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FLEXURAL RIGIDITY OF CONCRETE MASONRY WALLS

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ABSTRACT

An evaluation of axial and flexural rigidities of concrete masonry walls is very important for calculations involving axial and ultimate moment capacities as well as lateral deflections. Currently approximate and empirical methods are used to evaluate these parameters and to date there is no good agreement between theoretical and experimental results. Preliminary results of effective flexural rigidities of short concrete masonry walls based on strain measurements on the surface of these walls are presented and discussed. Results indicate an exponential nature of the relationship between total applied moment and effective flexural rigidity for the heights of walls tested. Complete results of the experimental study will be published in future papers.

PREVIOUS RESEARCH

A reliable prediction of the modulus of elasticity of masonry is essential in calculations involving the axial rigidity or flexural rigidity of a section. Axial rigidity, AE, is a function of net cross-section area, A, and modulus of elasticity, E, which decreases with increasing stress. The magnitude of flexural rigidity depends on intensity and distribution of stresses on a cross-section as well as the modulus of elasticity, E, which decreases with increasing stress and the moment of inertia, I, which decreases with flexural cracking.

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An empirical expression which accounts for changes in E and I was proposed as follows (Yokel et al., 1971).

$$EI = E_o I_o [0.2 + \frac{P}{P_o}] \leq 0.7 E_o I_o \qquad [1]$$

where I_o is the moment of inertia of an uncracked net section, P is the compressive load at failure, and P_o is the axial capacity derived from prism tests with flat support conditions. This equation was proposed in a study on the capacity of brick masonry walls tested under various combinations of flexure and axial compression. The authors demonstrated that the proposed expression adequately approximates a substantial amount of test data for brick walls over a large range of vertical loads.

The accuracy of the equation for short-wall sections of brick walls, and possible application to concrete masonry, was investigated by testing eccentrically loaded short prisms (Fattal and Cattaneo., 1976). In short walls, the secondary moment, PΔ, produced by vertical load, P, acting on a transverse deflection, Δ, is negligible compared to the primary moment, Pe, where e is the eccentricity of the load. Assuming the specimen bends in constant curvature, the flexural rigidity, EI, can be derived from first principles by using a moment-curvature relationship as follow;

$$EI = \frac{Pet}{(e_1 - e_2)} \qquad [2]$$

where e_1 and e_2 designate the strains on the compression and tension faces of the specimens, P is the axial load, and e is the eccentricity of the load.

When the values of EI obtained for brick and concrete block specimens in this manner were plotted and compared to those given by equation 1, it was noted that EI values for concrete block prisms were underestimated.

The values of AE and EI for concrete masonry walls are further affected by grout and reinforcement. Previous research on reinforced concrete (MacGregor et al. 1974) shows that for load eccentricity greater than t/3, the steel may be in tension and the cracked zone may advance into a cross-section beyond the location of the steel. For this case the following empirical expression was suggested for the flexural rigidity of a reinforced concrete section (MacGregor et al., 1974).

$$EI = EI_o [0.5 - \frac{e}{t}] \geq 0.10 EI_o \qquad [3]$$

where E is modulus of elasticity of oncrete, I_o and I are the uncracked and cracked moments of inertia, e is the load eccentricity, and t is the wall thickness. To account for creep which in the long term will increase deflections and amplify the moment acting on a section, MacGregor [4] recommended the use of the following equation for evaluating the flexural rigidity of a member for design purposes:

$$(EI)_{design} = \frac{1}{1 + \beta_d} [EI] \qquad [4]$$

where β_d = ratio of dead load to live load, and [EI] is calculated from Equation 3.

From experimental evidence using lateral deflections Equation 3 was validated for all types of loading of plain and reinforced masonry walls (Hatzinikolas et al., 1978). However, the authors recommended that further research be carried out to evaluate the axial rigidity and flexural rigidity for commonly used masonry units and types of construction since data in this area were still lacking.

