LOADBEARING CONSTRUCTION WITH LOCAL BRICKS

by

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Abstract

Loadbearing masonry construction using local bricks is not promoted readily by practising engineers due to lack of confidence in the behaviour of brickwork. A detailed experimental programme has been carried out to address these problems. It is shown that a design strength of 1.5 N/mm^2 can be a reasonable value when a number of quality controlling measures are taken at the brick selection and construction stages. The use of a single design strength can be used to simplify the design process considerably since the only variable to be selected for the brickwork will be the thickness of the brick wall. Guidelines that can be used for the selection of initial layout at the preliminary design stage are also given.

1.0 Introduction

Brickwork is often used for loadbearing construction. Loadbearing brickwork construction is most appropriately used for buildings in which the floor area is subdivided into a relatively large number of rooms of small to medium size where the same floor plan is repeated on each storey throughout the height of the building. These considerations would minimise the possibility of unduly heavy, concentrations of vertical loads. The types of buildings which are compatible with these requirements include houses, flats, hostels and hotels.

However, in Sri Lanka, the use of locally available bricks for loadbearing construction is not as widespread as in other countries. This is primarily due to lack of confidence among the engineers because the quality of bricks vary widely from one manufacturing site to another. Such a variation of quality makes the engineers sceptical about the use of BS 5628 : Part 1 : 1978 [1] for the design of loadbearing brick walls. Therefore, despite the cost savings that can be achieved with loadbearing brickwork, many designers prefer reinforced concrete frame construction for multi-storey construction with two or three storeys.

In order to find suitable design strengths for the locally available bricks, a detailed experimental programme has been carried out. The results of this experimental programme has been used to show that a design strength of 1.5 N/mm^2 can be a reasonable value when a number of quality controlling measures are taken at the brick selection and construction stages. The use of a single strength can simplify the design process considerably since the only variable to select will be the thickness of the brick walls. A set of guidelines in the form of rules of thumb have been developed to select suitable wall thicknesses at the preliminary stages of the design.

2.0 Performance of local brickwork

Locally available bricks manufactured in various parts of Sri Lanka vary widely in composition and quality. It is reported that the strength of bricks depends not only on the clay, silt and sand percentages, but even on the grading of sand [2]. Thus, testing of bricks to determine the crushing strength would be essential to use loadbearing brickwork with confidence. However, testing of low strength bricks itself is a challenging task since these bricks tend to crush and continue to take load without giving a definite crushing point. It was reported [3] that it is extremely difficult to test the locally available bricks after saturating them, since the particles are well lubricated by the large amount of water absorbed. During testing, bricks begin to compress under gradually increasing load with a substantial increase in the bed area and the failure occurs at an unrealistic strain generally in excess of 50%. It is also difficult to observe a momentary decrease in the rate of advance of the indicator of the testing machine as specified in SLS 39 : 1978 while observing the fracture of the brick.

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This shows that there are considerable difficulties associated with testing of low strength bricks. The usefulness of testing bricks also is questionable since no grading of bricks are carried out at the kilns.

The above points show that the use of limit state philosophy, which requires considerable quality controlling during manufacturing of bricks and construction of walls, for the structural design of loadbearing structures with local bricks is somewhat questionable. Nevertheless, it is possible to find a considerable number of loadbearing brickwork multi-storey structures performing very satisfactorily in Sri Lanka constructed using locally available bricks.

In view of this situation, an attempt has been made to use proper design to loadbearing brickwork by adopting a physical testing criteria for the selection of bricks, without resorting to laboratory testing. These physical testing are simple ones that can be carried out at the site while selecting the bricks. A detailed experimental programme has been carried out to determine the strengths that can be obtained for bricks satisfying these criteria [4].

