EXPERIMENTAL COMPRESSIVE STRENGTH AND MODULUS OF ELASTICITY OF MASONRY

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Abstract: Compressive strength and Modulus of elasticity of masonry are significant parameters when considering structural masonry design. This paper presents those masonry properties which were determined experimentally. Three types specimens made of clay brick masonry and concrete block masonry were built. They were tested in compression until failure and conducted in accordance with the BS EN 1052-1:1999. Properties of structural units and the mortar were also determined. Results show that the mean compressive strength of the mortar, clay brick units and concrete block units are 4.2 N/mm^2, 63.0 N/mm^2 and 12.8 N/mm^2 respectively. The characteristic compressive strength of masonry made of clay brick is 11.2 N/mm^2 and that made of concrete block is 7.2 N/mm^2. The failure of the masonry tested in compression was due to development of tensile cracks parallel to the axis of the loading. Modulus of elasticity of masonry was close to 1000 f_k which is a formula given in Eurocode 6.

Keywords: clay brick, concrete block, mortar, masonry, compressive strength, modulus of elasticity.

KUAT TEKAN DAN MODULUS ELASTISITAS HASIL EKSPERIMEN DARI MASONRY

Abstrak: Kuat tekan dan modulus elastisitas dari *masonry* merupakan parameter penting yang diperlukan ketika mempertimbangkan rancangan struktur dari *masonry*. Tulisan ini akan mempresentasikan properti dari *masonry* tersebut yang ditentukan dengan melakukan eksperimen. Tiga jenis spesimen yang terbuat dari *masonry* dengan batubata dan *masonry* dengan batako dibuat. Specimen tersebut dites dengan memberikan beban tekan merata sampai runtuh dan mengikuti prosedur yang diberikan dalam peraturan BS EN 1052-1:1999. Properti dari batako, batubata dan spesi juga ditentukan dengan percobaan di laboratorium. Hasil percobaan memperlihatkan bahwa rata-rata kuat tekan dari spesi, batubata dan batako berturut-turut adalah 4.2 N/mm^2, 63.0 N/mm^2 dan 12.8 N/mm^2. Kuat tekan karakteristik dari *masonry* dengan batu bata adalah 11.2 N/mm^2 dan *masonry* dengan batako adalah 7.2 N/mm^2. Keruntuhan dari *masonry* akibat diberikan beban tekan merata adalah karena timbul dan berkembangnya sejumlah *tensile crack* yang arahnya sejajar dengan arah pembebanan. Modulus elastisitas dari masonry diperoleh adalah mendekati 1000 f_k yang mana merupakan rumus yang diberikan di Standar Eropa .

Kata kunci: batubata, batako, spesi, masonry, kuat tekan, modulus elastisitas.

INTRODUCTION

Masonry can be regarded as an assemblage of structural units which are bonded together in a particular pattern by mortar or grout. It is well known as being strong in compression but weak in tension. It can however be reinforced to carry tensile stresses or prestressed to eliminate them.

Parameters which are most significant when considering structural masonry design relate to strength and elastic properties; e.g. compressive strength, flexural strength, shear strength, modulus elasticity, coefficient of friction, creep, moisture moment and thermal expansion. Tensile strength is generally ignored in masonry.

Compressive strength of masonry is dependent on numerous factors such as mortar strength, unit strength, relative value of units and mortar strength, aspect ratio of the units (ratio of height to least horizontal dimension), and orientation of the units in relation to the direction of the applied load. Those factors give indications of the complexity of making an accurate assessment of masonry strength. However in the lack of data BS 5628: Part 1: 1992 gives values of structural unit strengths and masonry strengths. These values are derived from research data carried out on individual units, small wall units (wallettes) and full scale testing of storey height walls.

BS 5628 Part 2 (2000) has given the values of compressive strength of masonry which are dependent on the strength of the structural units and mortar in the absent of relevant test data. Eurocode 6 (1996) has also proposed a formula for calculation of the characteristic compressive strengths of masonry which are dependent on the normalised compressive strength of masonry units and the mean compressive strength of mortar.

