are very simple and their rapid installation makes it possible to carry out a complete test (1st and 2nd stage) in about 7-8 hours.

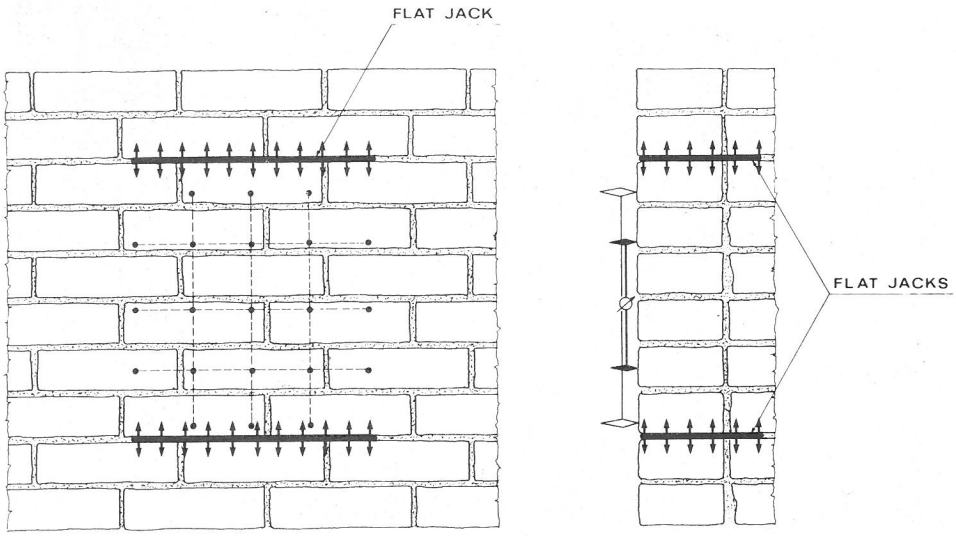

Fig. 3 Flat-jack test scheme.
2nd PHASE: Determination of deformability characteristics of the masonry.

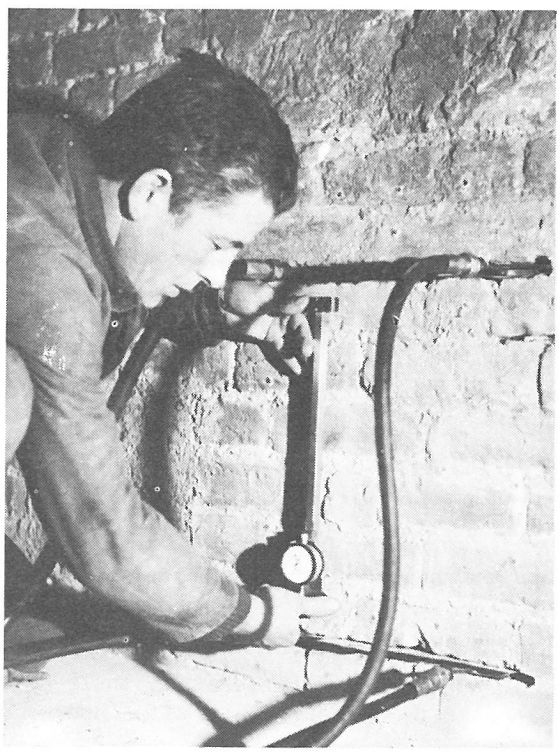

Fig. 4

Deformability test with two flat-jacks in a XIII century brick masonry. Measurement of axial deformation by means of a 400 mm base mouvable mechanical strain-gauge.

A last but not least advantage of the test consists in the possibility of using flat-jacks as pressure cells during the restoration works, in order to control any changes in the state of stress caused by the works.

4. CALIBRATION TEST BY PHYSICAL MODEL

It must be pointed out that the masonry sample on which the mechanical test is carried out is confined on three sides and free on the fourth one. For this reason, some difficulties arise in the interpretation of the results which make it necessary to carry out a series of calibration tests by physical and mathematical models. The research is now being carried out for investigating the effect of the layer thickness and the flat-jack size on the testing results.

A first preliminary test was carried out at laboratory on a large masonry sample (140 x 140 x 60 cm) on which a uniaxial state of stress was applied by means of a big loading machine (Fig. 5).

