USE OF REINFORCED BRICKWORK FOR CRACK FREE LOADBEARING CONSTRUCTION

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INTRODUCTION

Brickwork is a very good material for carrying compressive forces. It is also useful in carrying inplane forces and hence used to brace reinforced concrete frame structures. However, brickwork has certain weaknesses such as:

1. low tensile strength
2. low flexural strength
3. low bond shear strength between bricks and mortar
4. inability to resist differential settlements of foundations without cracking.

These weaknesses often lead to various types of defects in brick wall structures. When defects occur, considerable amount of money has to be spent on the rectification of those. If the cost due to the loss of utility during the repair is then added to the actual cost of repair, it becomes clear that the elimination of defects would give valuable financial benefits.

Very often, the structural significance of cracks tend to be exaggerated. This is a natural reaction of the owners or occupants of a building. Although, some cracks will be an indication of instability of the structure, but many others which look quite serious may have little or no effect on the stability; this is primarily because the brick wall buildings have a high factor of safety or because the affected area does not contribute to the stability of the structure.

Loadbearing brickwork buildings are constructed in Sri Lanka by adopting normal construction practices such as supporting a reinforced concrete slab directly on unreinforced brick walls. The door and window openings are provided with reinforced concrete lintels. The foundation often consist of random rubble work and generally a reinforced concrete plinth beam is used to tie the foundation. The buildings constructed with this normal method of construction often develop various types of cracks within one year of construction. This has often led to consider that loadbearing brickwork is not desirable for Sri Lanka due to low strength of bricks. The bricks manufactured in many areas of Sri Lanka are of low compressive strength and high water absorption type with extremely low tensile strength.

Reinforced brickwork is often used to replace the concrete lintels or reduce the size of those, thus achieving economy. Brick work can be reinforced in a number of ways. It is possible to improve the performance of brick work by embedding reinforcement in the bed joints or by using tie beams of small cross section to act in conjunction with the brickwork. The use of tie beams of small cross section is considered more appropriate in loadbearing construction due to superior durability and the possibility of using normal reinforcement with out galvanising. It was shown by Chandrakeerthy (1986) that low strength high water absorption bricks available in Sri Lanka can be successfully used for reinforced brickwork. In this paper, another application of reinforced brickwork is presented. That is its ability to resist tensile forces. It is shown that reinforced masonry can be very effectively used to minimise cracks in brickwork while performing its usual task of providing the flexural strength.

REASONS FOR DEFECTS

Defects in buildings can occur due to several reasons such as when the original design is inadequate, the building was not constructed in accordance with structural design, the workmanship is below standard, or the building has been subjected to forces and agents not allowed for in the design.

Major defects result from (Eldridge, 1976):

a. the application of forces, either externally or internally, greater than those which the building materials can withstand:- For example, excessive settlement of foundation or poor strength resulting from bad workmanship.

b. The changes of materials that take place with time:- As an example, the size of most porous building materials increase with an increase in their water content and vice versa. Often these changes will not be noticeable, but sometimes may result in defects of appreciable magnitude. The decrease in size when wet materials dry out leads to shrinkage cracks particularly noticeable in the early life of the building. On the other hand, the absorption of water or moisture may lead to expansion in ceramic products like bricks and tiles.

c. Changes in temperature of various parts of the building:- This is a common feature due to diurnal and seasonal changes of temperature. For a country like Sri Lanka, located close to the equator, the brick walls facing either north or south can be exposed to about 10-12 hours of direct sun light per day during certain parts of the year. Thus, considerable amount of precautions should be taken to keep the walls free of thermally induced cracks.

DEFECTS IN WALLS

Any defect either due to bad workmanship, thermal stresses or moisture movement of materials, would result in cracks especially in external walls. The cracks that occur in walls can be classified according to the direction as vertical, horizontal or diagonal. The direction of crack can be coupled with either straight or toothed for further information. These cracks are shown in Figure 1.

The construction of crack free brick work structures should start with good quality bricks. The bricks available in Sri Lanka vary from one manufacturing site to another. Therefore, certain precautions should be taken in selecting suitable bricks for construction. It has been suggested by Jayasinghe (1998) that physical testing of bricks can serve as an important indicator for the selection of good quality hand moulded bricks. It is based on a detailed testing programme carried out for locally available bricks. The most important physical test has been the ability of a brick laid on ground to withstand an impact caused by another brick falling from a height of 1.2 m without breaking. Such bricks have given a characteristic compressive strength in excess of 1.5 N/mm^2 when constructed with 1:6 cement sand mortar.