This paper presents modulus of elasticity and compressive strength of masonry with structural units of clay brick and concrete block determined experimentally. These material properties of masonry were applied for modelling dynamic behaviour of post-tensioned masonry column studied by Budiwati (2007)

LITERATURE REVIEW

Masonry units

Masonry units form the main part of masonry. Units are produced from clay, concrete and calcium silicate. All units have broadly similar uses although their properties differ depending on the raw materials and the method of manufacture. The selection of a particular type of unit for any given structure is also dependent on strength, durability, adhesion, fire resistance, thermal properties, acoustic properties and aesthetics.

Bricks and blocks are produced in many formats: solid, perforated, and hollow. Clay bricks are obtainable in strength up to 100 N/mm^2 but much lower strength 20-40 N/mm^2 are generally sufficient for domestic building and for cladding for taller building. Where no recent test certificates are available, tests may be carried out to demonstrate that the units satisfy the engineering requirements.

The specifications for the sizes of clay brick and precast concrete masonry units (concrete block masonry) are given in BS 3921:1985 and BS 6073 Part 1: 1981 respectively. The standard work sizes for individual clay brick units are 215 mm length x 102.5 mm width x 65 mm height. Many varieties are available for the sizes of concrete block masonry.

Mortar

The primary purpose of mortar in masonry is to bond masonry units into an assemblage, which acts as an integral element having particular functional performance characteristics. Its properties such as compressive strength, flexural strength, Elastic Young's Modulus and Poisson's Ratio are all important in determining the strength and quality of masonry. The modern mortar constituents are cement, lime, sand and water in specified proportions.

The British Standard of Masonry, BS 5628 Part 1 defines four types of structural mortar which are named as given designations (i), (ii), (iii) and (iv). Varying the percentages of the components used to make the mortar produces the different types of mortar. The strength of mortar depends on the proportions of cement and lime in addition to the water/cement ratio used in making it.

Of the four structural mortars, designation (i) is the strongest, designation (iv) is the weakest, with designations (ii) and (iii) having intermediate strength. The standard specifies mortar type by volume and gives the mean compressive strength at 28 days as shown in the Table 1. Designations given have been selected to provide the most suitable mortar which will be readily workable to enable the production of satisfactory work at an economic rate and provide adequate durability.

Table 1. BS 5628 Mortar Compressive Strength

Mortar designation	Types of mortar (proportion by volume)			Mean Compressive Strength at 28 days (N/mm^2)	
	Cement: Lime: Sand	Masonry Cement: Sand	Cement:Sand with plasticizer	Preliminary (Laboratory tests)	Site Test
(i)	1 : 0to1/4 : 3	-	1:3	16.0	11.0
(ii)	1 : 1/2 : 4to41/2	1 : 21/2to31/2	1:3to4	6.5	4.5
(iii)	1 : 1 : 5to6	1:4to5	1:5to6	3.6	2.5
(iv)	1 : 2 : 8to9	1:51/2to61/2	1:7to8	1.5	1.0

Various mortar properties such as workability, water rentitivy, bond strength and compressive strength have influences on the performance of masonry. Those properties vary with mortar type therefore it is important to select the proper mortar types for each particular application.

Material Properties of Masonry

Compressive strength values of masonry with different unit compressive strength and any known combination of mortal designation are given in BS 5628 Part 1: 1992. The tabulated values which can be seen in Table 2 are intended for use with masonry in which the structural units are laid on their normal bed faces in the attitude in which their compressive strength are determined and in which they are normally loaded. Linear interpolation within the tables is permitted. Variations to this can be accommodated and testing procedures are specified in Appendix A of the standard. The desired compressive strength of units and the mortar designation is normally specified by the designer.

