IV–31. Full-Scale Tests of Brickwork Panels Under Simulated Wind Load

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ABSTRACT

The Experimental Building Station is undertaking an investigation into the lateral load resistance of masonry infill panels with the aim of providing suitable guidance for designers and formulating design rules for the Australian Brickwork Code. The project involves full-scale testing of wall panels and auxiliary testing of small specimens of various types, chosen to monitor and investigate bond and flexure properties.

A description of the test apparatus is given, including the criteria adopted for its design. The instrumentation and control systems used in the testing are described and experience in the use of the testing frame is discussed.

The testing program is outlined and results to date are discussed and compared with the results of small specimen tests. Various theoretical analyses are compared with the test results in an attempt to discover which approach is best in particular circumstances.

Die Versuchsbaustelle unternimmt eine Untersuchung in den seitlichen Belastungswiderstand von mit Mauerwerk ausgefüllten Paneelen, mit der Absicht geeignete Orientierung für Konstrukteure zu geben und Konstruktionsregeln für den australischen Backsteinbau Kode zu formulieren. Das Projekt schliesst vollständige Proben von Wandpaneelen und zusätzliche Untersuchung von kleinen Mustern verschiedener Art ein, um ausgewwählte Verbund- und Biegungseigenschaften zu beobachten und zu untersuchen.

Eine Beschreibung des Testapparats ist gegeben, einschliesslich den für die Konstruktion adoptierten besonderen Merkmalen. Das Instrumentarium und Kontrollsysteme die in dem Test benutzt werden sind beschrieben und Erfahrung in dem Gebrauch des Probegestells.

Das Testprogramm ist beschrieben und bisherige Resultate werden besprochen und mit den Resultaten von kleinen Spezimentests verglichen. Verschiedene theoretische Analysen werden mit den Testresultaten verglichen in einem Versuch, ausfindig zu machen, welche Methode die beste unter individuellen Umständen ist.

La Station Expérimentale de la Construction entreprend une enquête sur la résistance à la pression latérale des panneaux fourrés en maçonnerie, dans le but de procurer aux planificateurs des conseils appropriés, et de formuler une règlementation du design pour le Code Australien de la Maçonnerie. Le projet implique des essais intégraux sur des pans de murs et des essais secondaires sur divers modèles réduits choisis pour contrôler et investiguer leurs propriétés de liaison et de flexion.

Une description de l'appareillage d'essai est donnée, comprenant les critères adoptés pour sa conception. L'instrumentation et les systèmes de commande utilisés dans les essais sont décrits, et l'expérience obtenue par l'utilisation du modèle d'essai est débattue.

Le programme d'essai est exposé dans ses lignes générales, et les résultats à ce jour sont discutés et comparés avec les résultats des essais sur les modèles réduits. Diverses analyses théoriques sont comparées avec les résultats des essais, pour tenter de découvrir la meilleure façon de s'y prendre dans des situations particulières.

La Stazione Edilizia Sperimehtale sta compiendo un'indagine sulla resistenza a carico laterale di panelli in muratura da riempimento al fine di fornire una conveniente guida ai progettisti e formulare norme di progettazione per il Codice Australiano dei lavori in muratura. Il programma comprende delle prove a tutta forza su panelli di mattoni e prove supplementari su piccoli campioni di vari tipi, scelti per controllare e indagare sulle proprieta' di connessione e di curvatura.

Viene fornita la descrizione dell'apparecchio di prova, includendo i concetti adottati nella sua progettazione. Sono descritti i sistemi di strumentazione e di controllo usati nelle prove e viene trattata l'esperienza fatta nell'impiego del telaio di prova.

E' descritto il programma delle prove e vengono commentati i risultati ottenuti, facendo un raffronto con i risultati delle prove eseguite sui piccoli campioni. Vengono messe in confronto varie analisi teoriche con i risultati delle prove nel tentativo di scoprire quale sia il miglior modo di farle in circostanze particolari.

INTRODUCTION

An extensive investigation is being conducted at the Experimental Building Station in Sydney to determine the lateral load resistance of infill panels of masonry. The aim is to provide design guidance suitable for incorporation in the Australian Brickwork Code. Following the design and construction of a testing apparatus an initial testing program is being carried out on full-scale wall panels subjected to uniformly distributed out-of-plane loading. An integral part of this program is the testing of various types of small specimens to provide data on the bond and flex-

ure properties of the masonry in the expectation that these data will correlate with measurements of wall performance.

