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Studies on Calibration Factor of Flat-Jack for Measuring In-Situ Stress on Concrete Members

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Abstract— There are numerous concrete structures which served more than a decade. The aging of concrete structures is produced primarily by the continuous impact on the material by the surrounding environment. So deterioration may occur that can significantly affect the service life of the structures. It is of critical importance to evaluate these deterioration mechanisms and how they influence the safety of the whole structure. In view of the above, assessment of in-situ stress in concrete structures will act as a baseline for strengthening and repair, if any required. For this reason, the need for adequate tools for assessing in-situ stress in concrete structures has become a subject of crucial economic and social interest. In past years the Flat-Jack testing technique was applicable only for masonry structures. Some research on masonry structures were carried out. This paper presents an overview of Flat-Jack technique, its applicability in concrete structures, selection of Flat-Jack dimensions, and calibration of Flat-Jack.

Index Terms— Aging, Calibration Factor, Concrete Structures, Flat-Jack, In-situ stress.

1 Introduction

THERE are numerous concrete structures which served more than a decade. The aging of concrete structures is produced primarily by the continuous impact on the material by the surrounding environment. So deterioration may occur that can significantly affect the service life of the structures. It is of critical importance to evaluate these deterioration mechanisms and how they influence the safety of the whole structure. In view of the above, assessment of in-situ stress in concrete structures will act as a baseline for strengthening and repair, if any required. For this reason, the need for adequate tools for assessing in-situ stress in concrete structures has become a subject of crucial economic and social interest.

In recent years, large investments were made in this area, leading to developments in inspection, non-destructive testing, monitoring and structural analysis of existing concrete structures. Nevertheless, understanding, analyzing and repairing existing concrete structures remains one of the most significant challenges to the modern engineers.

The analysis of existing concrete structures poses important challenges because of the variability of the mechanical properties over a period of time and the absence of knowledge on the existing damage from the actions which affect the constructions throughout their life and the lack of codes. That is why it is necessary to have a rational methodology of the analysis, based on the multidisciplinary knowledge of different agents, in order to undertake such interventions with the maximum possible rigor.

In addition, restrictions in the inspection and the removal of specimens in existing buildings of high 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.

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

In past years the Flat-Jack testing technique was applicable only for masonry structures. Some research on masonry structures were carried out. This paper presents an overview of Flat-Jack technique, its applicability in concrete structures, selection of Flat-Jack dimensions, and calibration of Flat-Jack.

2 Literature Review

The literature review describes about the application of Flat-Jack testing technique. A Flat-Jack is a Non (Minor) destructive testing technique to measure the In-situ stress. By using this technique, majority of works are done in assessing In-situ stress on masonry structures. The following section briefs on works carried out using this technique.

Geoffrey R. Hose and Narendra Gosain [1] carried out structural evaluation of the historical construction (Montgomery River walk Stadium) by using Flat-Jack testing technique. They investigated that the baseball stadium in Montgomery, Alabama, is an adaptive reuse of a railway station head house and loading dock. The architect's plan to house the entry, concessions and suites along the right and left field lines would require new elevated floors inside the loading dock. Flat-Jack testing was used to determine if the existing masonry walls had the strength to accommodate the new loads. Three locations on a typical wall construction were tested for masonry compressive strength with the In-situ Deformability Test. Because of planned additional floors and large new openings in the existing walls, they had to determine the existing building's lateral load resistance and used the In-situ In-plane shear strength test. These tests helped them determine where the existing masonry had adequate strength and where strengthening or supplemental support was required.

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PawelGregorczyk, Paulo B. Lourenço (2000) [2] carried out an experimental investigation at University of Minho using the Flat-Jack method. The objective of the tests carried out at University of Minho was not to confirm the suitability or accuracy of the Flat-Jack method as this has already been done in many laboratory experiments worldwide. Since there is some disagreement in recommendations for Flat-Jack tests between standards and authors, these different recommendations were followed in different experiments. Additionally, it is known that good slot quality is essential for obtaining correct test results. Since knowledge of the true contact area during the Flat-Jack testing is valuable for decisions about test validity, a very simple and inexpensive method was introduced which allowed that information to be obtained. To investigate the existing possibilities, different techniques and tools for mortar removal were used during experiments. Three different stress tests have been carried out in two walls. The slot for the first test was made partly by stitch drilling and partly by saw cutting. Stitch drilling proved not adequate at all for the combination of masonry units and modern hard mortars. The drilling was quite irregular and difficult. For this reason, the slot was further opened by saw cutting. The second and third tests were fully carried out in a saw cut slot. They found out that this non-destructive technique is a powerful tool for the mechanical characterization of historical masonry structures.