2.1 Physical testing of bricks

The physical testing of bricks is a qualitative testing method which is often used to distinguish low quality bricks from good quality ones. The physical testing methods available can be summarised with the notations used in Table 1 as follows:

Surface texture:

A smooth surface texture is an indication of the attention paid to maintaining quality of bricks. Poorly prepared soils will have a large amount of particles of varying size that may give a poor uneven surface texture with some large particles visible on the surface. The notations used include R for rough surface texture and S for smooth surface texture.

Ringing sound:

When two bricks are tapped together, well burnt bricks with dense structure generally give a ringing sound. Bricks of high porosity, which results due to use of excessive amount of water during moulding of bricks, would not give a sharp ringing sound. Partially burnt bricks also would not give a ringing sound. The notations used include D for dull sound or no ringing sound, DR for dull ringing sound and SR for sharp ringing sound.

Interior texture:

Well brunt bricks will have a uniform colour when broken into two pieces. The notations used include W for well burnt bricks with uniform colour and P for poorly burnt bricks showing partially burnt clay at the centre.

Dropping of one brick on another:

A brick is dropped on another brick placed on level ground, from a height of 1.2 m. Due to the impact, the brick on the ground can either crush, or break into two pieces or would not break. The notations used include C for crushing of brick on the ground, B for breaking of brick on the ground into two pieces, and S for sound bricks that have not broken into two pieces.

2.2 Strength of brickwork with local bricks

In order to relate the strength of walls to the physical testing criteria, a detailed experimental programme has been carried out. In this programme, wall panels constructed with bricks from seven manufacturing sites have been tested 28 days after casting to determine the wall strengths.

It is recommended in BS 5628 : Part1 : 1978 that the experimental determination of characteristic compressive strength of masonry should be done by obtaining the ultimate strength of brick panels tested to destruction. Duplicate tests should be carried out on nominally identical panels, thus a minimum of two panels are required per test. The panel size recommended is 1.2m to 1.8m in length with a minimum cross-sectional area of $0.125m^2$ and from 2.4m to 2.7m in height. Panels having dimensions outside these limits are permitted provided that the general principles laid down in the test procedure are applied.

The test panels should be covered with polyethylene sheets for a period of three days after construction and then left uncovered until tested. It is recommended that the panels be tested at an age of 28 days, and this may be extended to 35 days when circumstances require extension.

When the panels are tested to determine the ultimate strength of brickwork, the load should be applied on the wall panels uniformly over the whole area of the top and bottom of the panel. The platens or cross heads through which the load is applied should be restrained against rotation to produce a flat ended condition. The load should be applies at a rate so that the stress increases at about 1 N/mm^2 per minute. The characteristic compressive strength of masonry panel can be calculated using the following equation:

$$fk = (Fm.\varphi u.\varphi m)/(1.2 \times A) \qquad (1)$$

The factor 1.2 is introduced to relate the characteristic strength to the mean value. The factors φu and φm are the reduction factors for the samples structural units and strength of mortar, which can be considered as equal to 1.0 for a research study.

The panel size used for this experimental investigation was 3 bricks long and 10 courses high. The advantages of using this panel size is that height/thickness ratio is less than 8. Thus, the slenderness effects will not be present under compressive loads. The height of the panel is about 0.6m so that there is no confinement due to the platens of the machine. This panel size is more manageable when testing a large number of panels.

The mortar mix used for this experimental programme is 1:6 cement sand, since it has been shown [5] that there can be a considerable increase in the wall strength when the mortar is changed from 1:8 to 1:6 cement sand with locally available bricks. The mortar is volume batched. The cement used for testing has been manufactured to meet BS 12 requirements.

Since there are so many brick manufacturing sites in Sri Lanka, bricks from seven sites have been selected for a research study covering areas close to Ma-oya, Malwathu-oya, Kelani, Kalu, Ginganga and Mahaweli. These manufacturing sites have been identified as Locations 1 - 7. It was intended to determine the variability of strength associate with local bricks, thus the bricks were selected as good quality and average quality as identified by the brick manufacturers. The good quality bricks have been identified as Series A, and the average quality as Series B.