The other physical testing can be the checking for ringing sound by tapping two bricks together or inspecting a broken face of a brick for the uniform colour to evaluate the degree of burning and excessive pores.

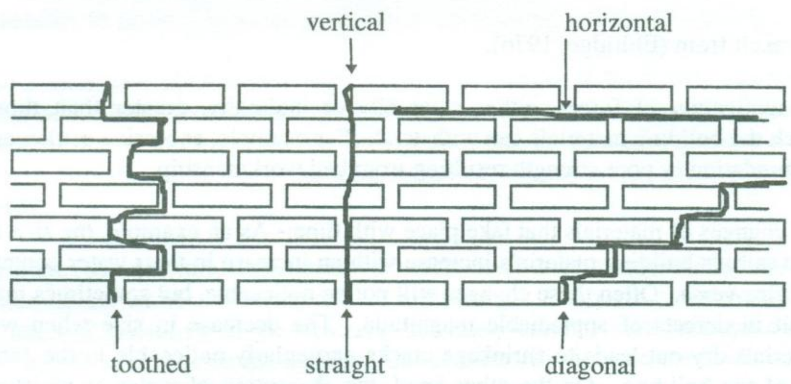

Figure 1: Forms of cracks in a brickwork

Vertical Cracks on External Walls due to Temperature Variation

Since Sri Lanka is a tropical country with long hours of sunshine, temperature induced cracks are a common feature on walls that are exposed to the direct sunlight. For a house of approximately rectangular shape with front facing south, the following exposure conditions will occur during an year. The front face will be exposed to the sun from

October to March everyday from the sun rise to the sun set. The amount of sunlight received by the wall depends on the length of the eaves and the shading offered by nearby trees. The rear face will be exposed to sun from May to September everyday from the sun rise to the sun set. The side facing east will receive sunlight from the sun rise until noon throughout the year. The side facing west will receive sunlight from noon until the sun set.

Out of these faces, the worst affected are those facing north and south since they receive direct sunlight for about *10-12* hours for at least five months of the year. The most common location for the occurrence of a thermal crack is the wall portion below a window as shown in Figure 2.

These cracks will generally appear at the end of the first five month spell of direct sunlight after the construction of a house build with normal practice in Sri Lanka. Initially, they appear as hairline *through cracks*. *Through cracks* are those that penetrate the full width of the wall, thus appear on both inside and outside face. Those cracks will gradually widen up to about *0.3-0.5 mm.* The crack is almost vertical and extends from the window sill level towards the foundation level. The crack width close to foundation level would be smaller.

It is possible to verify that these cracks are due to temperature variation by using the following simple technique. When a crack below the window is repaired with a non-flexible repair material like plaster of Paris at the end of a season of direct sunlight, the crack will not reappear until the next season. If the crack is due to any other reason, this type of seasonal variation would not be possible.

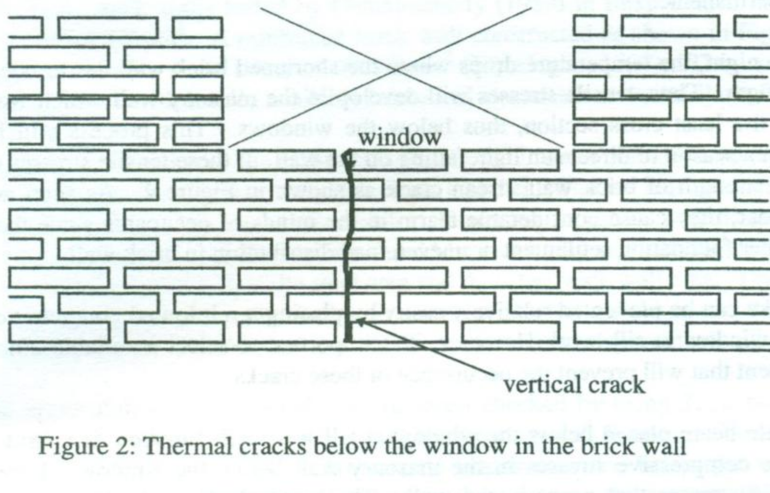

Figure 2: Thermal cracks below the window in the brick wall

The reason for these vertical cracks can be found by considering the cause for early thermal cracks in water retaining structures such as ground water reservoirs (Anchor, 1992). The concrete walls of ground water reservoirs can develop early thermal cracks which are almost vertical. These cracks occur in the following manner. A few hours after the concrete has been poured, the temperature of concrete can rise by about *30-50 °C* above the ambient temperature. However, the concrete that has been poured to the shutters would not be able to respond to the temperature rise by expanding freely. Any restraint to thermal expansion of concrete will give rise to compressive stresses in concrete, which will be relieved to a certain extent due to the creep of concrete resulting in shortening of concrete. Creep of concrete at these initial stages can be relatively high due to low strength of concrete.