EXPERIMENTAL PROGRAM

To evaluate the axial and flexural rigidities of common concrete masonry walls, an extensive experimental program was initiated and is still in progress. The scope of the experimental program involves testing both plain and reinforced concrete masonry walls 800 mm wide by 1200 mm high. The parameters of interest in this study include load eccentricity (e/t), reinforcement, and slenderness ratio (h/t). A nominal slenderness ratio (h/t) of 8.5 was adopted for this experimental program. Testing of plain concrete masonry walls is complete while the reinforced walls await testing. A minimum of three specimens were tested in each case. The walls were built by an experienced mason using type S mortar and joint reinforcement was placed every second course. Two of four cores of the walls were grouted 2 to 3 days later using grout mixed in the laboratory. A uniformly graded sand and aggregate of maximum size 10 mm were used for mixing the grout. The walls were allowed to cure in the laboratory for at least 60 days before being tested in a testing frame using a hydraulic ram of capacity 1800 kN (400 kips). Samples of concrete masonry blocks, grout, and mortar were tested according to the relevant ASTM standards.

TEST SETUP AND INSTRUMENTATION

Figure 1 shows the details of the test setup. Pinned support conditions were maintained for all specimens and lubricated roller supports were used to reduce friction. A stiffened I-beam at the top was used to distribute the load from the hydraulic ram and a similar beam was used to seat the wall. To avoid disturbing the joints and possible cracking, the walls were braced with channels and lifted into place. Prior to placing, holes were drilled in the walls using a concrete drill for attaching the linear strain converters (LSCs) previously calibrated to an accuracy of 0.00001 mm.

The LSCs were fixed over specified gauge lengths across mortar joints using plastic fasteners and screws. For eccentrically loaded specimens, four LSCs were attached on the compression side and three on the tension side. A similar arrangement was maintained for axially loaded specimens. The wall was made plumb and a small axial load was applied to the wall before the temporary supports were later removed. The leads from the LSCs were connected to a data acquisition system (DAS). Gauge lengths for the LSCs were measured and recorded prior to testing. A load cell previously calibrated in pounds and connected to the DAS was used to monitor the axial load. Lateral deflection at mid-height of the wall was measured using an endless dial gauge. Axial load was steadily applied to the wall until failure. However, to avoid destruction of the instrumentation, the LSCs were removed prior to failure except in one instance when unexpected failure occurred and there was no time to remove the LSCs. In case of axially loaded specimens, compression failure was the predominant mode of failure and explosive in nature. However, for the eccentrically loaded specimens there was some bending before failing explosively.

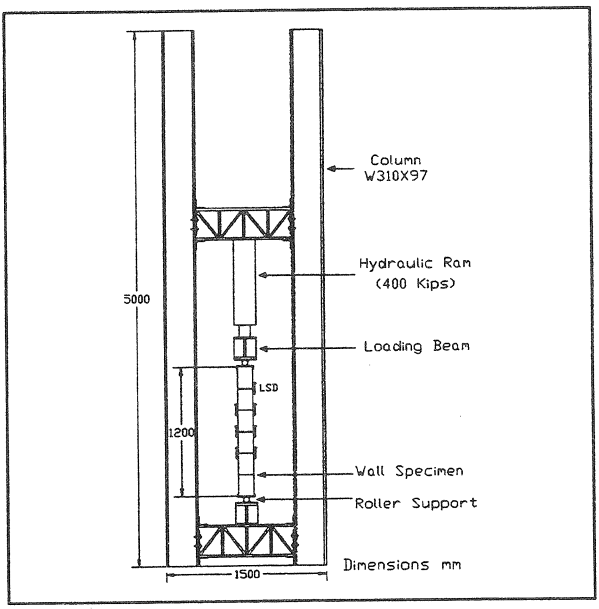

Fig. 1: Testing frame and experimental setup

TEST RESULTS AND DISCUSSION

Two-high grouted prisms.

Results of tests performed on grouted prism specimens are presented in Table 1 below. A total of ten batches was needed to grout all the 15 wall specimens. In each case a minimum of five prism specimens were prepared and tested at about the same age as the corresponding walls. Two-high grouted prisms tested with flat end conditions failed typically by compression failure. These prisms instrumented with two LSCs on either side and loaded axially were used to determine the stress-strain relationships of grouted concrete masonry up to failure load since the LSCs were not removed prior to failure.

