Cost Effective Buildings with Local Bricks

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Abstract

Load bearing brickwork can be used in two to three storey buildings eliminating the reinforced concrete framework thus leading to a considerable economy. However, this method of construction is not often used since the locally available bricks are of low quality and hence structural engineers are rather reluctant to promote it. It is shown here that it is possible to achieve a characteristic strength of 1.5 N/mm^2 when bricks satisfy certain physical testing criteria. The quality control measures required for such construction are also highlighted. It is also shown that although the use of 1.5 N/mm^2 design compressive strength offers satisfactory behaviour with respect to primary effects, further precautions will be required in load bearing brickwork structures to prevent cracking due to stresses of secondary nature.

Introduction

Brickwork can be used in building construction for two different applications. They are as infill panels in reinforced concrete framed buildings and as load bearing brickwork. Brickwork can be used in any type of concrete framed buildings, especially in residential type, as a partition material due to its good sound insulation, fire resistance and thermal insulation properties. The only drawback is the material, which leads to a rather heavy concrete frame. In modern office buildings, lightweight partitions are preferred to brick panels.

Load bearing brickwork can be in houses, flats, hostels and hotels, preferably of two or three storeys, where the floor area is subdivided into a relatively large number of small to medium size units. In these buildings, the loadbearing brick walls can serve the dual purpose of carrying structural loads while serving as partition walls, thus leading to a considerable economy. However, many structural engineers in Sri Lanka are somewhat reluctant to use load bearing brickwork in two and three storey buildings. The following reasons can be attributed to this:

1. The strength of locally available bricks is generally low and the quality varies from one manufacturing site to another.

2. The strength data pertaining to brickwork out of local bricks can not be obtained from standard codes of practice such as BS 5628: Part 1: 1978.

In this paper, it is shown that these drawbacks can be overcome to a considerable extent so that the locally available bricks can be used with confidence by employing some quality controlling measures at the brick selection and brickwork construction stages. It is also shown that certain additional measures will be required in load bearing brick wall structures to ensure crack free structures, thus fully realising cost effectiveness.

Economics of Load Bearing Brickwork

In order to highlight the cost effectiveness of load bearing brickwork, a simple example can be considered. In this example, the cost of a load bearing brick wall is compared with the cost of an alternative consisting of a reinforced concrete frame with a brick panel partition.

The length of the wall is *3.0m* and the height is *2.7 m* with one brick thickness. It supports a *125 mm* thick concrete slab. The alternative for this load bearing brick wall consists of a reinforced concrete column, a beam and one brick thick partition wall. In this example, only one column has been considered for the cost calculations since columns are shared in more than one direction. The size of the column is *0.2m* x *0.2m* square and the size of the beam is *0.2m* in width x *0.3m* in depth. The size of the column base is *1.0m* x *1.0m* x *0.2m*. The amount of reinforcement has been determined to ensure that the reinforced concrete frame can carry the upper floor wall and slab loads. The cost of rubble foundation construction has been assumed to be the same for both alternatives.

The Cost Comparison was carried out on the basis of the following information.

a. Cost of $1m^2$ of one brick thick brickwork	= Rs. 550/=
b. Cost of $1m^3$ of concrete	= Rs. 4,300/=
c. Cost $1m^2$ of shuttering	= Rs. 300/=
d. Cost of 1 *Tonne* of reinforcement	= Rs. 48,000/=

These rates include the cost of labour and materials.

Alternative 1:

Cost of mansonry wall of size *3.0m* x *2.7m*	= Rs. 4,455/=

Alternative 2:

Cost of *0.50* m^3 of concrete	= Rs. 2,150/=
Cost of *0.055* Tonne of reinforcement	= Rs. 2,640/=
Cost of *5.36* m^2 of shuttering	= Rs. 1,608/=
Cost of *2.8m x 2.4m* of brickwork	= Rs. 3,696/=
Total cost of alternative 2	= Rs. 10,094/=
Cost saving of alternative 1	= Rs. 5,639/=

It can be seen that the use of load bearing brickwork can save more that *50%* of the structural cost at the ground floor level. If there are 16 columns in a two storey house, the saving can be about Rs.*16* x *5,639/=*, which is equal to Rs.*90,224/=*. It should be noted that the cost of reinforced concrete frame can increase further if higher spans are used. Hence a saving of the order of Rs.*100,000/=* could be easily achieved for a two storey house where the reinforced concrete frame is replaced by load bearing brick walls at the ground floor level. It is assumed that the upper floor will be constructed with brickwork in both cases.

A saving of Rs.*100,000/=* would mean a saving of about Rs.*1,800/=* per month on mortgage payments with about 17% interest rate prevailing in Sri Lanka over a period of about *10* years or about Rs.*1;600/=* over a period of *20* years when the money is raised for construction as a loan. In addition to the above cost savings, load bearing brickwork also allows rapid construction of the structure thus reducing the overall project duration.

Use of Local Bricks as Loadbearing Material

In load bearing brick wall buildings, the dead and imposed loads from the roof and the brick walls, in addition to the weight of brick walls should carry floors. Therefore, in normal practice, a proper structural design should be carried out prior to the construction to select the appropriate strength of bricks and the mortar designation. However, this approach is not quite possible with locally available bricks since the brick manufacturers do not practise the grading of bricks according to the strength. In Sri Lanka, the bricks manufactured should comply with the requirements given in SLS 39. However there can be considerable difficulty in assessing the strength of bricks.