Professor Luigia Binda and Claudia Tiraboschi [3] said single and double Flat-Jack tests were firstly applied to brick masonry in 1981. A discussion is presented on the limit and advantages of the test in the case of different types of masonries: brick and stone masonries with thin joints, brick masonries with thick joints, irregular stone and multiple leaf masonries.
Diagnosis of the state of damage of historic buildings can only be carried out if a deep knowledge of materials and structures is available. Visual inspection, geometrical and crack pattern survey, surface decay mapping are necessary to understand the damages and their causes and carry out a first interpretation of the phenomena. Some experiences performed on site on the use of single and double Flat-Jack test on masonry allow to draw the following comments: the Flat-Jack test is a powerful tool to know the local situation of masonries, as it can give the value of the acting stress (compression) and the stress-strain behavior. The results can be used successfully in diagnosis of masonry structures and in the calibration of mathematical models.

Lombillo, Villegas and Elices, J [4] found out that the purpose of this test is to provide a vision of some of the Minor Destructive Techniques (MDT) and Non Destructive Techniques (NDT) applied to the diagnosis of masonry structures. They came to the conclusion that it is necessary to have a rational methodology of the analysis, based on the multidisciplinary knowledge of different agents, in order to undertake such interventions with the maximum possible rigor. There is a prevailing need to govern the processes of intervention and inspection in the refurbishment of existing buildings. From their point of view of the technology of structures is imperative to know the mechanical characteristics of the structural elements involved, as well as the stress levels existing in service. Currently the tendency is to obtain such knowledge in a non-destructive way from the involved buildings, producing only a small damage, as little as possible.

A.Carpinteri, S.Invernizzi and G.Lacidogna [5] carried out Flat-Jack test as follows. The single Flat-Jack test concerns the measurements of In-situ compressive stress in existing masonry structures by use of a thin Flat-Jack device that is installed in a saw cut mortar joint of the masonry wall. The method is relatively non-destructive. After the slot is formed in the masonry, compressive stress in the masonry at that slot region makes the slot get closer, which inturn reduces the thickness of the slot. Inserting the Flat-Jack into the slot and increasing its internal pressure until the original distance between points above and below the slot is restored, can thus measure the compressive stress in the masonry. The slots in the masonry are prepared by removing the mortar from masonry bed joints, avoiding disturbing the masonry. Care must be taken in order to remove all mortar in the bed joint, so that the pressure exerted by the Flat-Jack can be directly applied against the cleaned surface of the masonry units. The state of compressive stress in the masonry is approximately equal to the Flat-Jack pressure multiplied by factors which account for the ratio 'Ka' of the bearing area of the jack in contact with the masonry to the bearing area of the slot, and for the physical characteristic of the jack 'Km'.

Dario Almesberger, Antonio Rizzo, Sergio Meriani and Raffaella Geometrante [6] presents the non-destructive testing investigations performed the clock tower (Torre dell'Orologio), placed in San Marco Square in Venice. The results presented, demonstrate the importance of non-destructive methods for the evaluation of the static conditions of the structures under investigation. Various level of damage, developed on the tower during its life, has been investigated in order to achieve a structural diagnosis which is determinant for the optimization of the restorative intervention. 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. They have used Flat-Jack technique method to find the In-situ stress measurement.

Michael P. Schullar, PE [7] has presented the recent advances in nondestructive testing technology to mainstream use of several methods for evaluating masonry construction. Non-destructive approaches such as rebound hardness, stress wave transmission, impact-echo, surface penetrating radar, topographic imaging, and infrared thermography are useful for qualitative condition surveys as well as identification of internal features such as voids or areas of distress. In-situ test methods are also available for determination of engineering properties.Flat-Jack methods are used to measure the state of compressive stress and compression response. The masonry bed joint shear stress may be evaluated by an in- situ shear test, and mortar unit bond strength is tested by an adaptation of the bond wrench approach. Standardized methods exist for many of the evaluation approaches and related efforts are ongoing within ASTM and RILEM. Among the other methods, the Flat-Jack test methods provide reliable means for inplace determination of existing masonry stress and masonry behavior subjected to uniaxial compression.