The initial testing program was designed to cover a practical range of aspect ratios and a set of realistic support configurations but was restricted to single-leaf walls of clay brickwork. This testing program is approximately half completed and some trends are beginning to emerge from the results. The approach at present is to compare test results with established methods of analysis to ascertain whether any of these methods can provide satisfactory predictions of wall behaviour. In the event that none of these analytical methods is suitable, modifications to them or entirely new approaches will be investigated. If necessary a set of empirical moment coefficients for use by designers could be derived from the test results.

DESIGN OF THE TEST APPARATUS

A frame was required which could hold wall panels of various thicknesses and various sizes up to six metres long and three metres high, and apply to these panels uniformly distributed loads sufficient to cause failure. A maximum pressure of 35 kiloPascals was thought to be adequate and inflatable bags were chosen as the best means of achieving a uniform distribution of pressure. In order that a range of aspect ratios (length/height) could be tested, the frame was required to provide for a number of different specimen heights and lengths. Clamped and simply supported edge conditions were required and a reaction frame was necessary to support the loading bags and resist the back pressure.

The stiffness of the main frame members was considered to be the most important design parameter. Masonry panels are brittle and are therefore sensitive to deformation of the supporting frame which could have a major effect on the distribution of bending moments within a panel and consequently alter the ultimate pressure considerably. This is true not only for out-of-plane support but also for in-plane support in cases where the test panel is subjected to arching restraint. Because the out-of-plane reactions are applied eccentrically to the supporting frame members these members are subjected to considerable twisting moments and must therefore possess high torsional rigidity. Although an attempt was made to calculate the bending and torsional stiffnesses required for the main frame members the interaction between wall and frame is extremely complex and a precise calculation was not possible. The configuration finally adopted for the main frame members was a pair of I-beams joined along their flanges to form a closed box section with a high bending stiffness in each direction and a high torsional stiffness. The combined width of the flanges allows a variety of wall thicknesses, including cavity walls, to be built within the frame. Figure 1 shows a cross-section through the frame and a typical test specimen. The bottom frame member was supported clear of the floor to provide identical support conditions for the top and bottom edges of the test specimen. Figure 2 shows a front view of the frame with a test specimen and instrumentation in place.

The height of the specimen may be either two and a half metres or three metres and the length may be two and a half, three and three quarters, five or six metres. It is thus possible to test panels with aspect ratios ranging from 0.83 to 2.4.

Simply supported edge conditions are obtained by building the front of the wall panel against a 25-mm-diameter steel rod (see Figure 1) and leaving a gap between the end of the wall and the flange of the main frame member. Because walls are built in-situ good abutment against this support is achieved and the use of a compressible insert is considered unnecessary. Fully restrained edges have been approximated by building the wall tightly into the main frame members and allowing arching action to provide restraint but it is envisaged that in some future tests ties will be welded to the supporting frame and built into the wall to provide a greater degree of restraint.

The weight and size of the main frame and of the wall specimens preclude construction of specimens remote from the frame and the subsequent marriage of the two. Consequently, specimens are built and cured within the frame and are tested at an age of 14 days. To facilitate construction of each specimen in-situ the reaction frame is mounted on wheels and is moved away from the main frame. Immediately prior to testing a specimen, the reaction frame is brought up to the main frame and joined to it by a series of bolts spaced at one metre intervals around the periphery of the wall panel. In this way support is provided adjacent to the panel edges, whatever the size and shape of the specimen. Figure 3 shows the rear of the reaction frame with the various positions for reaction bolts clearly evident. The bolts can also be seen around the periphery of the specimen in Figure 2. Strain gauges have been placed on these reaction bolts to measure the tensile force carried by each. In this way a check can be made on the total applied load and on the distribution of reaction forces.

THE LOADING SYSTEM

As a means of covering various sizes and shapes of specimen, any number from one to six air bags can be used. The multiple air bags are arranged so that they overlap and are folded in at the edges. In this way the bags can inflate and cover the entire surface of the wall with a uniform pressure. The bags are hung by flexible supports from the top of the reaction frame. This multiple air bag system also minimizes the adverse effects of bag leakage, and makes handling and manufacture of the bags easier.

The loading bags were originally fabricated from 200-micro-metre clear polythene film, sealed by a hand-iron which produced two parallel welds each 6 mm wide. Tyre valves were used for inlet and outlet connections. While these bags performed well it was subsequently found that the welded areas became brittle with age and that the bags often needed replacement. They are now being replaced with heavier bags made from vulcanised rubber.

