EVALUATION OF IN-SITU STRESS IN MASONRY STRUCTURES
BY FLAT JACK TECHNIQUE

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ABSTRACT

Engineers involved in structural analysis / health monitoring of existing masonry structures need information about the compressive stresses, the deformability properties and the loads applied. This knowledge is necessary for the evaluation of the current condition of structures and can be also useful for stress control during repair and rehabilitation operations. Flat jack technique can be efficiently used to determine the in-situ stress and compressive strength of masonry structures. A flat jack is a thin hydraulic load cell, for insertion into a typical mortar joint where a slot is formed. When pressurized, the flat jack exerts stress on the surrounding masonry and by measuring surface deformations; information on the existing state of stress as well as the stiffness and strength of masonry can be obtained.

Laboratory studies were carried out to assess the reliability of the flat jack technique for the determination of existing stress in masonry structures. Experiments were carried out on two masonry specimens to evaluate the existing stresses using flat jack technique. The flat jack used for the test was calibrated before the actual test on the masonry specimen. Known stresses were created in the specimens by applying external loads. Flat jack technique was used to evaluate the applied stresses in the specimen. The stresses obtained from the flat jack technique were compared with the applied stress. This paper presents the details of the studies carried out to evaluate the existing stress in the masonry specimens and the calibration of flat jack.

Keywords: Flat Jack, Masonry Structures, In-situ Stress, Health Monitoring and Repair and Rehabilitation

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INTRODUCTION

The analysis of masonry constructions poses important challenges because of the complexity of their geometry, the variability of the properties of traditional materials, the different building techniques, and the absence of knowledge on the existing damage from the actions which affect the constructions throughout their life and the lack of codes. In addition, restrictions in the inspection and the removal of specimens in buildings of historical value, as well as the high costs involved in the inspections and diagnoses, often result in reduced information about the internal constructive system or the properties of the existing materials. In recent years, large investments were made in this area, leading for inspection, non-destructive testing, monitoring and structural analysis of monuments. Nevertheless, understanding, analyzing and repairing masonry structures remains one of the most significant challenges to the civil engineering community.

Engineers involved in structural analysis of existing masonry structures need information about the compressive stresses, the deformability properties and the loads applied to the masonry. This knowledge is necessary for the evaluation of the current condition of structures and can be also useful for stress control during repair operations.

Laboratory studies were carried out to evaluate the existing stresses in masonry structures using flat jack method. This paper presents the details of the study carried out to evaluate the existing stress in the masonry specimens.

LITERATURE REVIEW

The safety evaluation of historic masonry structure is not an easy task due to different reasons. Often the mechanical behaviour of this type of buildings is too complicated to be interpreted by simple mechanical models, even if they refer to the simplified schemes of the classical limit equilibrium theories. Besides, it is frequently quite difficult to perform reliable quantitative strength evaluations, due to the difficulty of gathering experimental data on the resistance of the structural elements and even on the mechanical properties of the materials. The following are the work carried out by researchers in the masonry.
Gregoreczk and Lourenço [1] carried out an experimental investigation at University of Minho using the flat jack method to compare the recommendations between standards and laboratory experiments with different slotting methods namely stitch drilling and saw cutting. Carpinteri, et. al., [2] carried out a case study of the eighth-century masonry tower called “Torre Sineo” (Alba, Italy). The masonry building called “Torre Sineo” dated as eighth century, is the tallest and mighty of the medieval towers preserved in the town of Alba (Italy). Single and double flat jack tests carried out to assess the stress level in the masonry. Nonlinear numerical analysis was also carried out in order to provide a stability assessment. The results from the numerical analysis, combined with monitoring of the structure, give valuable hints for assessing not only how, but also when, structural restoration has to take place. Bartoli, et. al., [3] had done work on the analysis and interpretation of the damage pattern in the Dome of the Siena Cathedral (Italy). The research was motivated by the failure of some elements of the internal stone-truss system connecting the two masonry shells which constitute the Dome structure. Numerical analysis and in-situ tests were conducted. This investigation was made with the aim to assess the change on the behaviour of the building in order to plan a retrofit of the Dome. The comparison between measured and numerical results allowed for the validation of main assumptions adopted in the model.

Dario Almesberger et al., [4] presents the non-destructive testing investigations performed on the Clock Tower (Torre dell’Orologio), placed in San Marco Square in Venice. Various levels of damage, developed on the tower during its life, have been investigated in order to achieve a structural diagnosis which is determinant for the optimization of the restorative intervention. The results presented, demonstrate the importance of non-destructive methods for the evaluation of the strength characteristics and of the static conditions of the structures under investigation. The testing technique based on the use of flat jacks has been carried out in two selected points of the last floor, chosen after an accurate preliminary investigation. Russell, et. al., [5] described the assessment of material properties of New Zealand’s un-reinforced masonry building stock. Due to the highly variable nature of masonry, testing was conducted not only on individual materials, but their interactions with each other, particularly the interaction between mortar and bricks. Schuller, [6] has presented the recent advances in nondestructive testing technology which have led to mainstream use of several methods for evaluating masonry construction. Flat jack methods are used to measure the state of compressive stress and compression response, masonry bed joint shear strength may be evaluated by an in situ shear test, and mortar unit bond strength is tested by an adaptation of the bond wrench approach.