It was reported by Chandrakeerthy and Mohottige (1985) that it is extremely difficult to test the locally available bricks after saturating them as specified in SLS 39, since the particles are well lubricated by the large amount of water absorbed. During testing, bricks begin to compress under gradually increasing load with substantial increases 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 while observing the fracture of the brick. This shows that there are considerable difficulties associated with testing of low strength bricks.

In order to overcome this difficulty, an alternative approach has been presented by Jayasinghe (1996). In this approach, physical testing of bricks is used to identify the bricks that are suitable for construction. The strength of the brick walls has been determined experimentally for bricks that satisfy physical testing criteria and for those that fail to satisfy. The physical testing criteria used is as follows:

1. When a randomly selected brick is dropped from a height of *1.2m* on another brick laid on level ground, the brick on the ground should not break due to the impact. This test gives an indication of the strength of the bricks.

2. When two bricks are tapped together, they should give a ringing sound. This is an indication of the amount of water used at the moulding stage and the degree of burning. The use of an excessive amount of water during moulding is profitable for the manufacturer since the volume of clay will increase thus giving a higher number of bricks. However, excessive amount of water will give a lower compaction thus leading to weaker bricks due to high voids ratio. It can also increase the water absorption of the bricks. Poorly burnt bricks are not acceptable since they tend to loose strength and disintegrate when exposed to water. The dimensional stability is also poor in partially burnt bricks. It is possible to identify partially burnt bricks by inspecting the cross section of a broken brick. If the brick is partially burnt, the core would have a colour different to the outer crust.

3. The surface texture of bricks should be smooth without lumps and cracks. The presence of lumps and cracks is an indirect indication of lack of quality controlling at the brick manufacturing stage. It may also be an indication of lack of will to produce quality bricks since bricks of any quality can be sold.

Jayasinghe (1998) has showed that the most important physical testing criteria is the dropping of one brick on another placed on the ground. For bricks that do not break, it is possible to obtain a characteristic strength having a minimum value of $1.5\ N/mm^2$. It is also shown by Jayasinghe (1998) that the stress at 1st crack for the bricks that satisfy physical testing criteria is sufficiently high so that a factor of safety for material strength, $Y_m = 3.5$ given in BS 5628: 1979: Part 1, is satisfactory. These findings can be extremely useful since they can simplify the structural design process considerably. With a unique design strength, the designer will be left with finding a suitable value for only one variable, that is the width of the brick wall.

In order to assist during the selection of initial layout for load bearing brick wall structure with local bricks, a set of rules of thumb has been develop by Dassanayake and Mohottige (1993) by considering a large number of possible structural arrangements. Since the size of the bricks available is also non-standard, a size of *200 mm* in length, *100 mm* in width and *50 mm* in thickness is used for the design study. Bricks of this size can give a wall width of *210 mm*.

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 fewer loads 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 calicut tiles or asbestos.

5. The slabs are considered as one way spanning. However, better load distribution can be obtained from two-way spanning slabs. They are also more economical than one way slabs due to better utilisation of reinforcing steel. They 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 an opening where a lintel or a beam is provided with sufficient bearing lengths on either side.

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 that the ratio of the length of opening to the total length of the wall is *0.5m*. 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 should be provided over the openings.

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 than *3.0m*, one brick thick walls may be used in 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 *100mm* or *150mm* thick hollow block work 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 *27*.

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 brick.

Generally, it would be possible to satisfy these conditions in a two storey house because there would be a considerable number of walls acting as partition walls. It is a good practice to have approximately the same arrangement of walls in the ground floor and in the upper floor as well. 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 margin, 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. These should connect the concrete columns to brick walls, with adequate bearing at the brick wall to ensure smooth transfer of loads without causing bearing failures.

These rules of the thumb are expected to guide the architect at the preliminary layout design stages. A structural engineer can use the same rules at the preliminary structural design stage when selecting the wall thickness. A proper structural design of the structure should be carried out subsequently to ensure that the allowable stresses are not violated.

Quality Control(ling) for Construction

If a characteristic strength of *1.5 N/mm^2* is used for structural design calculations, it is necessary to ensure that the brickwork is capable of developing this strength. Therefore, the following quality controlling measures should be taken:

1. The bricks, which satisfy all the following physical tests given in Section 3, should be selected for the construction

2. At the construction stage, the following factors should be paid considerable attention:

   a. The brickwork should be constructed with 1:6 cement to sand volume bathed 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. Dassanayake & Mohottige (1993) have shown that the characteristic strength of local brickwork can be reduced to about 1.1 N/mm^2 when the mortar mix is changed from 1:6 to 1:8 cement to sand. The cement used should comply with BS 12, the British Standard for testing cement.

   b. 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 since low strength partially burnt bricks will disintegrate when soaked in water until saturation. This will also remove dust from the brick surface thus enhancing the bond between mortar and the brick.

   c. The mortar bed thickness must be maintained between 10 –12 mm; a gauge rod as shown in figure 1 can be used to maintain the thickness of the mortar joint. Thicker mortar beds deform considerably increasing the shortening of the masonry wall when subject to vertical loads (Jayasinghe et al., 1987).

   d. 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.

e. It is shown that special curing of walls constructed using saturated bricks is not essential (Chandrakeerthy, 1987). However, curing may help in the enhancement 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.