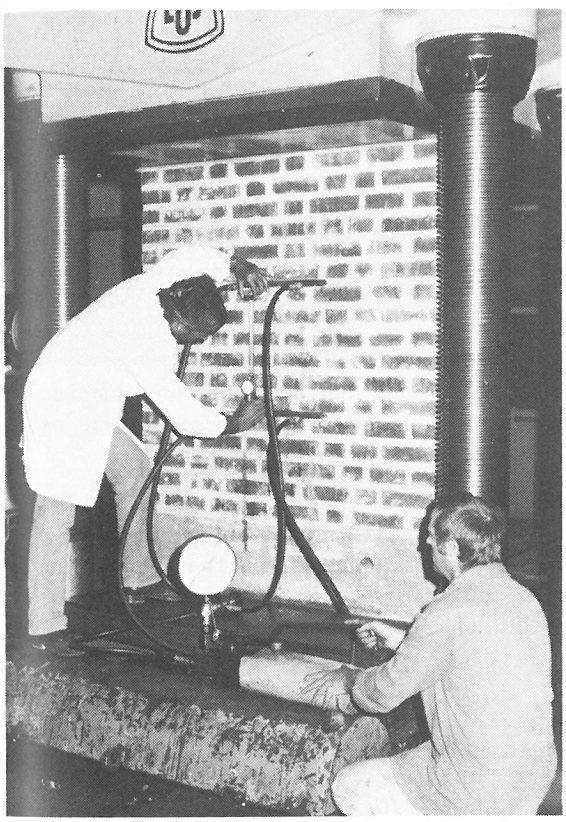

Fig. 5 Calibration test at laboratory on a large-size masonry sample (140x140x 60 cm).

The sample was built at laboratory, using a mortar with low mechanical characteristics set out in 25 mm-thick layers and alternated with 50 mm-thick bricks layers.

A uniformely distributed pressure was applied up to a maximum value of 1.0 MPa and the deformability characteristics of masonry were determined after several loading cycles.

Then, the two phases of the tests were reproduced at the center of the sample to determine both the state of stress and the deformability modulus.

The main results of the test are summarized in table 1, which shows a comparison between the real values and those obtained by the flat-jacks test.

It may be noted that the value of the state of stress determined by the test is slightly higher than that imposed to the sample. This is probably due to a non perfectly uniform distribution of the pressure following from a greater hardening of the mortar near the surface of the masonry.

As regards deformability moduli we note a very good agreement between the real and the determined values, when the pressure level does not exceed 0.5 MPa.

	REAL VALUES	VALUES DETERMINED BY FLAT-JACKS TEST
STATE OF STRESS	1.0 MPa	1.15 MPa
DEFORMABILITY MODULI:		
($\Delta\sigma$ = 0 - 0.5 MPa)	2450 MPa	2400 MPa
($\Delta\sigma$ = 0.5 - 1.0 MPa)	3400 MPa	3750 MPa

TABLE 1 Calibration test: comparison between the real characteristics of the masonry and those determined by flat-jacks test.

By increasing the pressure, the confining effect of the sample delimited by the two flat-jacks becomes evident. In this case, for loading cycles between 0.5 and 1.0 MPa, the real deformability modulus is about 10% lower than the value determined by the test.

This is obviously depending on the deformability characteristics of the masonry; therefore further calibration tests have to be carried out varying the mechanical characteristics of the masonry samples.

5. EXAMPLES

The testing technique illustrated in this paper has recently and successfully been used for solving static problems concerning the restoration of some important ancient buildings.

Three examples have been chosen, which illustrate, in their turn, three different types of intervention on ancient buildings: ie, preservative static restoration; static restoration with some changes in the supporting structures of the building; and, old building recovery for habitation purposes.

"Palazzo della Ragione", Milan

It is a medieval palace built in XIII century and modified in XVIII century to increase the volume of the central hall intended for the Notaries' Archieve. The building has a number of large cracks which appear on the XIII century walls, and continue upwards, at some points, also involving the reasing.

An extensive experimental investigation was carried out in order to know the static conditions of the building and the causes of deterioration, before studying the static restoration design.

Six non-destructive tests were carried out at different points of the wall to determine the mechanical characteristics of the masonry and to have a comparison of the local state of stress (Fig. 6).

After the original state of stress was determined, a first series

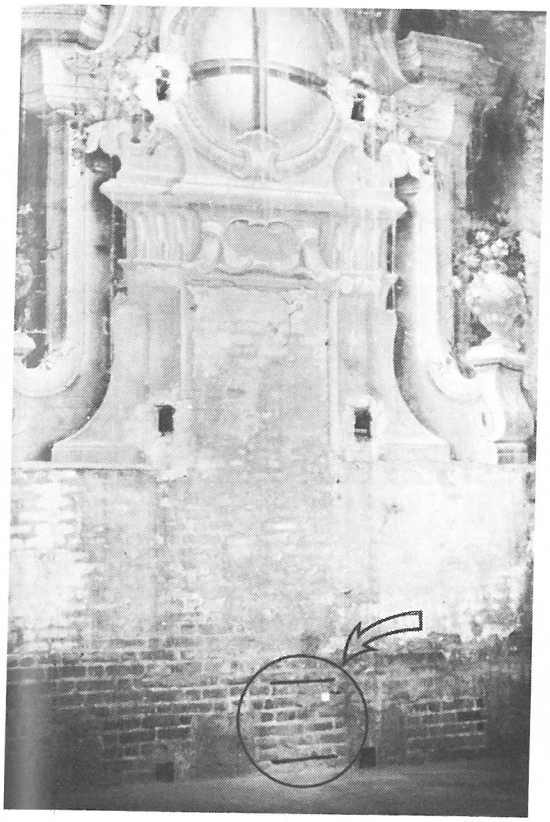

Fig. 6

"Palazzo della Ragione", Milan: View of a test point in the XIII century wall.

