AN INITIAL INVESTIGATION OF THE SHAPE FACTOR PLATEN EFFECTS WHEN TESTING MASONRY UNITS TO DETERMINE THE MATERIAL COMPRESSIVE STRENGTH

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Synopsis

This paper describes work undertaken by the Brick Development Association at Imperial College, London to investigate the way in which the platen of the testing machine affects the strength of differently-shaped units manufactured from the same intrinsic material.

The published draft Eurocode No.6 relates the characteristic compressive strength of masonry to the strength of the mortar and the normalised strength of the masonry unit. In turn, the normalised strength of the unit is related to the crushing strength of that unit (as determined by draft CEN standards applicable at the time of writing) by a shape factor.

This paper describes a programme of work in which British Standard clay bricks and calcium silicate bricks were tested in the laboratory to determine their relevant physical parameters. These parameters were then used in a non-linear finite-element (FE) analysis to establish the shape factor effect due solely to the restraint provided by the platens of the testing machine, acting on that particular shape of unit. The analysis was carried out for many shapes.

The paper describes the concept of shape factors, the laboratory work undertaken, and the results. It contains two tables of shape factors, one for each material, which were generated by applying non-linear numerical analysis to the problem assuming the physical parameters established by the laboratory work.

Introduction

EC6 (1) proposes an expression for the characteristic compressive strength for masonry in which one of the terms is the normalised strength of the unit. The normalised strength is an 'index' value and relates the strength of the unit to the strength of a 200mm cube unit which is made of the same material. This is, of course, an arbitrary size since the normalised strength of differently-shaped units can be referenced to any size of unit; the choice of the size of unit could vary and indeed, a 100mm cube is now being discussed as the reference size. The normalised strength, say f_b, is found by multiplying the strength of the unit determined by tests, say f'_b, by a simple geometric shape factor, say delta, such that:-

$$f_b = \delta \times f'_b$$

where δ is a multiplying factor to allow for the dimensions of the masonry. (In addition to δ, a 'wet to dry' conversion factor is applicable when the strength test has been performed on wet bricks.)

The shape factor δ is given in Table B of the Preface to EC6 (1). The values, as published, range from 0.54 through to 1.5 with a shape factor of 1 for a unit with a height and width of 200mm.

The purpose of the investigation was to determine values for δ for a broadly similar range of shapes to those published in EC6 and for two common brick materials. A clay brick and a calcium silicate brick were used, both being solid, without frog or perforation.

Approach adopted

The approach was based on a non-linear FE analysis capable of simulating the various shapes to be investigated. In this analysis the loaded surfaces of the unit were assumed to be completely restrained against horizontal movement by assuming full friction at the platen/unit interface. It was first necessary to establish the strength and deformation characteristics of the two materials in order to input these parameters into the computer simulation. These values were determined by tests in the laboratory.

Material testing

It is difficult to introduce compressive stress into a unit of material without introducing frictional stresses at the loaded ends, usually from the steel platens of the testing machine or some form of packing introduced to accommodate irregularities in the unit. Hilsdorf (2) attempted this but it is not the easiest of routine tests and an alternative approach was sought. When the test piece used is between 2.0 and 2.5 times as high as its least horizontal dimension, such end effects become of secondary importance and may be neglected with little loss of accuracy. Cylinders or prisms of height to thickness ratio of 2:1 were cut from the two brick types. The specimens conformed to one of two sizes; they were either 25mm x 25mm x 50mm or 40mm x 40mm x 80mm. Some of the test specimens were cut perpendicular and some were cut parallel to the bedface. Both end surfaces of the specimen 'coupons' were machined plain and parallel to each other and normal to the major axis of the specimen. In the testing machine, the axis of the specimen was located as near as possible to the centre of the platen. The machine had a spherical seat. The testing arrangement of the brick coupon is shown in Fig.1.

From such standard test, the uniaxial strength of the material, f_c, as well as the axial and transverse strains (and hence Young's moduli and Poisson's ratios) at various load levels were found.