The following readings have been recorded during the testing of wall panels:

load at 1st crack and the development of crack patterns

load deformations characteristics

crushing strength of brickwork

2.3 Results and analysis

The results of the testing programme is presented in Tables 1,2 and 3.

The average strengths obtained for bricks tested according to SLS 39: 1978 [6] have given strengths presented in Table 1. However, one notable feature was the wide variation in the strength of bricks obtained from a given site. For an example, four type A bricks that have been tested from Location 5 have given strengths of 5.89, 9.14, 9.80 and 5.51 N/mm^2. This has given an average strength of 7.58 N/mm^2.. However, the panels constructed with these bricks gave a characteristic strength of only 1.52 N/mm^2. The brickwork strength that can be expected according to BS 5628 for bricks of strength only of 5 N/mm^2 is 2.5 N/mm^2 with mortar designation iii. This shows that brick test results may not be a reliable indictor of the characteristic strength of brickwork.

Location	Brick Quality				
	Dropping on another brick	Ringing Sound	Burning	Surface Texture	Average strength of bricks N/mm^2
Location 1- A	C	D	W	R	5.34
Location 1 - B	C	D	W	R	2.68
Location 2- A	B	DR	W	R	4.40
Location 2 - B	B	DR	W	R	7.10
Location 3- A	S	SR	W	S	6.38
Location 3 - B	D	R	W	S	5.97
Location 4- A	C	D	P	R	3.13
Location 4 - B	C	D	P	R	-
Location 5- A	S	SR	W	S	7.58
Location 5-B	S	SR	W	S	7.42
Location 6 -A	S	SR	W	S	4.99
Location 6 - B	S	SR	W	S	4.20
Location 7 -A	B	SR	W	S	2.75
Location 7 - B	S	SR	W	S	2.80

Table 1: Physical testing of bricks from various manufacturing sites

The notations used for Table 2 are as follows:

A1, A2: Wall panels constructed out of bricks that have been identified as good quality by the manufacturers,

B1, B2: Wall panels constructed out of bricks that have been identified as average quality by the manufacturers.

The panels have been tested as explained is Section 2.2. The load at 1st crack and the ultimate load have been recorded. The crack patterns and the deformation of the panel at each load increment also have been recorded but not reported here since all the panels showed sufficient ductility.

The notations used for Table 3 are as follows:

A1, A2: Wall panels constructed out of bricks that have been identified as good quality by the manufacturers,

B1, B2: Wall panels constructed out of bricks that have been identified as average quality by the manufacturers

The stress at 1st crack and failure have been calculated by dividing the failure load by the cross sectional area. The characteristic strength has been calculated by using equation 1.

Location		Panel size length x width x height(mm)	Load at 1st crack (Tonnes)	Load at failure (Tonnes)
Location 1	A1	675 x 238 x 690	12.0	20.0
	A2	685 x 235 x 687	8.0	20.0
Location 1	B1	673 x 238 x 708	8.0	17.4
	B2	673 x 233 x 715	10.0	19.0
Location 2	A1	645 x 225 x 744	15.0	21.9
	A2	658 x 220 x 740	16.0	27.3
Location 2	B1	685 x 233 x 765	13.0	29.0
	B2	688 x 234 x 765	12.0	30.0
Location 3	A1	680 x 230 x 755	25.0	29.0
	A2	685 x 228 x 755	27.0	37.0
Location 3	B1	620 x 210 x 630	19.0	22.0
	B2	625 x 220 x 630	15.0	22.25
Location 4	A1	690 x 230 x 628	10.0	21.9
	A2	690 x 228 x 620	8.0	21.5
Location 4	B1	666 x 225 x 600	15.0	23.85
	B2	660 x 225 x 605	16.0	28.85
Location 5	A1	646 x 225 x 710	16.0	25.0
	A2	655 x 228 x 705	18.0	30.0
Location 5	B1	590 x 208 x 628	11.0	25.0
	B2	585 x 203 x 615	20.0	23.0
Location 6	A1	613 x 210 x 635	17.0	28.4
	A2	615 x 212 x 640	14.0	30.0
Location 6	B1	613 x 215 x 615	14.0	26.0
	B2	613 x 205 x 620	14.0	28.8
Location 7	A1	700 x 232 x 675	21.0	29.9
	A2	701 x 234 x 684	12.0	28.0
Location 7	B1	705 x 235 x 680	23.0	34.0
	B2	700 x 240 x 670	27.0	36.0