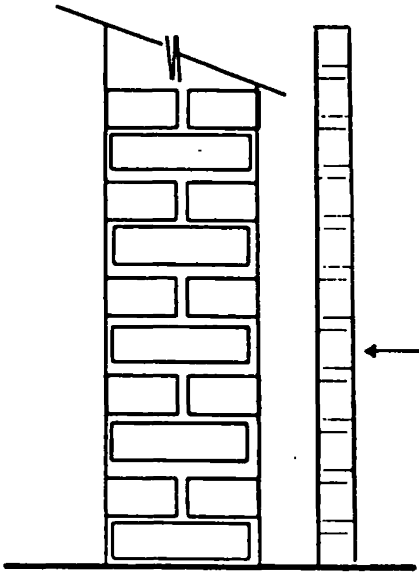

Figure. 1: Use of gauge rod to control the thickness of the mortar bed thickness

Secondary Stresses In Load Bearing Brickwork

The use of a design strength of 1.5 N/mm^2 will provide adequate safety against primary stresses, which would be the compressive stresses due to vertical loads such as dead, imposed and in plane loads induced by wind acting on the structure. However, even a properly designed load bearing structure can still develop vertical, horizontal and inclined cracks due to secondary effects such as:

1. thermal stresses caused by diurnal fluctuation of temperature of walls,

2. thermal stresses caused by exposed structural members such as concrete roofs and balconies without roofs, and

3. foundation movements.

The common locations for these cracks can be summarised as follows:

Cracks at windows

In many brick wall structures vertical and in lined cracks can be observed at external windows as shown in Figure 2. It has been shown that vertical cracks are caused by tensile stresses induced in brickwork due to shortening of the brickwork (Jayasinghe and Maharacchi, 1998). Such shortening occurs due to restraint offered by the floor slabs and foundations, which would be at a lower temperature. When subjected to compressive stresses of long durations, brickwork can relieve the stresses by shortening, which is called the creep of brickwork. The creep of brickwork can relieve the stresses by about 50% in brick walls (Henry, 1981). When the temperature of brickwork drops during the night, tensile stresses can develop in already shortened brickwork. These tensile stresses will build up gradually in the brick wall with the highest stresses below the windows. When the tensile stresses exceed the tensile strength, cracks will develop below the windows.

The inclined cracks occur due to uneven stress distribution that give rise to some tensile stresses in brickwork. It is possible to draw a Mohr's circle and show that the principle tensile stresses will occur in the direction shown in Figure 3 for the element shown in Figure 2, which is subjected to vertical stresses and shear stresses.

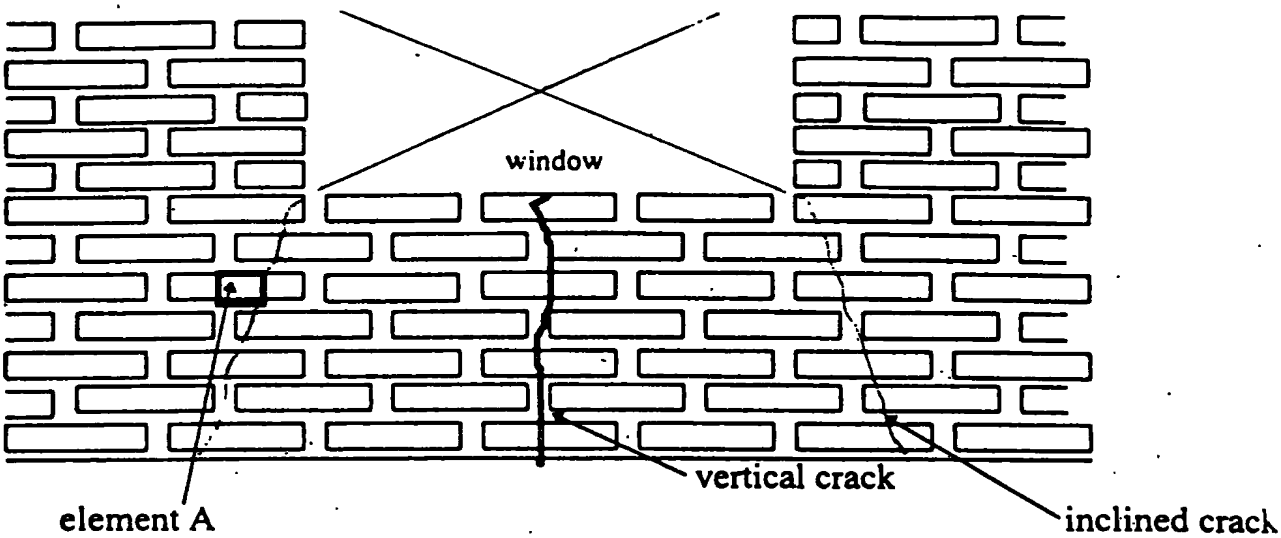

Figure 2: Thermal cracks below the window in the brick wall

Only reducing the shear stress can reduce the tensile stress. This shear stress occurs due to uneven stresses that occur under the window and away from the window.

Under the window, the stress in brickwork is very much lesser than that away from the window. The shear stress can be minimised by ensuring that a load of considerable magnitude is transferred to the area below the window which can be achieved by providing a tie beam at the window sill level.