Table 1 Grouted prism compressive strength

Batch #	Specimen Designation	Average Compressive Strength, f'_m (MPa)
1	HBGR1	18.5
2	HBGR2	18.1
3	HBGR3	19.1
4	HBGR4	19.9
5	HBGR5	19.8
6	HBGR6	19.3
7	HBGR7	18.8
8	HBGR8	18.1
9	HBGR9	18.7
10	HBGR10	17.2

Concrete Masonry Walls.

Concrete masonry walls tested in axial compression or loaded at load eccentricity of e/t=0.15 failed initially by web splitting at one end. This was followed by the crushing of two end courses and simultaneous splitting along the mortar joint at mid-point. A similar failure was observed by Yokel when he tested short prism specimens (Yokel et al., 1971). The predominant mode of failure for eccentrically loaded specimens was buckling instability. At a lateral deflection of about 5 mm(2") it was observed that the dial of the endless dial gauge started to move rapidly and the wall finally collapsed when horizontal cracks formed at mid-height of the wall.

Strength Considerations
Results of tests performed on 15 plain concrete masonry walls tested at load eccentricities e/t=0, 0.15 and 0.35 where e is the load eccentricity and t is the thickness, are presented in Table 2.

Table 1 Axial load capacities for various e/t

Spec #	# Cores Grouted	Load Ecc. (e/t)	Max. Load (kN)	Def'n at Max. Load (mm)
FLG56E01	4	0	1348	1.3
FLG67E11	4	0.15	1140	5.8
FLG45E21	4	0.35	670	8.0
2CGR3E01	2	0.0	1027	1.6
2CGR2E02	2	0.0	1115	1.5
2CGR4E03	2	0.0	1090	1.5
2CGR7E04	2	0.0	1148	1.7
Average	....	....	1095	
2CGR1E11	2	0.15	928	5.0
2CGR8E12	2	0.15	936	5.5
2CGR8E13	2	0.15	935	4.5
2CG10E14	2	0.15	823	1.6 *
Average	....	....	906	
2CG21E21	2	0.35	645	7.5
2CG10E22	2	0.35	515	6.0
2CG9E23	2	0.35	657	6.5
2CG9E24	2	0.35	659	8.0
Average	....	....	619	

1 Kip=4.448 kN, 1 in =25.4 mm; * Premature failure

In some cases it was difficult to note the lateral deflection at maximum load as the dial of the endless dial gauge was moving very rapidly.

Figures 2, 4 and 6 show graphs of axial load vs average flexural strains of compression and tension surfaces of the walls loaded at various eccentricities. Figures 3, 5 and 7 show graphs of axial load vs lateral mid-height deflections. Note the small lateral mid-height deflections for walls loaded at load eccentricity of 0.0. Figures 8 and 9 show the plots of effective flexural rigidity vs total applied moment for walls loaded at eccentricities $e/t=0.15$ and 0.35 respectively. The effective flexural rigidities were calculated from Equation 2 using surface strains on the walls but modified to account for lateral mid-height deflections. Thus the total load eccentricity, e, was replaced with $e + \delta$, where δ is the lateral mid-height deflection at an axial load P.