Zoltan Orbana and Marc Gutermann [8] investigated masonry arch railway bridges using non-destructive In-situ testing methods. According to their consideration mechanical properties of masonry (e.g. compressive strength, modulus of elasticity, stress-strain relationships, and existing stress state) are usually key input parameters for structural analysis. As an alternative to the conventional destructive methods where cores or small-scale samples are taken from the structure and tested in the laboratory, many of these properties can also be measured by minor-destructive procedures. They approached the railway bridges by the well-known Flat-Jack test, which has been developed by several research centers and laboratories. This minor-destructive procedure provides information on local stresses and some other mechanical properties of masonry by making slots perpendicular to the wall surface and measuring deformations induced by the slots. A thin Flat-Jack is placed inside the slot and the pressure is increased until the preliminary distance is restored. Using an equilibrium relationship the stress value can be calculated based on the applied pressure and two calibration constants. Their experience has confirmed that the Flat-Jack test is a powerful tool to identify the local stress state of masonry structures.

John C Scrivener [9] carried out the different type of test on old masonry buildings. He found the strength of that masonry building by using Non-destructive technique. Once the historical monuments are affected by earth quake dynamic loads, many tests would be conducted. Reuse of that type of structure is very difficult if dynamic loads affect on that. Initially he found strength of old masonry building using Flat-Jack technique. He used the Flat-Jack tests to determine the mechanical properties of earth quake affected structure. The compressive strength of that structure was determined by using single Flat-Jack. Double Flat-Jack type used to determine the deformation properties by making slot on masonry structure. With the recording of deformations in the load direction, the stress-strain history can be obtained. The load to cause first crack in the bricks enables the masonry compressive capacity to be estimated. Cutting the masonry bed releases stress and causes a partial closure of the cut. Use of this may be made with the first cut to determine the level of compressive stress in the masonry. Measuring points are installed on the face of the masonry above and below the cut and the initial distance between them is recorded. On cutting, this distance is reduced. The jacking force required to return the distance to its original amount may then be used to calculate the original stress level. A correction factor is required to take account of the effect of the Flat-Jack.

R. Fedele, G. Maier [10] has presented as an experimental-numerical method, centered on Flat-Jack tests, for the identification of local stress states and possibly deteriorated elastic properties of concrete in existing dams. It was shown herein that the synergistic combination of new pattern of Flat-Jack experiment, computer simulation of the test (by conventional finite elements) and inverse analysis allows to exploit experimental data more effectively than by the traditional procedure, and to achieve more information on material properties.

In fact, he has chosen locations on the free surface of the monitored dam, all the components of local (plane) stress state and the elastic moduli in two orthogonal directions (including shear stiffness) have been estimated by the proposed method. The inverse problem in point is formulated as a sequence of two parameter identifications, i.e. as a bi-level (in the sense of Stackelberg) mathematical programming problem. The solution in a stochastic context was achieved by means of a modified Bayes technique, allowed to obtain, in a "batch" (non-sequential) way, parameter estimated endowed with a covariance matrix which quantified their degrees of confidence and correlations.

Faiella D, Manfredini G, Rossi P.P [11] has presented the paper on the results of In-situ Flat-Jack test, i.e., the state of stress and deformability parameters of the rocks recorded during geo-mechanical investigations to be used for the best design and construction of five large underground pumped-storage power houses and for the study of the foundation rock of arch-gravity dam. The great amount of the data available was also used for a review of the Flat-Jack results which were furthermore compared with the original stress measurements (CSIR doorstopper method) and with the plate-loading tests. A different data processing approach for determining the deformability on the basis of the results obtained from an FE tri-dimensional model was also presented. The above mentioned analysis provides the evidence for emphasizing the accuracy and validity of in-situ Flat-Jack measurements. The literature review reveals that the application of Flat-Jack testing technique that is used for the evaluation of In-situ stress in the masonry structures is reliable. Based on the literature review, the objective of the present study has been formulated and an effort has been made to understand the Flat-Jack testing technique on concrete structures.

3 Flat-Jack Testing

The Flat-Jack is an envelope-like bladder made of two sheets of thin stainless steel. Each sheet is generally 0.1 mm to 0.75 mm thick. They are either rectangular or circular in shape as shown in Fig 1. The jack has an inlet and outlet that so it can be pressurized with hydraulic oil. Metal shims or other partial pressurized Flat-Jack bladders are installed for this purpose.