Table 2. Characteristic compressive strength of masonry

Characteristic compressive strength of masonry, f_k in N/mm^2									
a. Constructed with standard format bricks									
Mortar designation	Compressive strength of unit (N/mm^2)								
	5	10	15	20	27.5	35	50	70	100
(i)	2.5	4.4	6.0	7.4	9.2	11.4	15.0	19.2	24.0
(ii)	2.5	4.2	5.3	6.4	7.9	9.4	12.2	15.1	18.2
(iii)	2.5	4.1	5.0	5.8	7.1	8.5	10.6	13.1	15.5
(iv)	2.5	3.5	4.4	5.2	6.2	7.3	9.0	10.8	12.7
b. Constructed with solid concrete blocks having a ratio of height to least horizontal dimension of between 2.0 and 4.0									
Mortar designation	Compressive strength of unit (N/mm^2)								
	2.8	3.3	5.0	7.0	10	15	20	35 or greater	
(i)	2.8	3.3	5.0	6.8	8.8	12.0	14.8	22.8	
(ii)	2.8	3.3	5.0	6.4	8.4	10.6	12.8	18.8	
(iii)	2.8	3.3	5.0	6.4	8.2	10.0	11.6	17.0	
(iv)	2.8	3.3	4.4	5.6	7.0	8.8	10.4	14.6	

A method for determining the compressive strength of masonry is specified in British European Standard BS EN 1052-1:1999. The compressive strength of masonry perpendicular to the bed joints is derived from the strength of small masonry specimens, tested to destruction. The materials, construction and bonding pattern are required to correspond to those used in practice.

In the experiment, the specimens are loaded uniformly in compression. The maximum load (*F_{max}*) achieved is recorded. The characteristic compressive strength of masonry is derived from the strengths of the individual specimens and calculated to the nearest 0.1 N/mm^2 using the following formula:

$$f_i = \frac{F_{i,\max}}{A_i} \quad \text{N/mm}^2 \ldots\ldots\ldots\ldots\ldots\ldots..(1)$$

A_i is the loaded cross-section of an individual masonry specimen, (mm^2).

Minimum three specimens are used in testing the compressive strength of masonry. The sizes given in the standard can be seen in Table 3.

Table 3. Small specimen sizes for testing the compressive strength of masonry

Face size of unit		Masonry specimen size			
l_u (mm)	h_u (mm)	Length l_s	Height h_s		Thickness t_s
≤ 300	≤ 150	≥ (2 x l_u)	≥ 5 h_u	≥ 3 t_s and ≤ 15 ts and ≥ l_s	≥ t_u
	> 150		≥ 3 h_u		
> 300	≤ 150	≥ (1.5 x l_u)	≥ 5 h_u		
	> 150		≥ 3 h_u		

Note.

(l_u), (h_u) and (t_u) is the length, the height and the width of the masonry unit respectively. (l_s) (h_s) (t_s) is the length, the height and the thickness of the specimen respectively.

The characteristic compressive strength of masonry is calculated to the nearest 0.1 N/mm^2 using the following formula (whichever is the smaller):

$$f_k = f/1.2 \text{ or } f_k = f_{i,\min} \text{ N/mm}^2 \ldots\ldots (2)$$

According to Hendry et al. (2004) some points have been derived from the compressive test on masonry such as the compressive strength of masonry is smaller than the nominal strength of the unit in a compression test and may greatly exceed the crushing strength of mortar. Analysis of test results shows that the compressive strength of masonry varies roughly as the square root of the unit strength and as the third or fourth root of the mortar cube strength.

To determine the modulus of elasticity, the masonry specimens are fitted with measuring devices in order to measure the change in height. Two devices are fitted on each side of the length of the specimen with the distance of the half length. The displacements are measured whilst applying the compressive force continuously where the maximum force is attained after 25 min to 30 min. The modulus of elasticity E_i is calculated as a secant modulus from the mean of the strains of all four measuring positions occurring at a stress equal to one third of the maximum stress archived.

$$E_i = \frac{F_{i,\max}}{3 \times \varepsilon_i \times A_i} \text{ N/mm}^2 \ldots\ldots\ldots\ldots\ldots\ldots(3)$$

The individual and mean values for the modulus of elasticity in N/mm^2 are calculated to the nearest 100 N/mm^2.