When the temperature drops to the ambient after about three days of casting the concrete, the length of concrete available is less than the original length. Therefore, a smaller length than required would have to occupy the available length, thus giving rise to tensile stresses in concrete. If these tensile stresses are large enough, vertical tensile cracks will develop in the concrete. These cracks will appear as through cracks. In water retaining structures, these thermally induced cracks are controlled by providing sufficient amount of reinforcement.

The cracks that occur in brick walls can also be explained with reasoning similar to those given for early thermal cracking in water retaining structures. When brick walls receive a considerable amount of sun light over long hours, the temperature of the brick walls would rise by a few degrees. However, this expansion is generally restrained by cross walls, foundations, lintels or concrete floor slabs. Thus, compressive stresses of small magnitude can develop in brick walls. These compressive stresses would be highest at sections where the masonry wall area is minimum; generally below the windows. When subjected to compressive stresses, masonry shortens due to creep. It is reported by Hendry (1981) that about 50% of stresses in brick walls can be relieved by creep if the loads are permanent.

During the night, the temperature drops where the shortened brick wall has to occupy its original length. Thus, tensile stresses will develop in the masonry wall which would be highest at the least cross section, thus below the windows. This process will happen everyday in a season of direct sun light falling on the wall. If these tensile stresses exceed the tensile strength of brick wall, it can crack as shown in Figure 2. As soon as these cracks appear, they cause considerable alarm in the minds of occupants since they may suspect either foundation settlement or uneven load distribution in brick wall.

These cracks can be prevented relatively easily by placing a reinforced concrete tie beam below the window at sill level. However, it is important to select a suitable amount of reinforcement that will prevent the occurrence of these cracks.

The concrete beam placed below the window at sill level will function as a strut which relieves the compressive stresses in the masonry wall below the window. It can also resist tensile stresses that occur in the wall. The beam should have been sufficiently embedded into the wall on either side of the window.

Unfortunately, it is not possible to determine the exact reinforcement requirement since it depends on the temperature variation, orientation and creep characteristics of the wall. However, the minimum amount of reinforcement required can be calculated on the assumption that when the wall cracks, the tensile stresses in the masonry will be transferred to steel reinforcement. This is very similar to the assumption made in water retaining structures to determine the minimum amount of reinforcement (ρ_{crit}).

One of the problems faced here is finding the tensile stress carrying capacity of brickwork. The tensile strength of brickwork can be found by testing a brick wall supported on a concrete lintel in two point loading by using an arrangement as shown in Figure 3.

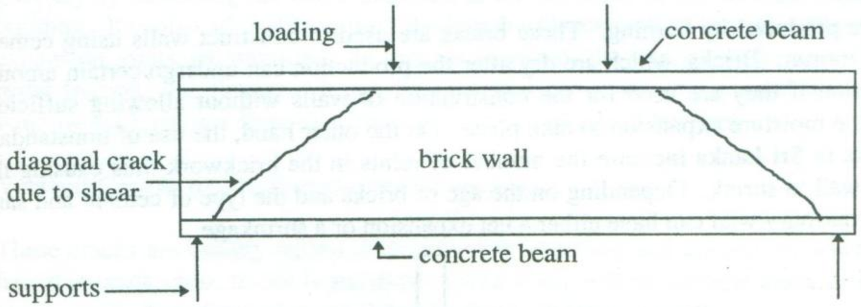

Figure 3: Testing of a reinforced brick wall in two point loading

The failure occurs due to principal tensile stresses induced due to shear stresses. The magnitude of the principal tensile stress is equal to the magnitude of the shear stress. Reinforced brick walls tested by Chandrakeerty (1989) in flexure have failed at a shear stress of 0.2 N/mm^2. A reinforced brick wall constructed as shown in Figure 3 also has given an ultimate shear stress of 0.2 N/mm^2 (Jayasinghe, 1997). Thus, it can be stated that brickwork with locally available bricks fail at a tensile stress of about 0.2 N/mm^2.