Typical results for the clay material are shown in Fig.2. All the available twelve stress/strain curves are shown. (Note that the axial (compressive) strain appears on the negative axis, the lateral (tensile) strain on the positive one.) The non linear behaviour is clearly seen as is the range of scatter of the results. The material was modelled using mean values of the stress/strain curve and the Poisson's ratio at the appropriate stress levels. Although the scatter from the twelve tests was found to be significantly greater, the non-linear behaviour of the material and the failure mechanism were found to be similar to that exhibited by concrete. Indeed, the appearance of the brick coupons after failure is very similar to that of failed concrete specimens. The mean strength values for the vertical and horizontal

It is interesting to note that the scatter in failure loads for the brick units tested was of the order of 5% (clay unit) and 14% (calcium silicate); such scatter is noticeably smaller than that usually encountered in brick tests, where the typical scatter is of the order of 14-21%.

Structural (FE) modelling

The data defining the material properties obtained in the laboratory was fed into a FE model for brittle materials. The three dimensional (3-D) FE used is the well known 20-node isoparametric element with parabolic interpolation functions. Although full use of the symmetry of the brick unit permits the analysis of only 1/8th of the structure, it was deemed to be conceptually easier to model the full width, T, of the brick while making use of the other two planes of symmetry, thus using a height of H/2 and length of L/2. In this way ¼ of the brick was always considered. This 3-D FE model has been used extensively to study concrete structures (3).

Following an initial parametric study, it was found that a load step of the order of 10% of the ultimate load was sufficiently accurate and that there was little difference between the 2-element and 1-element mesh. It was therefore decided to use a single element representing ¼ of the brick unit as being an adequate representation taking into account the excellent performance of the 3-D isoparametric element. The adoption of under-integration offers both computational economy and precision and this gives 2 x 2 x 2 = 8 Gauss points that provide a sensible number of stations at which stress variations within the ¼ brick structure can be evaluated. The modelling of full frictional restraint by the platens took the normal form of specifying that all nodes on the top surface of the element are constrained to zero horizontal deflection in both the x and y directions.

This model was used throughout the work for all the differently-shaped units.

Results

Table 1 shows the range of different shapes investigated and the effect of the shape on the predicted applied failure stress: this is shown for both materials examined. Three values of ultimate failure stress were investigated for each material. This was done because of the wide scatter of results and, more importantly, to investigate the significance of this parameter (f_c). The table contains results for both these extra values of f_c, one higher than the coupon mean and one lower.

Table 2 shows the theoretical shape factors emerging from this work, again for the corresponding variations in the relevant parameters. They have been adjusted assuming that the "unity" shape factor is associated with the 215 x 200 x 200 size.

Discussion of the results

It can be seen from the results contained in Tables 1 and 2 that although there is an effect when altering the height of the unit, H, there is no effect when adjusting the width or thickness of the unit, T. Thickness of the unit, therefore, does not appear to be a parameter. All the shapes investigated have been based on a length of unit, L, of 215mm. If the width dimension has no effect, by inference, there can be no length dimension effect either. This suggests that, instead of there being a platen shape effect, there is only a platen size effect. Indeed it is the height of the unit alone which has influence.

It is interesting to note that there are differences between the two materials. The size effect for calcium silicate material is different from that found for clay. It is also important to note that the effects tend to be small, of the order of 10% to 15%, depending on both the material and height of unit being tested. Significantly, such percentages are of the order of magnitude of experimental scatter in brick-unit tests.

Conclusions

From this limited study investigating the effect of the platens on the strength of differently-shaped units made of the same intrinsic material, the following tentative conclusions can be drawn:-

1. The width of the unit appears to have no effect: the critical dimension is height.
2. If the width has no effect, there should be no length effect either.
3. The shape-factor effect is therefore more a size factor effect, or more correctly, it is essentially a height of unit effect.
4. The different size factors found for units made of fired clay were different to those found for units manufactured from the calcium silicate material. It is reasonable to expect the size factor to be dependent on the material (as defined by its strength, say).
5. The size factor was found to vary within the scatter normally associated with the testing of masonry units.
6. The variation due to experimental scatter was found to be smaller than expected.
7. The magnitude of the platen-induced size-factor effect is of the order of 10% to 15%, the size factor for the clay material being less than that for calcium silicate.