BS 5628 (2000) and Eurocode 6 (1996) use the characteristic strength of masonry f_k which is dependent on the masonry units and mortar strength, as the basis for determining modulus of elasticity of masonry in the absence of relevant test data. The respective equations for BS 5628 and Eurocode 6 for E_m are:

$$E_m = 900 f_k \quad \text{N/mm}^2 \ldots\ldots\ldots\ldots\ldots\ldots..(4)$$

$$E_m = 1000 f_k \quad \text{N/mm}^2 \ldots\ldots\ldots\ldots\ldots\ldots...(5)$$

METHODOLOGY

Masonry units

Compressive strengths of the class B engineering clay bricks and the dense aggregate solid concrete blocks were determined. The clay bricks, three cores with a nominal size of 215 x 102.5 x 65 mm, were tested for conformity with BS 3921:1985. Ten bricks randomly selected from each batch of bricks were tested for determining compressive strength. The bricks were immersed in a water tank for 24 hours before testing. Each brick was placed between two 4 mm thick plywood sheets in the testing machine and tested with a loading rate of 35 N/mm^2/min until failure.

Compressive strengths of the dense aggregate solid concrete blocks with nominal dimension of 440 x 100 x 215 mm were tested in accordance with BS 6073-1:1981. The concrete blocks were immersed in a water tank for about 16 hours before capping with 5 mm mortar consisting of 1:1 ordinary cement: sand mixed by mass. The concrete blocks were covered with damp cloths for at least 16 hours after their first face were capped. Three cubes of mortar from the capping mixes were taken to determine the capping compressive strength. The concrete blocks were immersed in the water after capping the second face. Compressive tests of the concrete block were then carried out after the mortar cubes reached the compressive strength greater than 28 N/mm^2 usually three days after casting. The rate of the applied load was 10 N/mm^2/min.

Mortar

Mortar used to build the prisms was a designation (iii) mortar mixed with a ratio 1:1:6 of cement:lime:sand, batched by volume. Tilcon ready mixed lime-sand was used. A sufficient amount of water was added to produce a workable consistency as a designation (iii) mortar. Three 100 x 100 mm mortar cubes were cast for every batch made. Compressive strength of the mortar was determined in accordance with BS 4551: Part 1: 1998. Mortar cubes were immersed in a water tank until being tested in an Amsler Testing Machine. Load was applied at the rate of 1 N/mm^2/min.

Masonry prism

Material properties of the two types of masonry were determined during the experimental work using prisms. BS EN 1052-1:1999 recommendations were followed for constructing and curing the specimens.

Experiments were carried out to determine the moduli of elasticity of the types of masonry used in the tests using small masonry specimen (prisms). Six prisms, three rectangular wallettes and three square hollows, were built for clay brick masonry and three prisms (rectangular wallettes) for concrete block masonry. The prisms were tested in compression in accordance with BS EN 1052-1:1999 and during the compressive test the strain occurred were recorded where the results later were used to calculate modulus of elasticity of masonry.

Wallettes dimensions, 3 blocks high and 1½ block wide for block (670x100x685 mm) and 7 bricks high and 2 bricks wide (440x102.5x535 mm) for clay bricks, complied with British Standard requirements, Figures 1-3. British Standard BS5628-2:2000 recommends that the determination of characteristic strength of brick masonry can be obtained using specimens that should be built in the same attitude as they would be on site and the ratio of height to thickness of the specimens should preferably be five but not less than two. Following the British Standard recommendations, square hollow prisms (328x328x385 mm outer and 123x123x385 mm inner)) with the ratio of height to thickness equal to 1.17 were built to study the difference between their properties to those of rectangular wallettes.

The preparation, building, curing, test procedure and calculation of the results were in accordance with BS EN 1052-1. Before building the prisms, polythene sheets were laid onto steel plates, which were supported by concrete blocks on the laboratory floor. The plates were horizontally levelled. All the bricks used to build the test specimens were brought to the laboratory for about one month before building started by the same mason.

The units were laid on the prepared surface by normal brick laying techniques. The mortar was batched by volume and its consistency was gauged by the mason to be suitable for use with the bricks or blocks. The thickness of mortar joint was kept 10 mm. Each test group was built in a day. Prior to laying, the bricks were immersed in water in order to reduce suction of the mortar. The prisms were capped on the same day of their building on both bottom and top surfaces with the same mortar used for their construction. The top cap was formed by mean of glass plate of 6 mm thickness.

On completion of building, the prism specimens were cured under polythene sheets for three days and then they were left uncovered in the laboratory conditions for the remaining period. Special care was taken when the prism specimens were transported to the testing machine.