of loading cycles was carried out up to a maximum stress value equal to the original stress, which was about 0.4 MPa. Additional series of cycles were then performed at increasing values of the maximum load: 1.0 and 1.6 MPa.

Although a test of this type cannot be carried out, for obvious reasons, up to failure, nevertheless it makes it possible to identify, by extrapolation, a reliable value of ultimate load.

A typical behaviour of the masonry in question is illustrated in Fig. 7 which shows the diagrams of axial and transversal deformations versus axial loads.

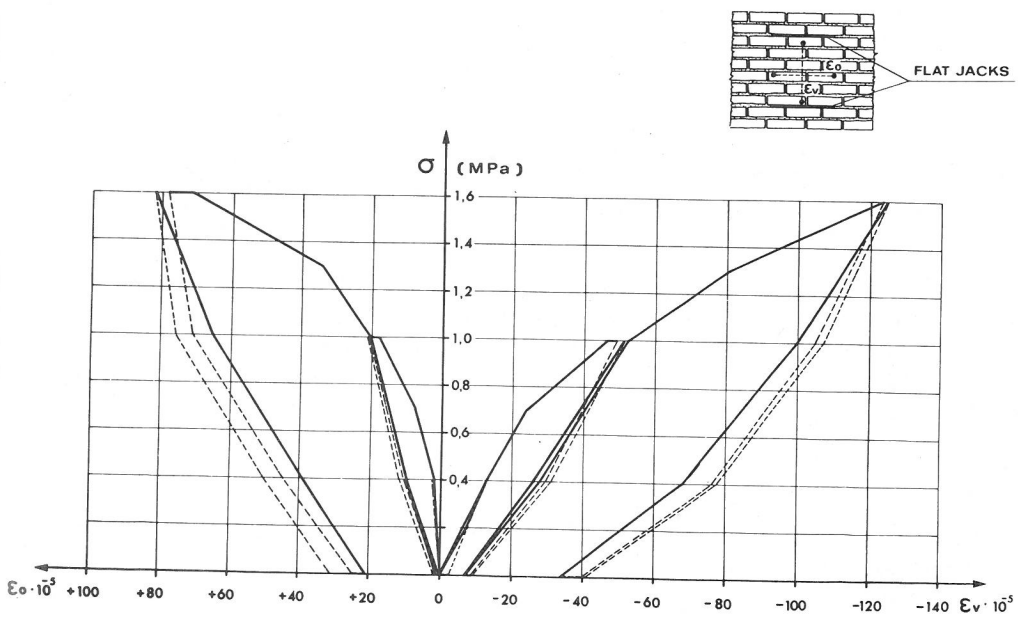

Fig. 7 "Palazzo della Ragione", Milan: Typical diagrams of axial and transversal deformations.

"Classense" Library, Ravenna

This important building of XVI century is now concerned with a delicate restoration project which involves both the foundations and the masonry wall.

Especially delicate was the problem of opening some arches in a wall resting on a series of pillars made up of brick masonry.

Two flat-jack tests have been carried out in two pillars before and after the arches were opened, to check the changing of the state of stress caused by the restoration work (Fig.8).

Fig. 8
Flat-jack test on a pillar of the "Classense" Library, Ravenna.

Recovery of an old building in Milan

This large square-plan building, constructed in Piazzale Dateo at the beginning of XX century, now shows evident signs of deterioration.

The Commune of Milan, before carrying out a complete restoration of the building for habitation purposes, asked ISMES to perform a wide experimental investigation in order to have a detailed picture of physical and mechanical characteristics of the structures and of the static conditions of the building itself (Fig. 9).

Non-destructive flat-jack technique was used to determine the mechanical characteristics of the main supporting walls.

Ten tests were carried out at points of expected stress concentration. At those points stresses were found of about 0.6 to 0.8 MPa with peak values up to 1.0 MPa.

The results obtained by flat-jacks deformability tests were compared with those obtained by geophysical investigation and laboratory tests on large masonry samples cored from the walls.

Fig. 9

View of the old building at "Piazza le Dateo" - Milan to be recovered for habitation purposes

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