FLAT JACK METHOD

Flat jack testing can determine the engineering properties of existing structures for structural evaluation. This method is also used to determine the in situ stress and compressive strength of masonry structures. A flat jack is a hydraulic load cell manufactured to be very thin, for insertion into a typical mortar joint into which a slot has been formed. When pressurized, the flat jack exerts stress on the surrounding masonry and by measuring surface deformations; information on the existing state of stress as well as the stiffness and strength of masonry can be obtained.

This method directly measures the actual state of compressive stress present within the masonry and is useful for determining stress gradients present within a masonry wall or column. Prior to forming a flat jack slot, the distance between gauge points on opposite sides of the slot location is measured. After the slot is cut, compressive stress present within the structure forces the slot to close slightly. Flat jacks are then placed in the slot and pressurized to restore the slot back to its original position. The pressure required to restore the gauge points to their original position, modified by the flat jack calibration constant, provides a measure of the state of compressive stress normal to the slot.

The measurement consists of two distinct phases:
- Cutting a slot (preferably by a diamond saw)
- Insertion of a flat jack into the slot and pressurization until compensation (re-establishing the deformation stage prior to saw cutting)

The in-situ stress is evaluated using the following equation

$$\sigma_m = \rho \cdot k_m \cdot k_s$$  (1)

Where $\sigma_m$ = in-situ stress component to be determined, $\rho$ = restoration pressure in flat jack at full compensation, $k_m = \text{flat jack calibration factor}, k_s = \text{proportion of area of flat jack to area of slot}$.

The particular advantage of the stress relief and flat jack method is that knowledge of the elastic constants of the tested material (e.g. young’s modulus and Poisson’s ratio) is not required. This is in contrast to other stress measuring methods.

LABORATORY INVESTIGATIONS

Preparation of Specimen

Two brick masonry specimen of size 1200 X1000 X 340 mm were cast as per IS: 1905-1987[7]. The cement mortars used for casting the specimens were in the mix ratio 1:6. Second class brick was used to prepare the specimen with English bond. Fig 1 shows the masonry specimen after casting. The specimens were cured for 28 days.

Instrumentation and Testing

In order to measure the magnitude of the deformation during flat jack testing four / five pair of pellets were fixed across mortar joint on one face of the masonry where the slot will be made as shown in Fig. 2. The distance between the pellets was 250mm. Extensometer of 250mm gage length was used to measure the deformation during testing.

The instrumented specimen was kept at the 1000kN reaction frame at STL, CSIR-SERC. The masonry specimens were loaded under two point symmetrical loading where, point load is distributed uniformly by providing channel covering the...
full length and width of the specimen. Over that two hinge plates were placed at one-fourth points to ensure the proper distribution load along width. Using hydraulic jacks, uniform load was applied to the specimens. Load was applied in steps of around 5tons. Each load steps deformations from the instrumented locations were recorded (Fig. 3). At the load of 35t the loading was stopped. The stress developed due to this load is the existing stress in the masonry specimen. The deformation at this load level is measured and kept as the initial displacement.

A slot of 400x200 mm with a thickness of around 6mm was made on the mortar joint using the cutting machine as shown in Fig. 4. As a consequence of the slot the deformations in a direction normal to the slot will takes place. Distances between the gauge points were decreased. The displacement between the gauge points was recorded after making the slot. Cutting the slot causes partial stress relief in masonry above and below of the slot. Measurement was also carried out after cutting the mortar joint.

The flat-jack of size 400x200 mm was inserted into the slot and the gap between flat-jack and surrounding masonry was filled with shims as shown in Fig. 5. With the aid of this flat jack, pressure (compressive stress) is applied to the masonry. Since knowledge of the contact area during flat-jack testing is important when deciding about test validity, to gain better understanding of this area, a very simple and inexpensive method was used in experiments. A sheet of carbon paper, sandwiched between two white sheets, was placed between the flat jack and a surface of the shim.

The paper was marked in places of contact, conversely to places without contact, where the paper remained white. To restore the original position, flat jack is pressurized with the increment of 3 – 4 bars. At each increment of pressurization the pressure readings were recorded. The necessary canceling pressure \( \rho \) is obtained by applying the pressure and simultaneous measurement of gauge readings, at some point of time the original distance between the gauge points were reached.