The prisms were tested when they were at least 28 days of age in an Avery Test Machine under load control. Prior to testing the capped faces of each prism specimen were brushed clean. The specimen was then position in the testing machine. The loading platen was adjusted until contact was made with the specimen and testing began. The load was applied at a steady rate such that it should take 15 to 30 minutes for prisms to fail. To measure strains in the prisms four electrical linear potentiometers (linpots) were mounted on the prism. For rectangular wallettes two linpots were mounted on each of its wide faces and for square hollow the four linpots were equally distributed on each of its sides, Figures 1, 2 and 3.

An Orion data logger was used to record strain measurements and applied loads. The readings were monitored and stored in a desktop PC where they were later saved onto magnetic disks. The average strain reading was used to calculate the modulus of elasticity. The modulus of elasticity was calculated as a secant modulus from the average of strains at a stress equal to one third of the maximum stress achieved during the test.

Figures 1 and 2 show typical rectangular wallettes and typical square hollow of the clay brick prisms respectively before and after testing. Typical concrete block wallettes before and after testing are shown in Figure 3.

Figure 1. Typical rectangular wallettes of clay brick prisms before and after testing

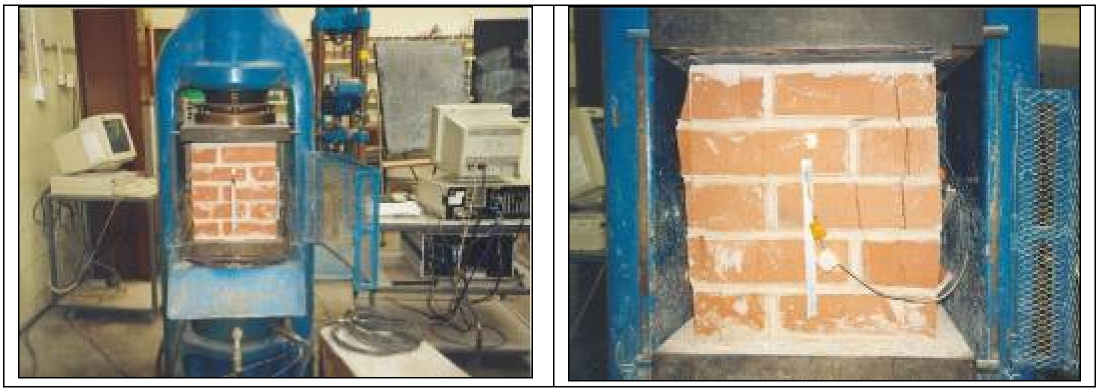

Figure 2. Typical square hollow of clay brick prisms before and after testing

Figure 3.Typical rectangular wallettes of concrete block prisms before and after testing

RESULTS AND DISCUSSION

Compressive strength of clay brick and concrete block units are given in Table 4 and Table 5 respectively. The load caused the failure of the units were in the range between 1131 kN and 1622 kN for clay brick and between 423 kN and 672 kN for concrete block. The area of the applied load was 22038 mm^2 for clay brick and 44000 mm^2 for concrete block. One of clay brick specimens was not included in calculating the mean compressive strength. The specimen did not fail until maximum capacity of the machine applied. One failure load was not also available for concrete block units due to broken specimen before testing.

The average compressive strength of the ten clay brick and concrete block units was 63 N/mm^2 and 12.8 N/mm^2 respectively. The values comply with the standards requirement of BS3921:1985 for clay brick which classified the clay brick as Engineering B. The density of clay brick and concrete block was 1675 kg/m^3 and 2374 kg/m^3 respectively.