Table 2: Dimensions, load at 1st crack and ultimate load for wall panels

Location		Stress at 1st crack (N/mm^2)	Stress at failure (N/mm^2)	Average stress at failure (N/mm^2)	Characteristic Strength (N/mm^2)
Location 1	A1	0.73	1.22	1.22	1.01
	A2	0.48	1.22		
Location 1	B1	0.49	1.08	1.13	0.94
	B2	0.62	1.19		
Location 2	A1	1.01	1.48	1.66	1.38
	A2	1.08	1.85		
Location 2	B1	0.80	1.78	1.81	1.5
	B2	0.73	1.83		
Location 3	A1	1.57	1.85	2.08	1.73
	A2	1.69	2.32		
Location 3	B1	1.43	1.66	1.62	1.35
	B2	1.07	1.59		
Location 4	A1	0.62	1.35	1.34	1.11
	A2	0.50	1.34		
Location 4	B1	0.58	1.56	1.73	1.44
	B2	1.06	1.90		
Location 5	A1	1.08	1.69	1.83	1.52
	A2	1.18	1.97		
Location 5	B1	0.88	2.00	1.98	1.65
	B2	1.65	1.97		
Location 6	A1	1.79	2.16	2.21	1.84
	A2	1.05	2.26		
Location 6	B1	1.04	2.14	2.08	1.73
	B2	1.09	2.03		
Location 7	A1	1.27	1.81	1.74	1.45
	A2	0.72	1.67		
Location 7	B1	1.36	2.01	2.05	1.70
	B2	1.57	2.10		

Table 3: Stress at 1st crack, ultimate stress, average stress and characteristic strength of wall panels.

It can be seen from Table 3 that the characteristic compressive strength obtained for bricks from various manufacturing sites can vary from 0.94 N/mm^2 to 1.84 N/mm^2. However, the characteristic strength of 2.5 N/mm^2 given in BS 5628 : Part 1 : 1978 for 5 N/mm^2 bricks and mortar designation iii has not been achieved by the bricks from any of the above manufacturing sites. Nevertheless, a characteristic strength of above 1.5 N/mm^2 has been achieved by the bricks of Series A from Locations 3, 5, 6, and the bricks of Series B from Locations 2, 5, 6 and 7.

It is interesting to note that the strength obtained with the brickwork can be closely related to the results of physical testing given in Table 1. The most important physical testing is the ability of the bricks to withstand an impact which is tested by dropping one brick on another brick placed on the ground. It can be seen that the bricks which pass this test without breaking generally gives a characteristic strength in excess of 1.5 N/mm^2. The bricks that just break into two pieces like Series B from Location 3 would give a characteristic strength in excess of 1.35 N/mm^2 and those which crush would give a very low strength; an example is Series A and B from Location 1.

It can be seen that the ringing sound given when two bricks are tapped together is also an indication of the quality of bricks. However, this test should be used to identify good quality bricks initially which can be verified later by subjecting them to impact loads. Other physical testing will also help to identify the quality of bricks in general initially.

Brick walls should exhibit sufficient ductility. This will ensure a sufficient warning before the failure of the wall. Although bricks can be considered as a brittle material, brick walls exhibit considerable ductility which can be explained as follows. Generally, the initial cracks in brick walls would appear on the sides at stresses well below the failure stresses. It can be seen in Table 3 that there is a considerable difference between the stress at 1st crack and the stress at ultimate failure. The formation of these micro-cracks would increase the deformation of the brick wall. However, it will continue to carry load until the lateral strains caused in the bricks due to interaction between brick and mortar is sufficient to cause splitting of the bricks. When the splitting of the panel occurs, it will cease to take any more load.