Load is applied to a wall panel by admitting compressed air through any one of four adjustable low-pressure regulators to a large manifold. In this way a regulator appro-

priate to the desired range of pressures is used to maintain fine control over the applied load. The air bags are individually supplied with air from the manifold; separate connection is made to each bag to allow the pressure in it to be monitored. In practice the control of bag pressure achieved with this system is sufficiently fine (better than plus or minus one per cent) over the whole range from zero to 35 kiloPascals.

INSTRUMENTATION

The instrumentation used to measure and record pressures, displacements and strains, has been automated as much as possible.

The pressure in the air-supply manifold is measured by sensitive LVDT-type pressure transducers with a resolution of 0.005 kPa for low ranges and 0.05 kPa for high ranges and the pressure in each air bag is measured by an individual strain-gauge-type pressure transducer. In addition a series of mercury manometers provides a visual display of manifold pressure and the individual bag pressures.

Displacement readings are taken on both the wall surface and the supporting frame. These measurements are made by LVDT-type displacement transducers independently supported on the floor (see Figure 2). The displacement transducers used provide a high sensitivity (0.005 mm) and a wide range of measurement (50 mm).

In some tests strains on the surface of the wall have been measured by vibrating-wire strain gauges. This type of gauge was chosen because of its long gauge length which provides an average of brick and mortar strain rather than a localized measurement and because it can be readily attached to an uneven surface.

The various transducers are connected to an automatic data logger which scans the readings and records them on punched paper tape. A digital computer then tabulates and plots the physical quantities. Monitoring of behaviour during the conduct of a test is achieved by using X − Y recorders and digital voltmeters.

A qualitative impression of cracking activity is obtained by amplifying the output of an accelerometer through a loudspeaker. The accelerometer is mounted on the surface of the test specimen and was chosen to have a response covering the audible range. The sensitivity of the system is high enough for the detection of cracks which are invisible, and it provides a loud warning of major cracks.

THE TESTING PROGRAM

As each wall is laid a number of beam specimens are constructed to enable measurements to be made of flexural strength and modulus of elasticity normal to and parallel to the bed joints. It was reasoned that any changes due to the use of a different brick and mortar would be reflected in these small specimens and that it was therefore sufficient to correlate wall performance with measurements of the strength and stiffness of these beams for a single combination of brick and mortar.

A range of aspect ratios (length/height) from 0.83 to 2.4 is included in the program. It is possible to construct eight different sized panels within the frame having aspect ratios between these limits. It is considered that aspect ratio is a more important parameter in determining wall performance than the magnitude of length or height because changes in the aspect ratio can produce different modes of failure whereas wall strength is likely to be inversely proportional to height squared or length squared (with all other parameters constant).

The five different combinations of simply supported and restrained edges shown in Figure 4 have been chosen for initial study. Three of these have support on four sides, including the simple cases where all four edges have the same conditions. The remaining two cases have the top free—this condition has become very common with the increased use of expansion gaps.

In addition to the tests on wall panels and the tests on small beam specimens mentioned previously, measurements are being made of other properties such as shear strength and the tensile strength of brick and mortar. Sufficient data are being collected to enable the underlying statistical distributions of the properties to be investigated.

EARLY RESULTS

The test facility has been found to fulfill its functions well. Sufficiently fine control over the air supply is achieved and the supporting frame does not distort significantly when the specimen is loaded. Tests on nominally identical specimens have given results which agree closely with each other. Figure 5 shows a typical graph of central deflection against pressure for a wall panel.

The cracking pressure and the ultimate pressue for each wall test have been reduced to moment coefficients (α) in terms of the moment of resistance across the bed joints (M_R) and the square of the panel height (H). The relationship between these parameters is:

$$\alpha = \frac{M_R}{\omega H^2}$$

where ω is the cracking or ultimate pressure, as appropriate. The moment of resistance across the bed joints has been chosen because this is the most common measure of bond strength and a standard method for its determination is contained in the Australian Brickwork Code. The height of the panel has been used because this usually has a limited range and is known in the early stages of a design. Non-dimensional moment coefficients are convenient for the comparison of results with elastic plate analysis, yield-line analysis and strip analysis. Figures 6 and 7 show these comparisons for two configurations of supports. The crosses and squares correspond to ultimate and cracking pressures, respectively, as measured in the tests. The strip theory is that proposed by Baker* and involves the simple addition of the load capacities of vertical and horizontal strips through the centre of the panel.