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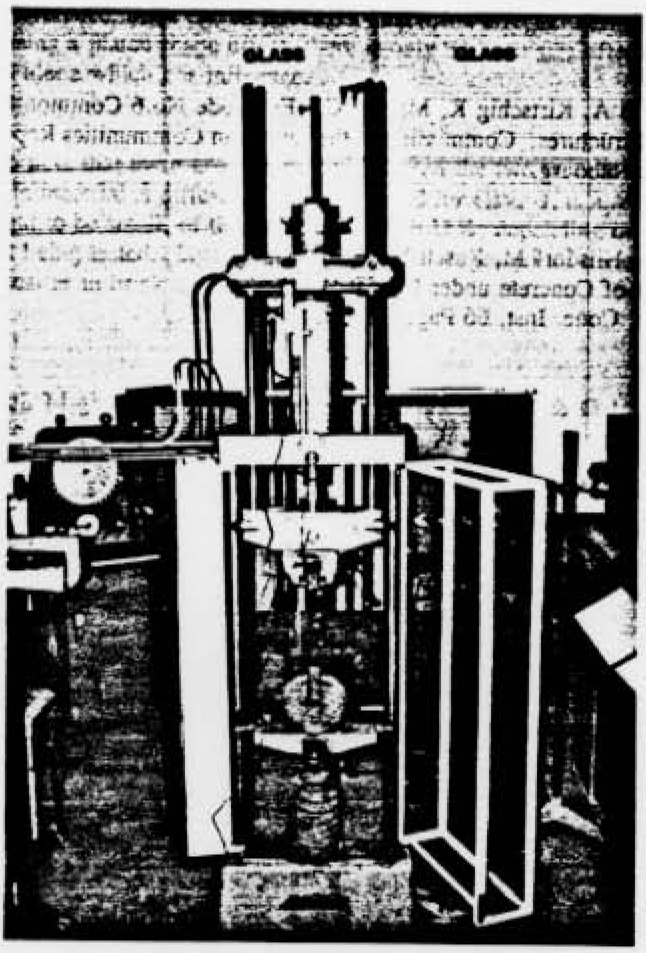

Figure 1. Material test set-up.

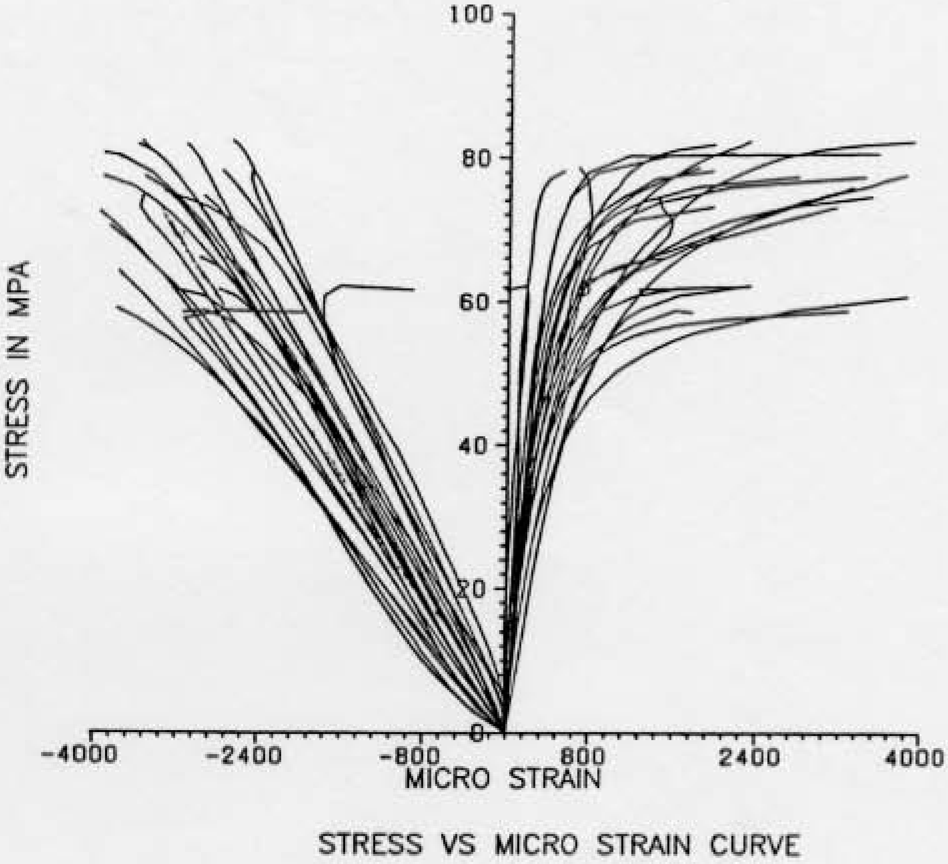

Figure 2. Typical stress-strain characteristics for the clay material units.