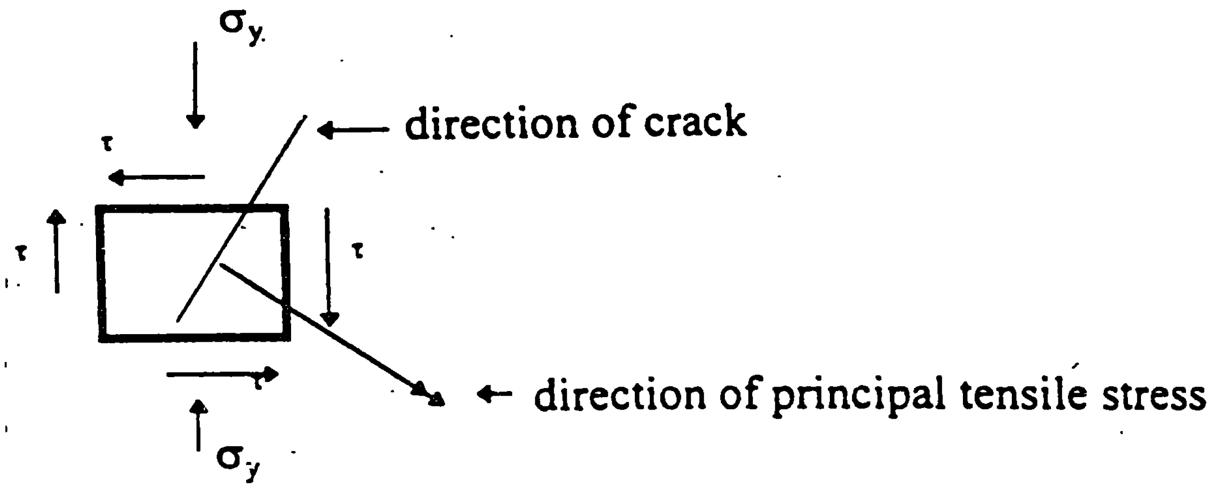

Figure 3: Stresses acting on element A and the direction of principle tensile stress

Cracks under Exposed Roof Structures and Balconies

When concrete roofs are used for load bearing masonry buildings, the horizontal roof will absorb a lot of heat during the day time, where the intensity of solar radiation can be in the range of 1 kW/hour (Silva & Vas, 1984). The expansion of roof slabs can cause a lot of cracking as shown in Figure 4. The inclined and vertical cracks are associated with thermal expansion. Horizontal cracks occur due to creep shortening of brick walls in the vertical direction. The stress distribution below the slab is not uniform and this can give rise to differential shortening in the brick wall that expands below the slab.

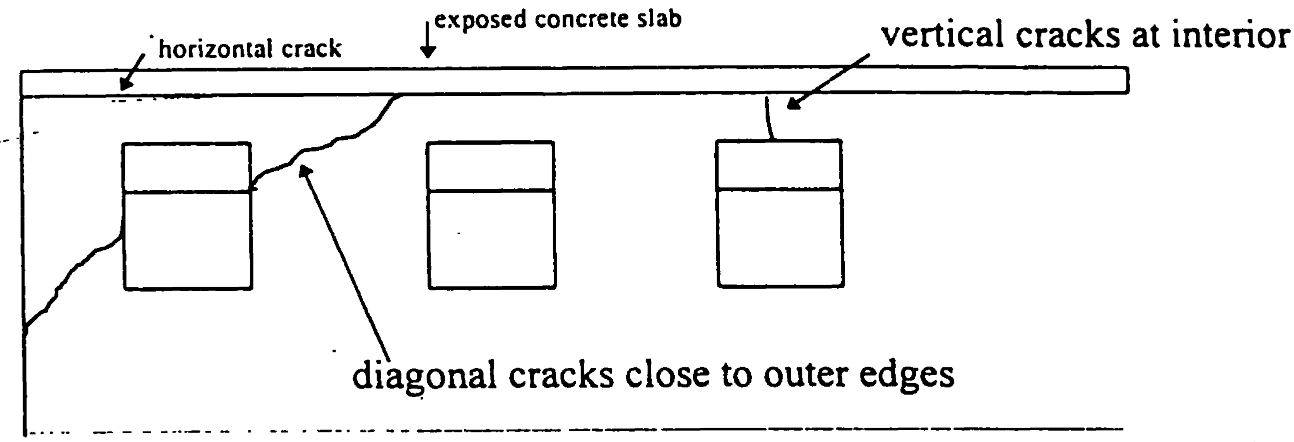

Figure 4: **Vertical, horizontal and diagonal cracks in a load bearing wall supporting an exposed concrete slab.**

Cracks due to Foundation Movement

The foundation movement that occurs in a brick wall structure can be either due to differential settlement or heaving of the foundation. Differential settlements often occur in weak clayey soils and this can lead to diagonal cracks as shown in Figure 5.