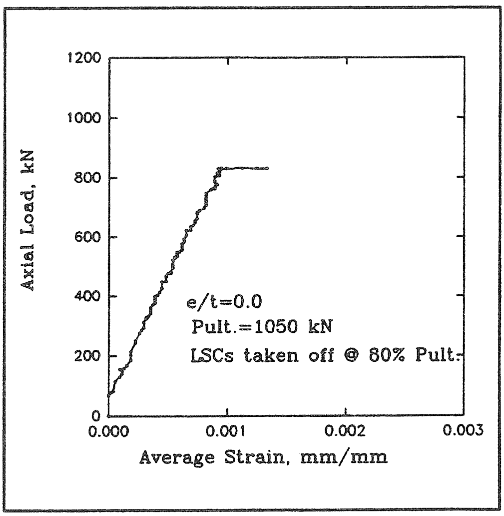

Fig. 2: Axial load vs average vertical strains, $e/t=0.0$

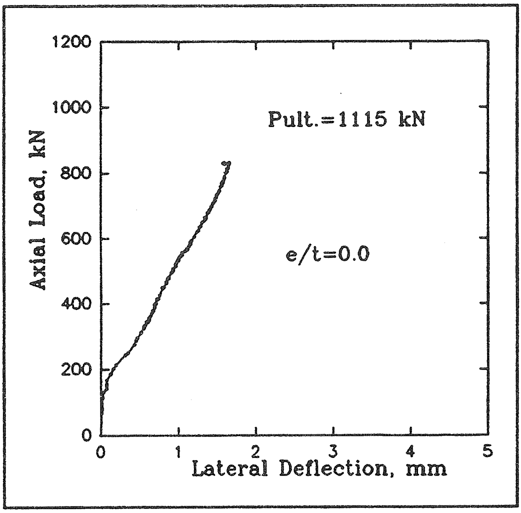

Fig. 3: Axial load vs mid-height lateral deflection, e/t=0.0

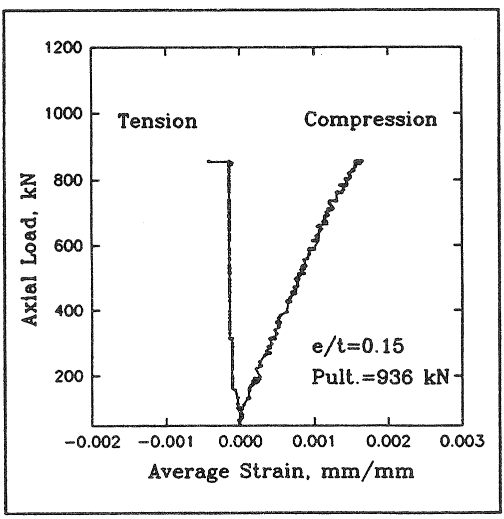

Fig. 4: Axial load vs average flexural strains, e/t=0.15

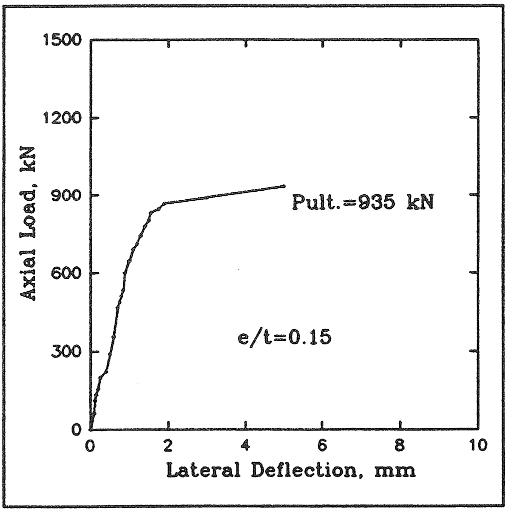

Fig. 5: Axial load vs mid-height lateral deflection, e/t=0.15

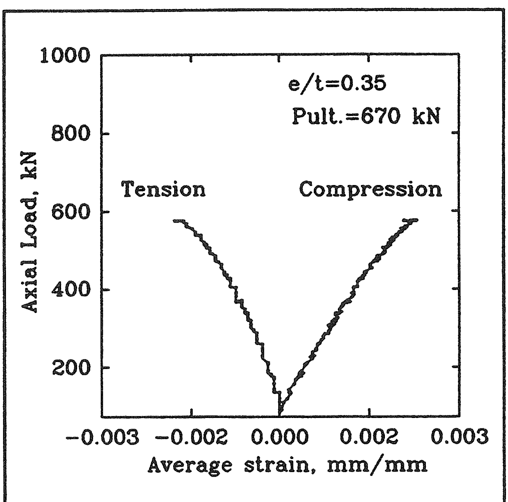

Fig. 6: Axial load vs average flexural strains, e/t=0.35

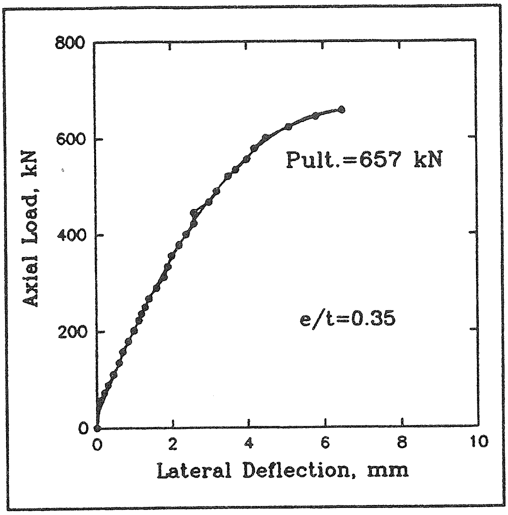

Fig. 7: Axial load vs mid-height lateral deflection, e/t=0.35

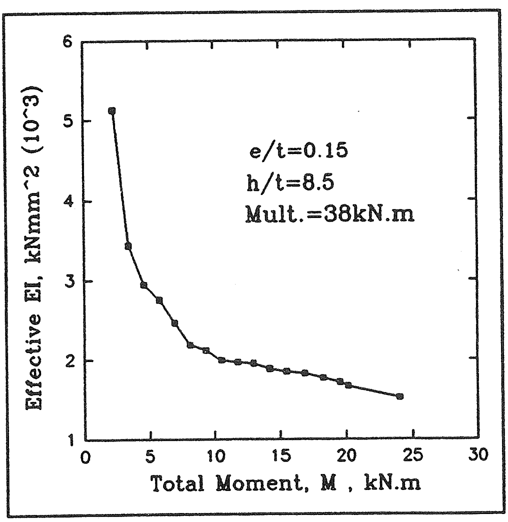

Fig. 8: Effective EI vs total moment, M, e/t=0.15

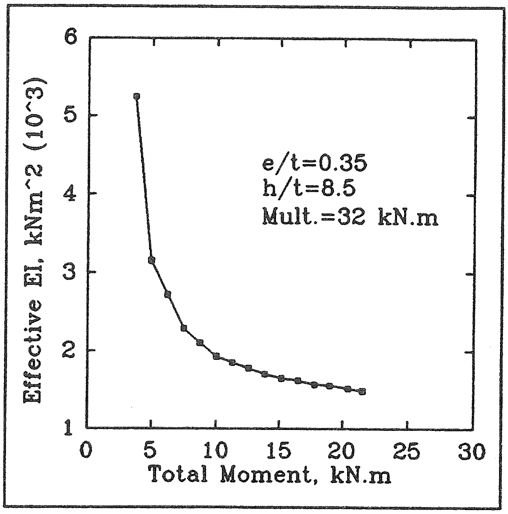

Fig. 9: Axial load vs effective EI, e/t=0.35

DISCUSSION

Prism compressive strengths indicated little variation in strength for different grout batches. This was reflected in the ultimate axial capacities of group walls tested at load eccentricities e/t=0.0, 0.15, and 0.35. A closer observation showed that within each group the standard deviation of axial load capacities was small.

Results of strain measurements along the entire height of the walls showed little variation in magnitude at different levels except near the supports where the strains were found to be slightly higher. These readings were left out when averaging the strains on the compression and tension surfaces for use in Equation 2. These higher strains can be attributed to end effects.

Preliminary results show that strain measurements on the surface of short walls can be used to determine the effective flexural rigidity of concrete masonry walls loaded at various load eccentricities. Results also show that the relationship between the effective flexural rigidity and total applied moment tends to be exponential in nature. Complete results of the study will be published in future paper.

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COMPRESSIVE STRENGTH OF TUFF BRICKS IN DIFFERENT TEST CONDITIONS. FINAL RESULTS

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ABSTRACT

This paper is the final part of an experimental research program aimed at collecting information about the most used masonry stone in the Neapolitan area, the yellow tuff. The influence of shape, dimentions, moisture, friction between testing machine platen and specimens on the compressive strength is investigated. The results of the analysis is presented both graphically and numerically.

INTRODUCTION

Yellow tuff has been an important building material for hundreds of years, in the Neapolitan area, thus a large part of architectural heritage of the region consists of this natural stone masonry building. In spite of the great interest in restoration of ancient building, there is a great lack of data about the mechanical characteristics together with the lack of standardized testing methodology, so the few available data are not always useful. Hence, the accuracy and consistency with which the mechanical properties are determined is significant, so reliable testing procedures are required together with experimental data.

This paper deals with the results of a large number of tests, performed on cylindrical, prismatic and cubic specimens in different moisture and restraint conditions. In order to collect information about yellow tuff mechanical properties, which vary from quarry to quarry, the results of a large number of compressive tests performed on tuff specimens taken from two different quarries are presented.

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