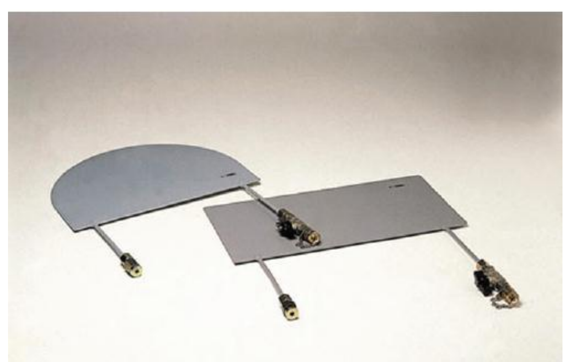

Fig 1 Flat-Jack Equipment

3.1 Types of Flat-Jack

A Flat-Jack may be manufactured in many shapes and sizes. The actual dimensions are determined by its function, slot preparation technique and the properties of the masonry being tested. Flat-Jacks with curved edges (types d, e in Fig 2) are designed to fit in a slot cut by a circular saw. Rectangular jacks (types a, b, c, f in Fig 2) are used where mortar must be removed by hand or with stitch drilling. Regardless of the shape, a Flat-Jack must fit the slot well. The thickness of the Flat-Jack is determined by its specific function: An ideal Flat-Jack will completely fill the slot in the mortar joint. However, if such Flat-Jack is not available, then shims are used together with the Flat-Jack to completely fill the slot thickness.

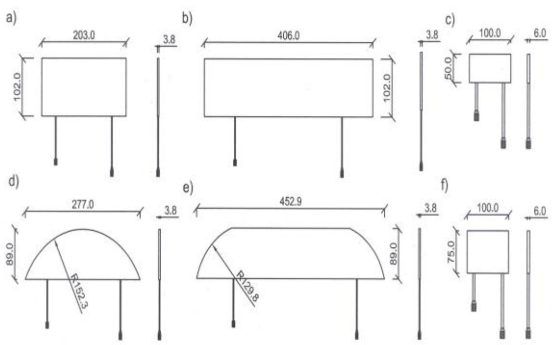

Fig 2 Different Flat-Jack configurations

A Flat-Jack is hydraulic load cell manufactured to be very thin, for insertion into a typical mortar joint (or) proposed slab in structures into which a slot has been formed. Various shapes and sizes of jacks are manufactured: rectangular jacks fit into slots where small amount of portion was removed by stitch drilling. Semi-circular jacks are manufactured to fit the diameter of a rotary saw used to form slot. When pressurized, the Flat-Jacks exert 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 concrete structures can be obtained.

Flat-Jacks have an inherent stiffness, requiring some internal energy to deform, and as a result it must be calibrated in a load machine to determine the Flat-Jack's calibration coefficient 'Km'. The Flat-Jack calibration constant can vary as the jack expands to fill the slot and it is essential that Flat-Jack slots be carefully prepared to minimize the above issue.

Flat-Jack tests are not truly Non-Destructive. But can be considered as being "temporary destructive", requiring removal of a short section from structures for Flat-Jack placement. After the completion of tests, Flat-Jacks are removed from wall and slots pointed with new mortar (or) concrete to restore the structural appearance.

3.2 Principle of Flat-Jack

The magnitude of compressive stress present in masonry and concrete can be determined by a simple process of stress relief. Prior to forming a Flat-Jack slot, the distance between gauge points on opposite side of the slot location is measured. After the slot is cut, compressive stress present within the structure forces the slot to close slightly. A Flat-Jack is then placed in the slot and pressurized to restore the slot back to its 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 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 tests are evaluated as follows.

$$\boxed{\sigma_n = \rho^* K_m{}^* K_a}$$

Where,

σ_n= Normal stress component to be determined
ρ= Restoration pressure in jack at full compensation
K_m= Flat-Jack calibration factor
K_a= Proportion of area of jack to area of slot

The particular advantage of the stress relief and Flat-Jack method is that the knowledge of elastic constants of the tested material (e.g. Young modulus E and Poisson's ratio γ) is not required. This is in contrast to other stress measuring methods.

4 CALIBRATION OF FLAT-JACK

Experimental studies were done for calibration of Flat-Jack by using Flat-Jack equipment. The calibration factor is very important for finding out the In-situ stress evaluation of concrete structures.

The calibration factor "Km" can be found out by using different methods. The Flat-Jack equipment used for this test is 100 x 50 x 8 mm and also inlet and outlet port of this equipment is provided for the purpose of pressurizing the oil. The Flat-Jack used for the calibration test is shown in Fig 3.

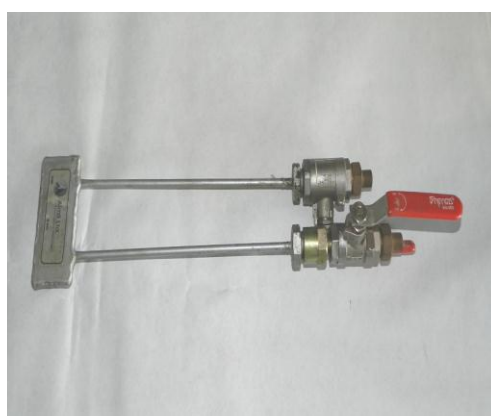

Fig 3 Flat-Jack used for test

4.1 Purpose of Calibration Test

Flat-Jacks are designed to have an output pressure (one that is applied to concrete structures) 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-Jacks applies to the concrete structures. The Flat-Jack must be calibrated to provide the conversion factor 'Km' to relate internal fluid pressure to stress applied. The coefficient that provides conversion (Km) is determined during the calibration process.