*See BAKER, L.R. 'Structural Action of Brickwork Panels Subjected to Wind Loads'. Journal of the Australian Ceramic Society, Vol. 9, No. 1, May 1973, pp. 7–13.

It is clear from Figures 6 and 7 that none of the theoretical analyses is a consistent predictor of cracking or ultimate moment coefficients for panels throughout the practical range of aspect ratios. Further test results are required before definite recommendations can be made and it may be necessary to refine the analyses so that they take greater account of the particular properties of brickwork before useful predictions can be obtained. As more test results are accumulated it is expected that an empirical set of safe moment coefficients will be recommended to designers as an interim measure, pending the completion of sufficient testing for a method of theoretical analysis to be proposed.

SUMMARY

A full-scale facility for testing laterally loaded masonry panels has been designed and constructed and has proven to be adequate in use. Test data are being collected for a range of conditions which are considered to represent practical infill panel walls. At the completion of the initial testing program enough data will be available to make recommendations for the design of single-leaf panels and these data might provide the basis for refinement of available methods of theoretical analysis.

Future testing programs will investigate other important variables such as wall thickness (including cavity construction), the presence of openings and various edge conditions such as the use of metal ties attached to the supporting frame. It will also be possible to verify results for a range of brick and mortar properties and to conduct tests on concrete masonry walls.

ACKNOWLEDGMENT

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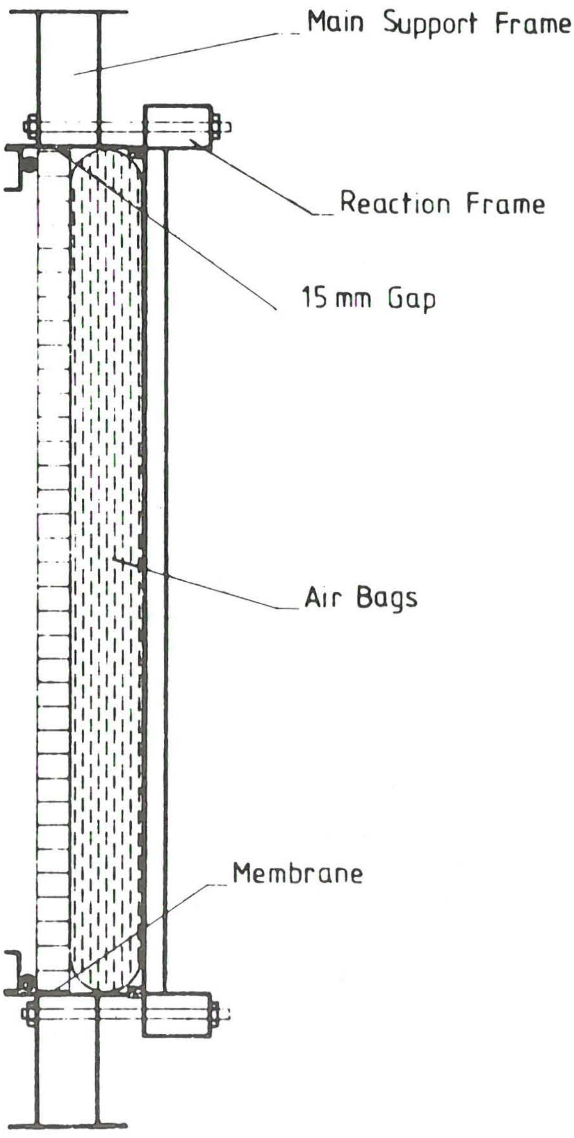

Figure 1. Cross-Section of Frame and Specimen with Simple Supports Top and Bottom

Figure 2. Specimen in Testing Frame.

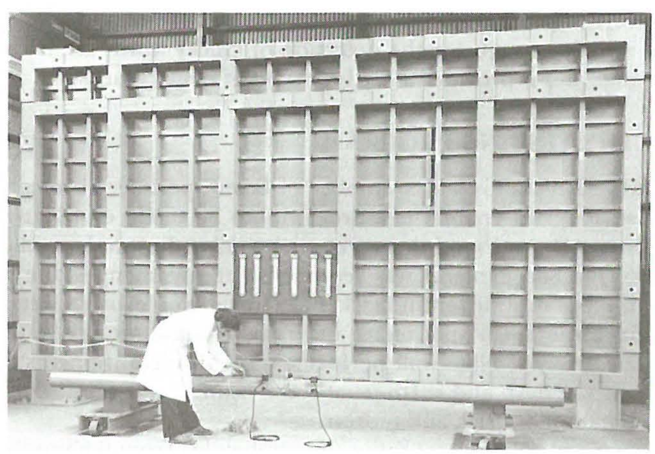

Figure 3. Rear View of Reaction Frame.