Table 4. Compressive strength of clay brick unit

Specimen	Failure Load (kN)	Compressive Strength N/mm^2	Mean Compressive Strength N/mm^2
CBR-1	1286	58.4	63.0
CBR-2	1131	51.3	
CBR-3	1244	56.4	
CBR-4	1539	69.8	
CBR-5	1199	54.4	
CBR-6	1622	73.6	
CBR-7	1468	66.6	
CBR-8	1422	64.5	
CBR-9	1590	72.1	
CBR-10	-	-	

Table 5. Compressive strength of concrete block unit

Specimen	Failure Load (kN)	Compressive Strength N/mm²	Mean Compressive Strength N/mm²
CBL-1	475	10.8	12.8
CBL-2	508	11.5	
CBL-3	637	14.5	
CBL-4	672	15.3	
CBL-5	587	13.3	
CBL-6	423	9.6	
CBL-7	663	15.1	
CBL-8	551	12.5	
CBL-9	553	12.6	
CBL-10	-	-	

Compressive strengths of mortar are given in Table 6. Mean compressive strength from three different batches are shown. The failure loads of the mortar were in the range between 39.5 kN and 45.0 kN. The area of the applied load was 10000 mm^2. The mean compressive strength of the mortar was 4.2 N/mm^2 where the range was between 4.0 and 4.3 N/mm^2. This met the requirement of mortar (iii) as given in Table 1 of BS 5628-1:1992. The density of mortar was 1911 kg/m^3.

Table 6. Compressive strength of mortar

Specimen	Failure Load (kN)	Compressive Strength N/mm²	Mean Compressive Strength N/mm²
M-1	45.0	4.5	4.3
M-2	42.1	4.2	
M-3	41.0	4.1	
M-4	39.5	3.9	4.0
M-5	40.7	4.0	
M-6	40.2	4.0	
M-7	42.0	4.2	4.2
M-8	42.1	4.3	
M-9	42.2	4.3	
Mean compressive strength of mortar			4.2

Results of compressive strength and elastic moduli of masonry specimens are presented in Table 7. Individual and the average results are given. The characteristic compressive strength of masonry was calculated by dividing the mean compressive strength of masonry by a factor of 1.2 as suggested in BS EN 1052-1:1999. Dimension of each specimen of the same type was slightly different compared to the nominal size requirement. The nominal loaded area for clay brick rectangular wallettes was 45100 mm^2, 92455 mm^2 for square hollow prism and 67000 mm^2 for concrete block wallettes. The inner cross section of square hollow prism was of 123 x 123 mm.

The characteristic compressive strength of clay brick rectangular wallettes was 11.2 N/mm^2. The result was lower than the value presented in Table 2 given by BS 5628 Pt. 1:1992. From Table 2 the characteristic compressive strength of clay brick masonry with mortar (iii) and compressive strength of clay brick unit of 63.0 N/mm^2 was 12.2 N/mm^2. The lower value should be used in designing structural masonry. The density of clay brick wallettes was 2097 kg/m^3.

The characteristic compressive strength of square hollow clay brick was 16.7 N/mm^2. It was 50 % higher than that of the clay brick wallettes. Its loaded area was twice of that the wallettes. The density of square hollow clay brick prism was 2050 kg/m^3.The results show that the square hollow clay brick prism was stronger than the clay brick wallettes.

The characteristic compressive strength of concrete block wallettes was 7.2 N/mm^2. The result was 28 % lower than the value presented in Table 2 given by BS 5628 Pt. 1:1992. From Table 2 the characteristic compressive strength of concrete block masonry with mortar (iii) and compressive strength of concrete block unit of 12.8 N/mm^2 was 9.2 N/mm^2. The density of concrete block wallettes was not available from the experiment conducted. The results show that the strength of concrete blocks masonry in compression obtained using Table 2 was too strong compared to the experiment.

Failure of the rectangular clay brick wallettes occurred explosively in a brittle manner. This was in the form of vertical cracking through the narrow faces. The explanation for such a failure mode could be attributed to the lateral expansion of masonry due to Poisson's Ratio effect. The failure of the masonry tested in compression was due to development of tensile cracks parallel to the axis of the loading. All specimens tested showed similar behaviour.