The Flat-Jack used for the test was calibrated before the actual test on the concrete specimen. The calibration factor has been conducted on the Universal Testing Machine (UTM) which has a capacity of 40 Tonnes. Fig 4 shows the testing arrangement for calibration.

Fig. 4 Arrangement of calibration test

4.2 Procedure for Calibration Test

The calibration factor 'Km' has been carried out by using UTM. Initially a square shaped base plate is placed on the lower portion of UTM machine. A 20 mm thick rectangular bearing plate of size slightly larger than the Flat-Jack is placed over the base plate. Then the Flat-Jack was placed over the rectangular steel plate. Another 20 mm thick bearing plate of similar size is placed on the top by maintaining 1 mm gap between the Flat-Jack and the top plate using the shim plate. The gap between the bearing/ cover plates is filled using plaster of paris, to ensure uniform transfer of stress. A load cell was placed on the top of bearing plate to accurately measure the load applied during the test process. Load cell was able to measure upto 5000 kg with accuracy of 50 kg. To ensure uniform pressure on the Flat-Jack, two dial gages were used on both sides of the top bearing plate to measure the deflection. The displacement from dial gauge and readings from load cell was recorded by using a digitalized data logger shown in Fig 5. A hydraulic pump was used to apply pressure on the Flat-Jack. The maximum pressure that can be applied to Flat-Jack using the hydraulic pump is 50 bars (kg/cm2). Prior to the test, Initialization of the instrument is done. Then pressure is applied from hydraulic pump at an increments of 5 bar (kg/cm2) upto 50 bar (kg/cm2). At the each increment, Flat-Jack hydraulic pressure and force measured by load cell was recorded and shown in table. A plot of load applied by the Flat-Jack, calculated as internal pressure times gross area of the Flat-Jack, vs load measured using load cell is given in Fig.6, the slope of the line is equal to the Flat-Jack constant. i.e. calibration factor. The readings taken during calibration tests of Flat-Jack are given in Table 1 below.

TABLE 1
CALIBRATION TEST RESULTS

S.No	Pressure applied from Pump (kg/cm^2)		Load Applied Flat-Jack (kg)		Load Measured Load Cell (kg)	
	Trail 1	Trail 2	Trail 1	Trail 2	Trail 1	Trail 2
1	0.00	0.01	0.0	0.7	0	15.4
2	5.97	6.85	298.6	342.4	77.1	92.5
3	11.65	12.19	582.5	609.5	154.2	169.6
4	18.28	20.59	914.0	1029.3	277.6	293.1
5	25.83	31.90	1291.4	1595.0	431.9	509.6
6	36.53	41.54	1826.5	2076.8	647.9	694.2
7	46.43	52.24	2321.4	2611.9	848.4	941

Fig. 5 Digitalized data logger

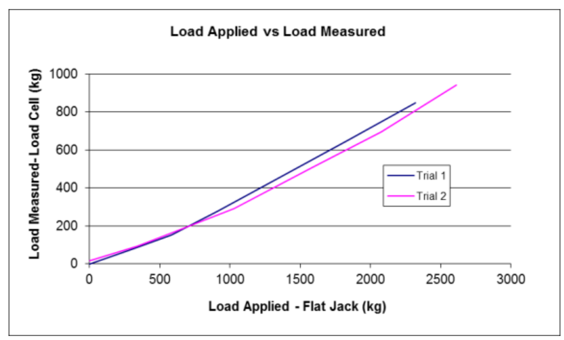

Fig. 6 Load Applied vs Load measured

From calibration test, the Flat-Jack calibration factor value (Km) evaluated (Fig. 6) is 0.366.

5 CONCLUSION

Based on the experimental study on calibration of specially designed Flat-Jack for measuring in-situ stress in concrete structures, the conclusions were derived as follows,

The calibration factor 'Km' for Flat-Jack of size 100 x 50 x 8 mm, which is used for in-situ measurement of concrete structures, is directly proportional to the size of the Flat-Jack. This is due to the effect of end restraint on the stiffness of the Flat-Jack. The stiffness of the Flat-Jack increases as the size decreases. Due to this the internal pressure required is more to compensate the external pressure, i.e. the pressure applied to the Flat-Jack is greater than the stress the Flat-Jacks applies to the concrete structures.

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