On the basis of these results it may be suggested that the bricks that pass all the physical testing, specially dropping of a brick from a height of 1.2m on another on level ground, are most likely to develop a characteristic strength in excess of 1.5 N/mm^2, and also show sufficient ductility.

3.0 Use of BS 5628 for loadbearing brickwork with local bricks

BS 5628 : Part 1: 1978 is based on limit state philosophy. Therefore, it is necessary to ensure that the material strengths are based on characteristic strengths. However, the question is whether it is possible to have characteristic strengths for locally available bricks since generally no strength testing is carried out to ensure quality.

As described in ISO 2394 : 1986(E) [7], it is necessary to have an effective quality control programme during planning, design and construction of a structure to achieve the required levels of reliability when the limit state principles are used for the structural design.

Here the structural designer has to face a serious problem. On the one hand, it is necessary to use the limit state theory for design. On the other hand, it is difficult to obtain reliable test results on material strengths such as strength of bricks and strength of walls. The inability to carryout detailed material testing is a situation similar to that arise with soils, when designing foundations.

In normal design, the designer specifies the structure and the material to be used. In this situation, the uncertainties lie largely in the statistical variability of the parameters that the designer has specified. However, in geotechniques, the structure considered is soil which is existing at the site. The engineer has to accept the existing soil unless he is going to improve it further with various techniques. The nature of this structural system is uncertain and must be hypothesised from the limited information such as bore hole data [8].

Under such circumstances, a rather different line of argument has been developed [9]. It is argued that the variability of soil parameters differ from site to site to such an extent that the definition of partial factors of safety in a code is useless. Therefore, it has been suggested to define "expected" and "worst credible" values for parameters which are then used in design without further factors of safety. The "expected" and "worst credible" values are chosen as a function of the degree of uncertainty in the parameter.

A similar technique can be used for local brickwork if the expected strengths, which means the minimum strengths that can be guaranteed with local bricks satisfying certain physical testing criteria are obtained. Then, these expected strengths values can be used as the characteristic strengths. As described in Section 2.3, it is possible to obtain a strength in excess of 1.5 N/mm^2 for bricks which satisfy all the physical tests described in Section 2.1, when 1:6 cement sand mortar is used.

If 1.5 N/mm^2 is considered as the characteristic strength that can be expected for bricks satisfying physical testing criteria, it can be used instead of 2.5 N/mm^2 characteristic strength specified in BS 5628 : Part 1: 1978 for 5.0 N/mm^2 bricks and mortar designation iii. It is also prudent to use a partial factor of safety for material equal to 3.5. The appropriate partial factor of safety for loads also should be applied.

The use of a partial safety factor of 3.5 with an expected strength of 1.5 N/mm^2 will give a working stress of 0.2875 N/mm^2; this value is calculated dividing 1.5 N/mm^2 by 1.5 x 3.5. The value of 1.5 is the average of 1.4 and 1.6, the partial safety factors used for dead and imposed loads, and 3.5 is the partial safety factor for material strength. As can be seen in Table 3, the stress at 1st crack is above 0.2785 N/mm^2 for all types of bricks, thus there will not be any cracks due to service loads for structures designed with a characteristic strength of 1.5 N/mm^2.

The use of a factor of safety of 3.5, which covers the degree of manufacturing and construction control and the uncertainty of load transfer [10], is also advisable from the following point of view. BS 5628 : Part 1 : 1978 recommends that a partial factor of safety of 2.5 can be used with special manufacturing and construction control. This is the factor of safety allowed for the uncertain load transfer and the statistical variation of strength. Hence, the factor of safety allowed for the variation of strength of materials due to average quality controlling is 3.5/2.5, which is equal to 1.4.