If a factor of safety of *1.5* is assumed, a value of *0.3 N/mm*^{2} should be used for the tensile strength of masonry; it should be noted that a higher value for tensile strength will give a larger steel area. The argument used for calculating minimum steel is that after tensile failure of brickwork, all the tension should be carried by reinforcements. Thus, $A_s/A_b = 0.3/(0.87 \times 460)$, where A_s is the steel area and A_b is the brick wall area. This gives an area of *126 mm*^{2} for high tensile steel with a wall of thickness *0.21 m* and the height below window of *0.8 m*. If mild steel is used, the reinforcement requirement will be *231 mm*^{2}.

The applicability of this calculation has been checked by using *2T10* bars that give an area of *157 mm*^{2} in several two storey loadbearing wall houses. These reinforcement were provided using *75 mm* x *210 mm* tie beams provided below the window. Not a single thermal crack has been observed in these houses three years after construction. However, such cracks have appeared within one year of construction in other houses without the tie beams when similar climatic conditions prevailed.

Thus, the use of tie beams with *2T10* high yield steel reinforcement below the windows is recommended. The size of the tie beam can be *75 mm* x *210 mm* for one brick walls. The thickness of *75 mm* is sufficient to give adequate cover for the reinforcement. It is reported by Chandrakeerthy (1989) that for reinforcement embedded in concrete, a cover of 30 mm can offer sufficient durability when used in reinforced brickwork. It is shown later that the reinforced brick wall formed due to this tie beam can be used to enhance the flexural strength so that brick wall will be able to resist cracking due to foundation settlements.

Vertical Cracks due to Moisture Movement

Bricks are produced by burning. These bricks are used to construct walls using cement and sand mortar. Bricks, which are dry after the production can undergo certain amount of expansion if they are used for the construction of walls without allowing sufficient time for the moisture expansion to take place. On the other hand, the use of nonstandard size bricks in Sri Lanka increase the number of joints in the brickwork thus causing the masonry wall to shrink. Depending on the age of bricks and the type of cement and sand used, the masonry wall can have either a net expansion or a shrinkage.

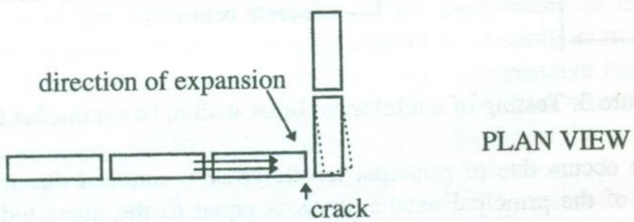

Figure 4: Cracking at the corners due to moisture or thermal expansion

The vertical cracks due to moisture expansion generally occur at the external corners. The same crack can also be caused due to thermal expansion as well. The nature of the crack is shown in Figure 4.

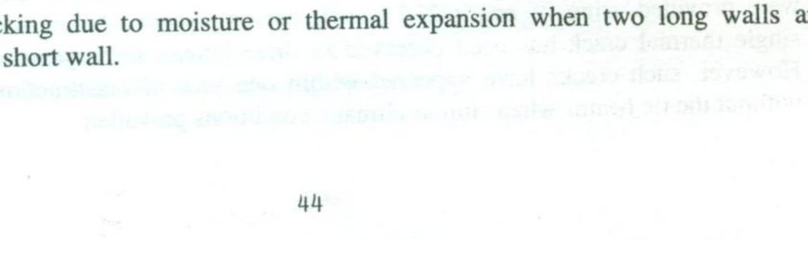

Figure 5: Cracking due to moisture or thermal expansion when two long walls are connected by a short wall.

When two parallel walls are connected by a short return wall on an external wall as shown in Figure 5, similar cracks can occur. These cracks are also a result of moisture expansion or thermal movement of two elevations of brickwork joined by the short return. When each section of brickwork on either side of the short return expands rotating the short return, the tensile cracks are caused on both sides. The expansion is generally accommodated without cracking by brick returns of the form shown in Figure 5 when those are generally more than *1.0m* in length. These cracks are not of any structural significance.

The shrinkage of brickwork due to shrinkage of mortar can not be prevented, but it is possible to distribute the shrinkage by connecting the brick walls together by a tie beam possibly by extending the beam provided at the sill level of the window right round the building. It is also advisable to limit the length of brick wall to less than *10.0 m*, when no expansion joints are provided. In this situation too, the reinforced brickwork is used to resist tension, not flexure. It can be seen that provision of a continuous tie beam at window sill level is a departure from the normal practice in Sri Lanka.