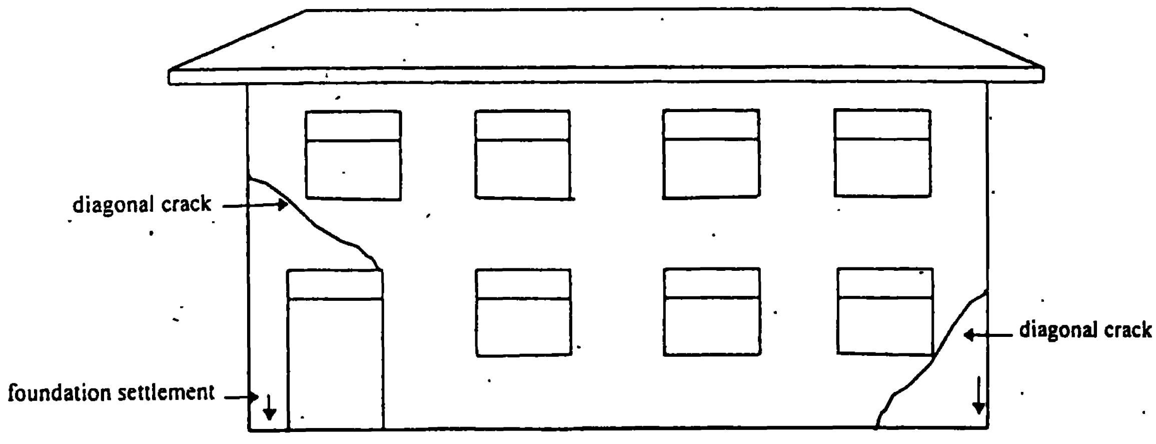

Figure 5: Diagonal cracks due to foundation settlements

Heaving of soil can occur when the sites are cleared of trees immediately prior to construction of a building. Heaving of soils can caused both diagonal cracks and vertical cracks as shown in Figure 6.

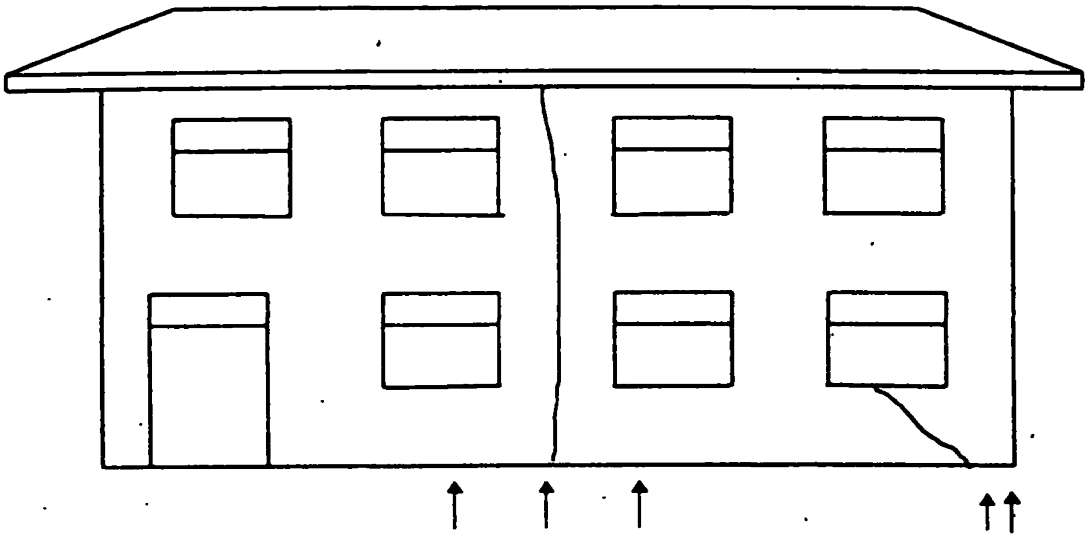

Figure 6: **Swelling of clay under the centre and the edge of a building and the cracking due to it**

Methods of Constructing Crack Free Load bearing Brick Walls

By taking adequate precautions, it is practically possible to construct load bearing brickwork structures, which would not show any signs of defects in the form of cracking. These precautions should be considered prior to starting the construction of the structure since some of them are applicable to site preparation, construction of foundations, walls, floor slabs, balcony slabs, roofs and finishes. Therefore, the builder has to be aware of these cracks and should take appropriate action to prevent the occurrence of undesirable cracking which often impairs the serviceability of brick wall structures.

The precautions can be summarised as follows:

1. The construction of crack free structures should be started at the site clearing stage. The site should be cleared of all large trees about one year prior to the construction of the structure whenever possible so that the soil will be able to regain naturally its moisture content during the rainy season.

2. A thorough soil investigation should be carried out at the site to identify the suitability of the soil. This can be done easily by using trial pits where the soil samples are inspected to identify the type of soil at every 0.3m depth up to a depth of about 1.5m - 2.0m, depending on the type of soil. This can be done easily by using trial pits where the soil samples are inspected to identify the type of soil at every *0.3m* depth up to a depth of about *1.5m - 2.0m*, depending on the type of soil. If undesirable soil types like peaty soil or clayey materials, which can shrink during dry spells are encountered, special precautions should be taken.

3. The foundation should be adequately tied so that it will be able to resist earthquake loads without disintegrating. Thus, the provision of a continuous tie shown in Figure 7 at DPC (damp proof course) level, which will connect all the internal and external walls, is highly recommended.

4. The brickwork should be constructed with bricks of length *200mm*, width 100mm, and a height of *50 mm*, since the use of smaller bricks will give a higher number of mortar joints, thus increasing the tendency for shrinking and cracking. The quality controlling measurements given in Section 4 should be followed at the brick selection and brickwork construction stages. The bricks selected should satisfy all the physical tests and should be constructed with adequate quality controlling measures.

5. It is advisable to provide a tie beam as shown in Figure 7 at the window sill level to prevent the occurrence of vertical thermal cracking close to the centre of the windows. These tie beams can also act together with the tie beam provided at the plinth level to resist settlement cracks. Thus, the foundation system given in Figure 7 can be adopted for laod bearing brick wall structures. Jayasinghe (1997) has shown that this foundation system can be effective against both settlement and heaving of soils. The amount of reinforcement provide can either be 2T10 or 3T10 and the detailed calculation method is also given in Jayasinghe's (1997) report.

6. It is not advisable to have exposed reinforced concrete roofs supported on brickwork in tropical countries like Sri Lanka, since the thermal expansion of the roof can cause diagonal cracks in the brickwork close to the external walls and vertical cracks in the interior of the building.