Table 7. Masonry test results

Type of Prisms	Dimensions (mm)	Compressive strength (N/mm^2)	Characteristic Compressive strength (N/mm^2)	Modulus of elasticity, E (N/mm^2)	Mean Modulus of elasticity, E (N/mm^2)
Clay brick rectangular wallettes	437 x 100 x 536	9.7		11800	
	444 x 101 x 535	14.7		12700	
	445 x 101 x 537	16.0		15400	
	Average	13.5	11.2		13500
Clay brick square hollow prisms	330 x 330 x385	19.5		17800	
	330 x 330 x 386	19.9		13600	
	328 x 328 x 385	20.8		16300	
	Average	20.0	16.7		15900
Concrete block rectangular wallettes	670 x 98 x 690	7.0		6900	
	670 x 98 x 690	9.3		7500	
	670 x 98 x 685	9.7		7500	
	Average	8.7	7.2		7300

Typical stress-strain curves are shown in Figure 4. The four curves present measurements the stress-strain of masonry using linpots fitted to the specimens. The graphs are initially linear up to a third of the crushing strength indicating elastic behaviour. The strains occurred in that the third of the crushing strength were measured. The elastic secant moduli for all specimens were calculated using the formula given in Equation (3). The results are presented in Table 7.

f_k In a similar way to crushing strength, the modulus of elasticity of clay brick square hollow prism was found to be 18 % bigger than the clay brick rectangular wallettes.

The ratio of the modulus of elasticity to the compressive strength E_m/f_k for clay brick rectangular wallettes, clay brick square hollow prism and concrete block rectangular wallettes was 1205, 952 and 1014 respectively. On average the ratio is close to 1000 which is close to the values stated in Equation (5) cited from Eurocode 6 (1996).

From the results obtained experimentally, it was found that the variations of the results given although the specimens were constructed from the same material or built on the same day and with the same material. Type of specimen used also affected the results. The designer should well judge the material properties which will be used in designing masonry structures.

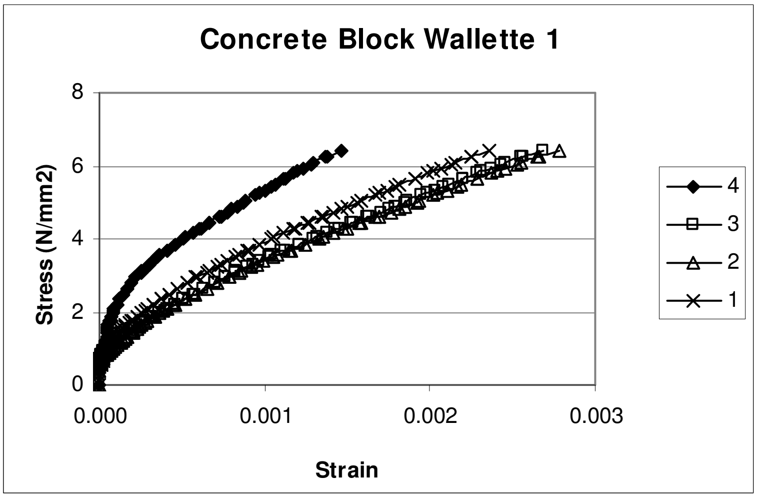

Figure 4. Typical stress-strain curves of masonry

CONCLUSION AND RECOMMENDATION

Conclusion

From the research conducted, the following conclusion can be drawn.

- The compressive strength of masonry units was 63.0 N/mm^2 for clay brick and 12.8 N/mm^2 for concrete block. The brick is classified as Engineering B.
- The compressive strength of mortar was 4.2 N/mm^2. The compressive strength of mortar (iii) determined experimentally fulfils the requirement defined.
- The compressive strength of clay brick and concrete rectangular wallettes was 11.2 N/mm^2 and 7.2 N/mm^2 respectively. By using the same material but forming different shape of specimen gave the compressive strength value of the square hollow clay brick 50 % bigger than clay brick rectangular wallettes. The values were in general smaller than those given in BS 5628 Pt.1 : 1992.
- The failure of the masonry tested in compression was due to development of tensile cracks parallel to the axis of the loading
- Overall, the modulus of elasticity of masonry was 1000 f_k which is close to the formula given in Eurocode 6 (1996)

Recommendation

- It is recommended that when testing modulus of elasticity of masonry strains in transverse direction should be measured in order to determine the Poisson's Ratio of masonry.
- The research conducted was in the UK and using the British and European Standards. It is of important to carry out the experimental in Indonesia as the development of masonry as structural masonry has not well known.

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