Table 1. Numerical results of the parametric study in terms of applied stress at failure.

			CLAY UNIT MATERIAL			CALCIUM SILICATE MATERIAL		
L	T	H	failure stress	failure stress	failure stress	failure stress	failure stress	failure stress
mm	mm	mm	when fc=50 MPa	when fc=69 MPa	when fc= 87 MPa	when fc= 15 MPa	when fc=22 MPa	when fc=28 MPa
215	65	65	60	78	90	18	26	32
215	100	65	60	78	90	18	26	32
215	150	65	60	78	90	18	26	32
215	200	65	60	78	90	18	26	32
215	240	65	60	78	90	18	26	32
215	65	100	60	78	90	18	26	32
215	100	100	60	78	90	18	26	32
215	150	100	60	78	90	18	26	32
215	200	100	60	78	90	18	26	32
215	240	100	60	78	90	18	26	32
215	65	150	54	72	90	16	24	30
215	100	150	54	72	90	16	24	30
215	150	150	54	72	90	16	24	30
215	200	150	54	72	90	16	24	30
215	240	150	54	72	90	16	24	30
215	65	200	54	72	90	16	22	28
215	100	200	54	72	90	16	22	28
215	150	200	54	72	90	16	22	28
215	200	200	54	72	90	16	22	28
215	240	200	54	72	90	16	22	28
215	65	240	(48)	72	90	16	22	28
215	100	240	(48)	72	90	16	22	28
215	150	240	(48)	72	90	16	22	28
215	200	240	(48)	72	90	16	22	28
215	240	240	(48)	72	90	16	22	28

( ) : These values were obtained in the analysis but are considered to be underestimates due to early numerical instability.

Table 2. Theoretical shape factors δ.

			CLAY MATERIAL			CALCIUM SILICATE MATERIAL		
L	T	H	shape factor	shape factor	shape factor	shape factor	shape factor	shape factor
mm	mm	mm	when fc=50 MPa	when fc=69 MPa	when fc= 87 MPa	when fc= 15 MPa	when fc=22 MPa	when fc=28 MPa
215	65	65	0.9	0.92	1	0.89	0.85	0.88
215	100	65	0.9	0.92	1	0.89	0.85	0.88
215	150	65	0.9	0.92	1	0.89	0.85	0.88
215	200	65	0.9	0.92	1	0.89	0.85	0.88
215	240	65	0.9	0.92	1	0.89	0.85	0.88
215	65	100	0.9	0.92	1	0.89	0.85	0.88
215	100	100	0.9	0.92	1	0.89	0.85	0.88
215	150	100	0.9	0.92	1	0.89	0.85	0.88
215	200	100	0.9	0.92	1	0.89	0.85	0.88
215	240	100	0.9	0.92	1	0.89	0.85	0.88
215	65	150	1	1	1	1	0.92	0.93
215	100	150	1	1	1	1	0.92	0.93
215	150	150	1	1	1	1	0.92	0.93
215	200	150	1	1	1	1	0.92	0.93
215	240	150	1	1	1	1	0.92	0.93
215	65	200	1	1	1	1	1	1
215	100	200	1	1	1	1	1	1
215	150	200	1	1	1	1	1	1
215	200	200	1	1	1	1	1	1
215	240	200	1	1	1	1	1	1
215	65	240	(1.13)	1	1	1	1	1
215	100	240	(1.13)	1	1	1	1	1
215	150	240	(1.13)	1	1	1	1	1
215	200	240	(1.13)	1	1	1	1	1
215	240	240	(1.13)	1	1	1	1	1

( ) : These values were obtained in the analysis but are believed to be subject to early numerical instability : the correct values are likely to be closer to 1.0.