7. It is appropriate to provide a roof for all the balconies so that the amount of heat absorbed by the exposed concrete can be minimised. The heat absorbed can cause various types of thermally induced cracks.

8. A concrete beam similar to the one provided at the ground floor window sill level should be provided below the upper floor windows as well. However, this beam need not be continuous. It may be possible to precast these beams to reduce the cost. Alternatively, these can be cast by using bricks as formwork as show in Figure 8. It is shown by Annamalai et al. (1984) that the thin beams formed resist flexure. The main advantages are that the formwork cost can be eliminated, concrete volume can be reduced and delays due to forming the tie beam can be minimised. Thus, it would be possible to prevent cracking due to thermal stresses and uneven stress distribution by using thin tie beams at the window sill level. Since the thin tie beams can alter the load transfer mechanism for the vertical compressive loads, these can preferably be used in the upper floor brick walls where the compressive stresses due to vertical loads are lesser in magnitude.

9. The lintel provided over the upper floor windows may be made continuous to enhance the resistance of the structure to withstand accidental loads like trees falling on the roof during high winds. It would also resist the spreading of the roof due to weakening of the roof structure with time. These could be in the form of a thin lintel as shown in Figure 8

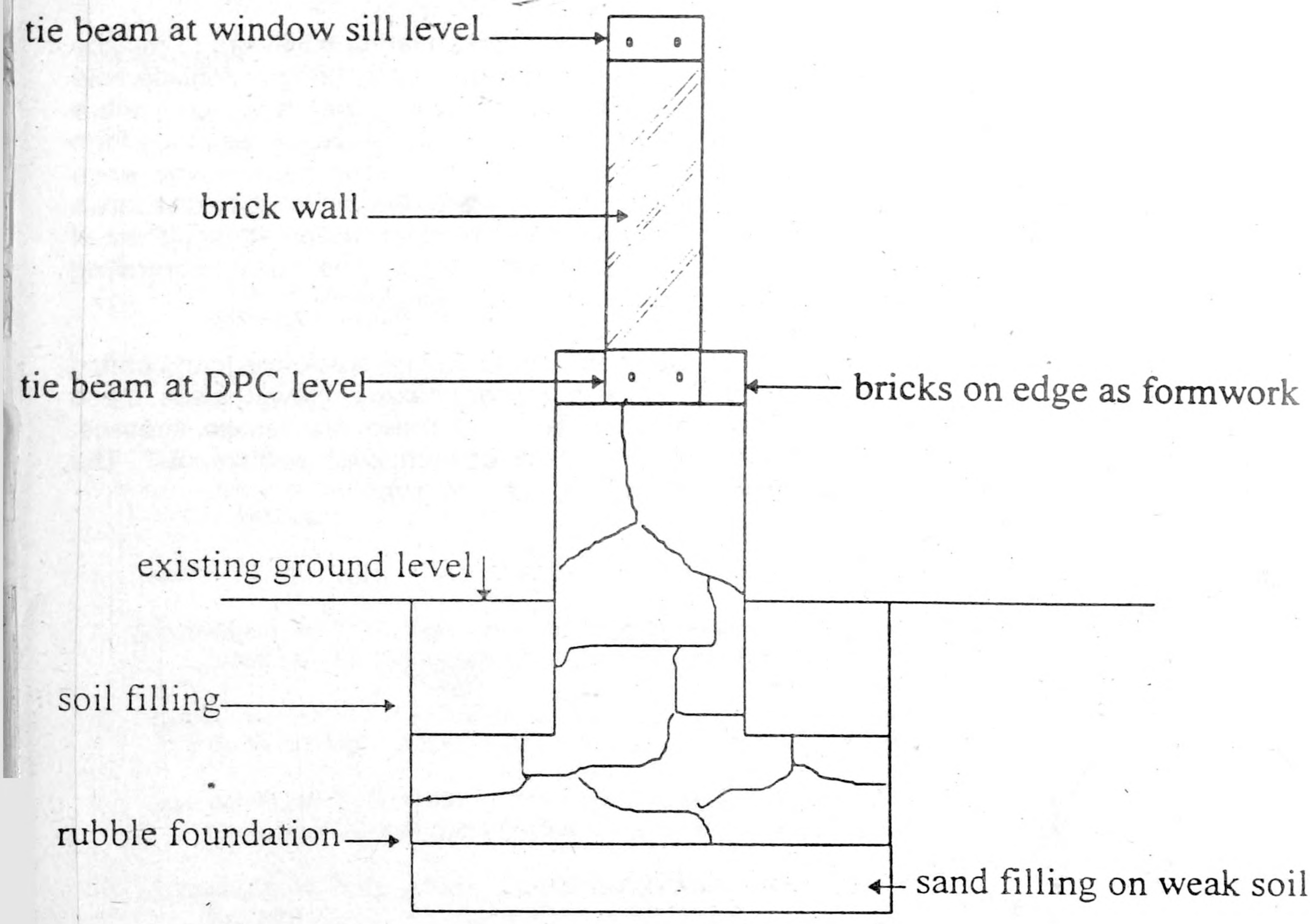

Figure 7: Rubble foundation with tie beams at DPC and window sill levels

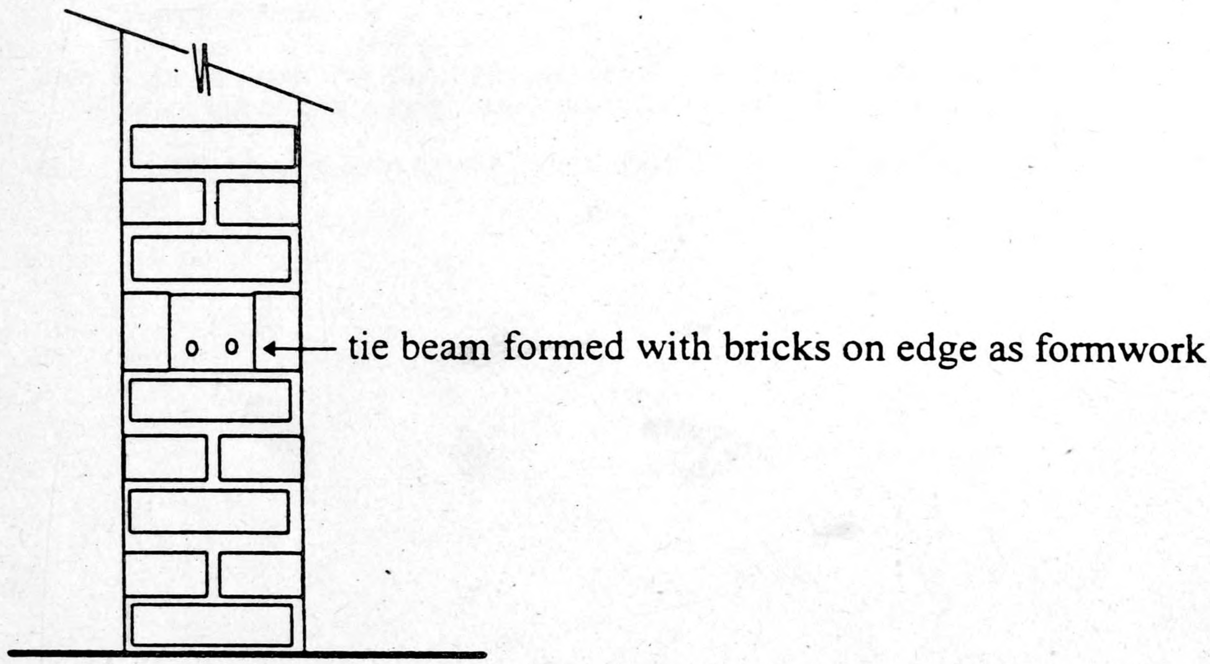

Figure 8: **Construction of thin tie beams where bricks on edge have been used as formwork.**

Conclusions

It is shown with a simple cost calculation that the use of load-bearing brickwork to replace the reinforced concrete frame construction with infill brick walls can bring a considerable cost saving. This can be extremely important when the building owner is working with a limited budget as in the case of housing sector where part of the finance comes in the form of a loan. It is stated that a characteristic strength of 1.5 N/mm^2 can be achieved when good quality bricks are used with 1:6 cement sand mortar where the bricks should satisfy a certain physical testing criteria. When this approach is adopted for design, a simple set of rules can be used as guidance at the preliminary design stage. The quality controlling measures that should be applied during the construction are also given.

The use of good quality bricks alone is not quite sufficient to ensure crack free load bearing brick wall buildings since, there can be stresses of secondary nature. Nevertheless, these stresses can cause cracking in brick walls since some of these are tensile stresses. Generally these stresses are due to thermal movement or foundation settlements. The methods that can be adopted to prevent such cracking are also given.