Thus, when the designs are carried out for a characteristic strength of 1.5 N/mm^2, the strength of masonry can vary up to (1.5/1.4) N/mm^2, which is equal to 1.07 N/mm^2. It can be seen in Table 3 that majority of bricks including those failing in the impact test give a characteristic strength in excess of 1.07 N/mm^2. This does not mean that the bricks which fail the physical testing should be used, but it gives more confidence to the structural designer that the designs done with a characteristic strength of 1.5 N/mm^2 are extremely safe when the construction is carried out with adequate quality controlling.

4.0 Quality controlling at construction

In order to achieve an expected strength of 1.5 N/mm^2 for local brickwork, certain precautions should be taken at the construction stage. It has been shown [11], that there are workmanship factors like incorrect batching of mortar, use of dry bricks, excessive bed joint thicknesses and non-verticality of walls that can adversely affect either the strength or behaviour of brickwork. Therefore following precautions should be taken at the construction stage.

Bricks should be selected by carrying out physical testing. Most important is dropping of a brick at a height of 1.2 m, where the brick on the ground should not break.

The brickwork should be constructed with 1:6 cement sand volume batched mortar with a sufficient quantity of water to give adequate workability. Mortar batching should be done with containers of fixed volume such as gauge boxes or buckets since batching with "thachchis" as commonly used can give a certain variability in mortar mix proportions; such a variability is not desirable especially with bricks of low strength. The cement used should comply with BS 12.

Bricks must be immersed in water for at least 10 minutes. This will ensure that bricks will not absorb the water available in mortar, thus allowing a satisfactory level of hydration of cement in mortar. Immersing bricks in water also helps to eliminate poor quality bricks since low strength partially burnt bricks will disintegrate when soaked in water until saturation, and it will also remove dust from the brick surface thus enhancing the bond between mortar and the brick.

The mortar bed thickness must be maintained between 10-12mm; a gauge rod can be used to maintain the thickness of the mortar joint. Thicker mortar beds deform considerably increasing the shortening of the masonry wall when subjected to vertical loads [11].

Walls must be built perfectly plumb so that any deviation from verticality is within the construction tolerances. Out of plumb walls will have lower strength due to increased eccentricity.

It is shown that special curing of walls constructed using saturated bricks is not essential [10]. However, curing may help in the development of strength and also reduce the shrinkage of mortar. Therefore, it is recommended to keep brick walls wet, as long as possible by spraying water.

5.0 Structural layouts with loadbearing brickwork

With the use of a unique design strength of 1.5 N/mm^2, it would be useful to have some idea about the type of layouts that can satisfy the above strength requirement. In a research study, more than 2000 different layouts that can be used for two storey houses have been analysed to develop some guidelines which can be used as rules of thumb at the preliminary design stage [5].

These rules of thumb have been developed on the following basis:

1. There are external and internal walls in a house. The external walls are likely to carry less load than the internal walls since the floor slab is only on one side.
2. The wall length considered for the analysis is 4.0m and the maximum length of the opening allowed is 2.0m in length. This opening can be either a door or a window.
3. The height to the soffit of the slab is less than 3.0m to limit the effects of slenderness.
4. The upper floor roof can be either clay tiles or asbestos.
5. The slabs are considered as one way spanning. However, a better load distribution can be obtained with two way spanning slabs and they are also economical than one way slabs due to better utilisation of reinforcing steel. This will improve the robustness of the structure as well. Hence two way slabs should be used wherever possible.
6. Slabs rest directly on masonry walls except at openings where a lintel or a beam is provided with sufficient bearing lengths on either side of the opening.

The proposed rules are the following:

1. The maximum length of an opening at a ground floor external wall is 2.0m over a length of 4.0m

which means the ratio of the length of opening to the total length of the wall is 0.5. This ratio should be maintained for shorter wall lengths.