**CALIBRATION OF FLAT JACK**

Flat-jacks are designed to have an output pressure (one that is applied to masonry) that is linearly dependent on the internal hydraulic pressure. A flat jack has an inherent stiffness which resists expansion when the jack is pressurized. The pressure applied to the flat-jack is greater than the stress the flat-jack applies to the masonry. The flat jack must be calibrated to provide the conversion factor, \( k_m \), to relate internal fluid pressure to stress applied. The coefficient that provides conversion \( (k_m) \) is determined during the calibration process.
The flat jack used for the test was calibrated before the actual test on the masonry specimen. The calibration was conducted in 400kN capacity UTM (Fig. 6). ASTM C1196 [8] was followed during the calibration tests. A 50mm thick steel bearing plate was placed on the lower platen of the UTM. The flat jack was placed on the lower bearing plate such that the edge of the flat jack with the inlet/outlet ports is coincident with the edge of the bearing plate. The steel spacers were placed around the other edges of the flat jack. Another 50mm thick bearing plate was placed on the top of the shims and flat jack and it was aligned in such a way that the upper and lower plate are in the same line. The moveable plate is raised such that the non-moveable plate is in contact with the top bearing plate. To maintain constant distance between platens during the calibration, a dial gauge was fixed over the 50mm steel plates. Before start of the calibration, three cycles of pressurization and depressurization with the maximum pressure in the flat jack not exceeding 50 bars was carried out. Pressure in the flat jack was increased to 2bar increments up to 28bars while holding the distance between platens constant. At each increment, flat jack hydraulic pressure and force measured by the UTM was recorded. The load applied by the flat jack was calculated as internal pressure times gross flat jack area. The load applied to the flat jack versus load measured by the flat jack was plotted. The calibration factor was evaluated by taking the slope of the plot. ie.

$$k_m = \frac{P_{\text{machine}}}{P_{\text{flat jack}}}$$

(2)

From the calibration test the flat jack calibration factor ($k_m$) evaluated was 0.714

RESULTS AND DISCUSSIONS

The instrumented specimen 1 was kept in the loading frame. Using hydraulic jacks, uniform load was applied to the specimen. Load was applied in steps of 50kN with the maximum load of 350kN. Each load steps, deformations from the six locations were recorded and given in Table 1. The stress developed due to this load is 0.863 N/mm². This is the existing stress in the masonry specimen. The deformation at this load level is measured and kept as the initial displacement.

A slot of 400x200 mm with a thickness of around 6mm was made on the mortar joint at the middle of the specimen. The displacements between the gauge points were recorded. Flat-jack of size 400x200 mm was inserted into the slot and the gap between flat-jack was filled with shims. To restore the original position before the making of slot, flat jack is pressurized with the increment of 3-4 bars. At each increment of pressure the displacements were recorded and shown in Table 2. The pressurization stopped when distance between the gage points reached nearer to the original distance prior to the slotting. The final flat jack pressure was recorded.

<table>
<thead>
<tr>
<th>Applied load in Tonne</th>
<th>Measured deformation in mm</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>D1</td>
</tr>
<tr>
<td>0</td>
<td>-0.058</td>
</tr>
<tr>
<td>4.77</td>
<td>-0.066</td>
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<tr>
<td>35.23</td>
<td>-0.556</td>
</tr>
</tbody>
</table>

The existing stress in the specimen was calculated based on the value of the flat jack restoring pressure. To determine pressure corresponding to the initial displacement is by interpolation between two pressure levels (corresponding to displacements greater and lower than initial displacements). Fig.7 shows the deformation versus the restoration pressure for specimen 1. The deformation is measured at four pair of reference gauges. The restoring pressure is calculated by; the point of intersection between the pressure/displacement graph and the pressure axis. The pressure from the four gages matching the initial displacement before making the slot was interpolated from the measurement and the average value was 22.04 bar. This pressure is canceling pressure to restore the original condition of the specimen before slot. The contact area of the flat jack measured from the impression of the carbon sheet is calculated. Area of the slot was also measured.
The in-situ stress is calculated by,
\[ \sigma_m = \rho \cdot k_a \cdot k_m \]
where \( k_a = 0.48 \), \( k_m = 0.714 \), \( \rho = 28.24 \) bar
\[ \sigma_m = 0.48 \times 0.714 \times 28.24 = 0.968 \text{ N/mm}^2 \]

Applied stress \( \sigma_A = 0.847 \text{ N/mm}^2 \)

The obtained stress value is close to the applied stress with the error of 14.28%. For practical applications such error in the stress estimation is reasonable and represents valuable information.

**SUMMARY AND CONCLUSION**

Flat jack tests are among the most useful and informative NDE tests available for determining structural properties. Unlike other NDE tests, the flat jack test provides a direct physical measurement of the engineering material characteristics needed for structural analysis and evaluation. The in-situ stress test provides a direct measure of existing stress in a structure—thus gives an indication of the factor of safety of the structure in terms of compressive failure.

Laboratory studies were carried out on two masonry specimen to evaluate the existing stresses using flat jack method. The stresses obtained from the tests are close to the applied stress with error is less than 15%. For practical applications such error in the stress estimation is reasonable and represents valuable information. Hence the flat jack method to evaluate the existing stress in the masonry structures can be applied to any field applications.

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**REFERENCES**