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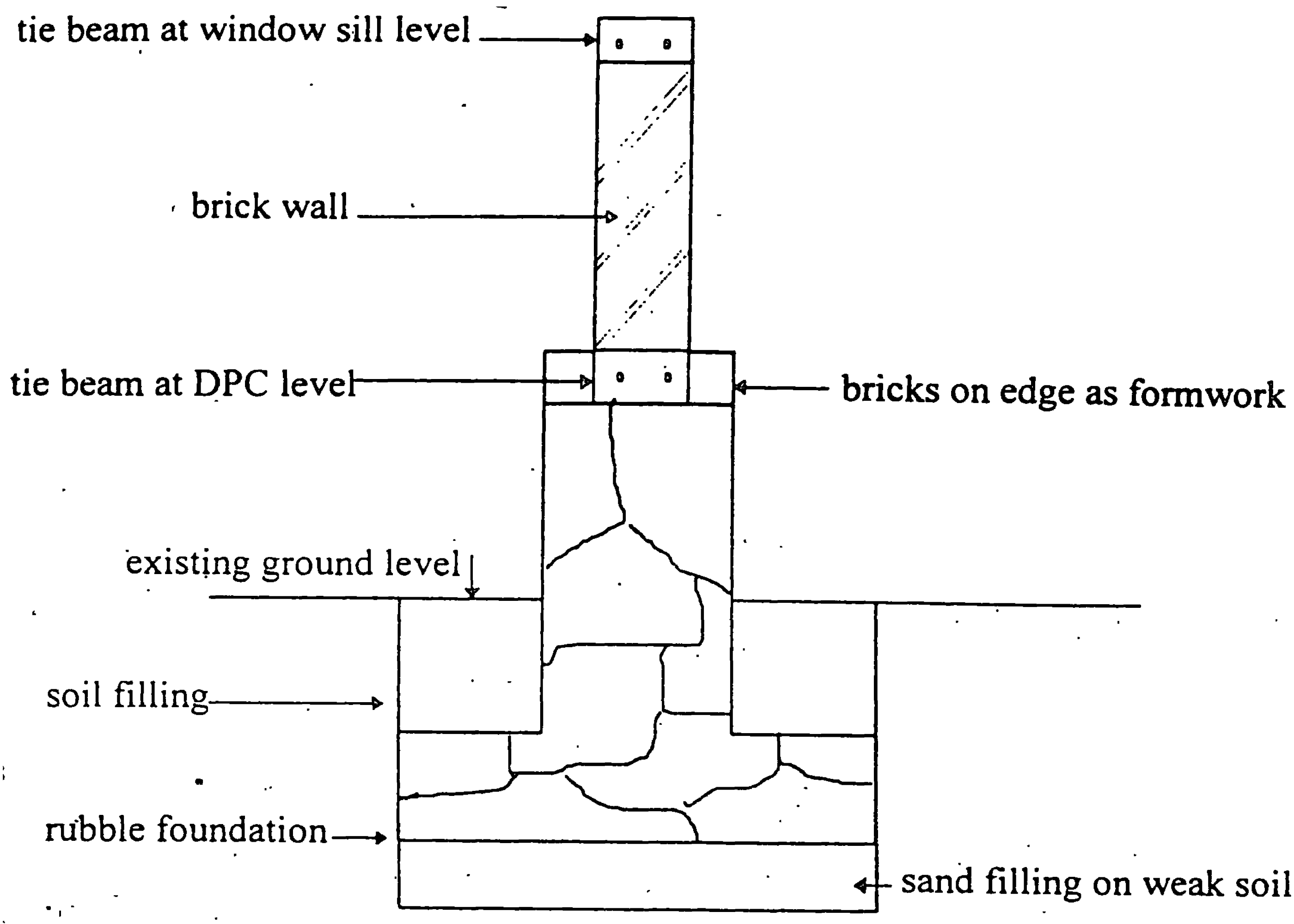
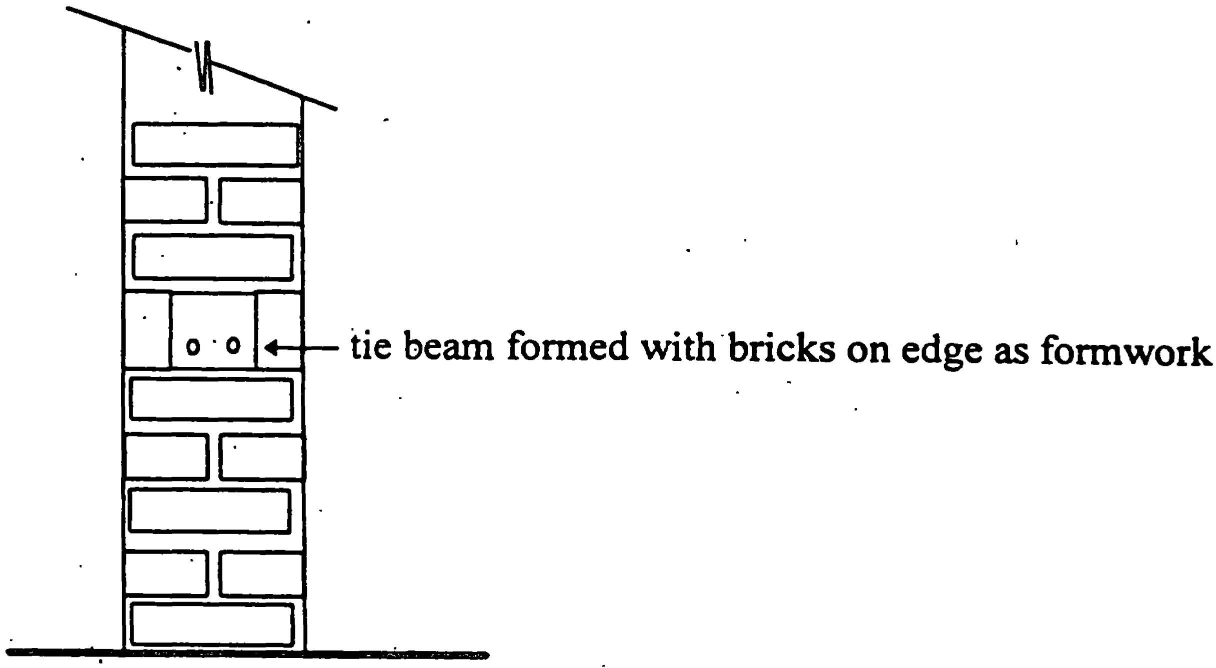


Figure 7: Rubble foundation with tie beams at DPC and window sill levels



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Conclusions

It is shown with a simple cost calculation that the use of load bearing brickwork to replace the reinforced concrete frame construction with infill brick walls can bring a considerable cost saving. This can be extremely important when the building owner is working with a limited budget as in the case of housing sector where part of the finance comes in the form of a loan. It is stated that a characteristic strength of 1.5 N/mm^2 can be achieved when good quality bricks are used with 1:6 cement sand mortar where the bricks should satisfy a certain physical testing criteria. When this approach is adopted for design, a simple set of rules can be used as guidance at the preliminary design stage. The quality controlling measures that should be applied during the construction are also given.

The use of good quality bricks alone is not quite sufficient to ensure crack free load bearing brick wall buildings since, there can be stresses of secondary nature. Nevertheless, these stresses can cause cracking in brick walls since some of these are tensile stresses. Generally these stresses are due to thermal movement or foundation settlements. The methods that can be adopted to prevent such cracking are also given.

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