2. For external walls, it is possible to use one brick thick walls (210mm) in the upper floor. There is no need to have the ground and upper floor openings coinciding as far as the above opening length to wall length ratio is maintained. A sufficiently stiff lintel with a suitable bearing length (at least 0.3 m) should be provided over the opening.

3. Since the internal walls are heavily loaded, the following precautions should be taken:

   a. If the slab spans on either side of the wall at first floor level are not more that 3.0m, one brick thick walls may be used for the upper floor internal walls with or without openings. Ground floor opening to wall length ratio should be maintained at around 0.25. The height of the upper floor wall should not exceed 4.0m.

   b. If the spans on either side of the wall at first floor level are between 3.0m and 4.0m, either half brick thick walls (100 mm) or 150 mm thick hollow blockwork should be used for the upper floor internal walls. The selection of material should be based on the maximum value for slenderness ratio which is set as 26.

4. When it is necessary to use one brick thick walls as the upper floor internal walls due to slenderness effects, it is advisable to increase the ground floor wall thickness to one and a half bricks.

Generally, it would be possible to satisfy these conditions in a two storey house because there would be a considerable number of walls used as partition walls. It is a good practice to have approximately same arrangement of walls in the ground floor and in the upper floor. This will minimise the effects of concentrated loads.

If the ground and upper floor arrangements are different, it would be a good practice to provide sufficient number of beams at the first floor level to transfer loads to the ground floor as approximately distributed loads.

When these arrangements fail to keep the stresses sufficiently low, it is possible to consider a number of other alternative solutions. One such alternative is to increase the thickness of the wall in the locality without affecting aesthetics. This will, however, reduce the space inside the building by a small amount which would need an adjustment of the external dimensions suitably.

Another alternative is to use concrete columns and beams only at the location where the loads are excessive. This may be preferable if the site is restricted and it is important to keep the internal space lost due to walls to a minimum. When reinforced concrete columns are used in isolation, it is important to provide beams, which connect the concrete columns to brick walls, with adequate bearing at the brick wall to ensure smooth transfer of loads without causing bearing failures.

There is a belief that the overhead water tank in a house should be supported by four reinforced concrete columns. However, the strength of brickwork would be sufficient to withstand the weight of the water stored and the self weight of the water tank without causing excessive stresses. It would be a good practice to support the water tank on at least two, one brick thick (210 mm), walls on opposite faces. The other walls can be either one brick thick or half a brick thick walls. It is usually convenient to locate the water tank either above the bathrooms or the chimney (if one has been provided in the kitchen) since there will be sufficient number of walls to support the additional loads due to the water stored.

Although these guidelines may appear as highly restrictive for the planner, it is not difficult to satisfy most of these requirements since it is necessary to have a sufficient number of partition walls in two storey houses, hostels and hotels.

These rules of thumb are expected to guide the design engineer at the preliminary design stages. A proper structural design of the structure should be carried out subsequently to ensure that the allowable stresses are not violated.

6. 0 Conclusions

Although loadbearing brickwork can reduce the cost of multi-storey construction considerably due to elimination of pad footings, columns and beams, it is still not widely used in Sri Lanka. The main reason is lack of guidelines for design strengths that can be achieved with locally available bricks and the concern about the quality of bricks. Both these problems have been addressed by presenting an expected value for strength, which is equal to 1.5 N/mm^2, when adequate precautions are taken in selecting the bricks and during the construction. This value can be used as the characteristic strength of brickwork for design purposes.

The use of a characteristic strength of 1.5 N/mm2 considerably simplify the structural design process of loadbearing brickwork; this allows the development of guidelines in the form of rules of thumb that can be used at the preliminary design stage. If the layout design complies with these guidelines, there is a considerable chance for the detailed structural design to satisfy the partial factors of safety required for material strengths.

When the strength of the walls is insufficient, the designer will be left with only few options, which are increasing the thickness of the wall or use of reinforced concrete frames.

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8.0 References

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