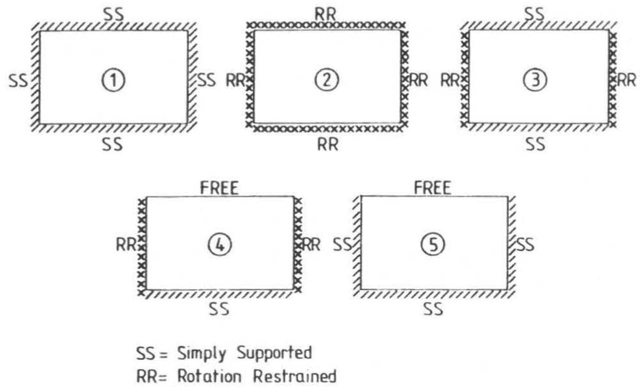

Figure 4. Support Conditions Included in the Test Program

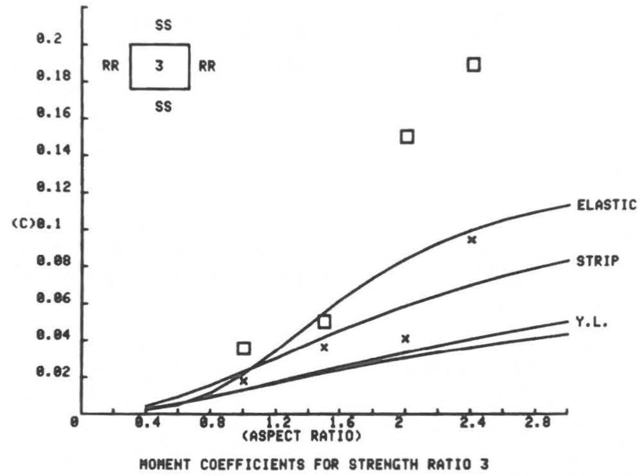

Figure 6. Comparison Between Theoretical and Experimental Moment Coefficients for Panels with Clamped Sides.

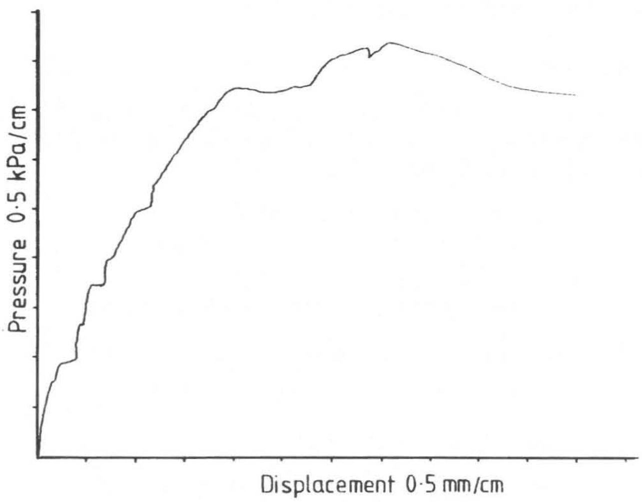

Figure 5. Typical Load-Deflection Graph

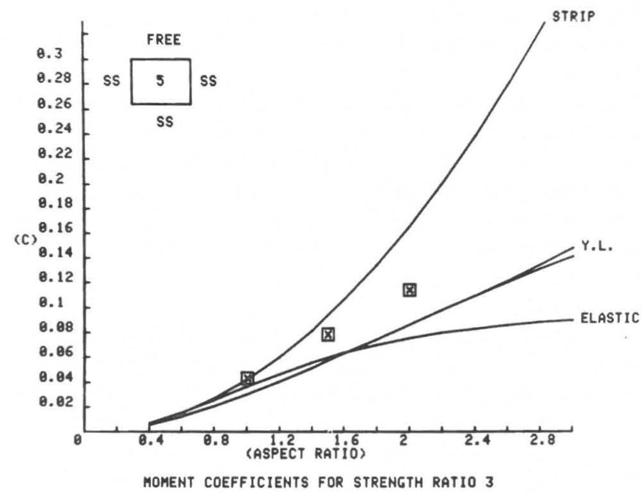

Figure 7. Comparison Between Theoretical and Experimental Moment Coefficients for Panels Free at the Top.