Vertical Cracks due to Foundation Expansion

These cracks are usually widest at the top of the building and diminishes downwards to a hair line crack close to the foundation. Often there will be a single crack in each of the two opposite elevations of the building as shown in Figure 6.

The defect, which is not quite common in regions where the rainfall is high, occurs when the foundations are laid on shrinkable clayey sub soils that is drier than normal due to either abnormal climatic dry conditions or to the ground having cleared of large trees immediately prior to the start of the construction of the building. The trees could have made the ground exceptionally dry and sufficient time has not been allowed for between the felling of trees and the start of construction (Eldridge, 1976).

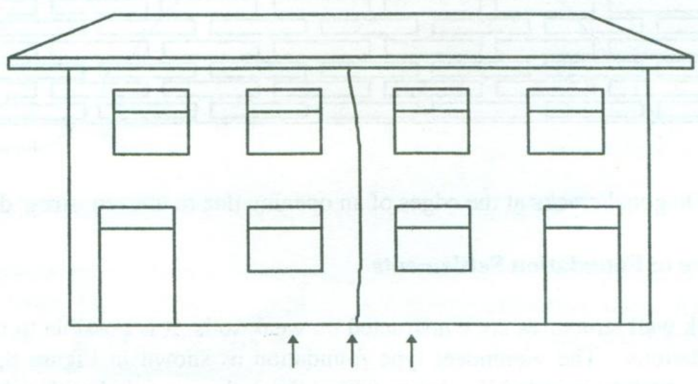

Figure 6: Swelling of clay under the centre of the building

The subsequent wetting of the clay sub-soil is accompanied by an expansion and the ground exerts an upward pressure on the foundation. This force may be considerable and can cause the vertical cracks of above nature. This type of cracks can be a possibility in masonry buildings constructed in the dry zone of Sri Lanka as soils with high clay content can shrink during the long dry spells and swell during the rainy season.

It is a good practice to do the site clearing well in advance so that a time lapse of about one year can be allowed before the construction commences. The provision of a continuous tie beam around the building at the window sill level may improve the flexural strength of brick wall building against heaving of soil. In this situation, reinforced brickwork is used in flexure.

Diagonal Cracks at the Edges of an Opening due to Uneven Stress Distribution

In loadbearing structures, it is quite common to observe diagonal cracks at the edges of an opening as shown in Figure 7. These cracks occur due to uneven stress distribution since the brickwork below the opening is stressed to a lesser degree. These diagonal cracks generally appear as hairline cracks.

In order to prevent these cracks, it would be necessary to ensure that the stresses in the brickwork is more or less uniform. This could be achieved to a certain degree by providing a concrete tie beam below the windows at the sill level which will provide the flexural strength required for the distribution of stresses. In this case reinforced brick wall acts in flexure.

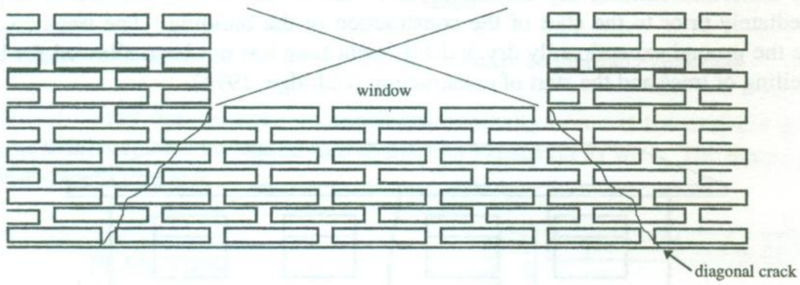

Figure 7: Diagonal cracks at the edges of an opening due to uneven stress distribution

Cracks due to Foundation Settlements

When brick wall structures are constructed on weak soils. It is possible to use Vierendeel type foundations. The vierendeel type foundation as shown in Figure 8, consists of a reinforced concrete inverted T - beam where the webs are filled with rubble instead of concrete, thus reducing the cost. However, in order to ensure composite action of top and bottom flanges, stub columns should be provided at an appropriate interval, generally considered as equal to the lever arm depth of the foundation.

Since this type of foundation is selected for soil where differential settlements are expected, the foundation design criterion can be based on the possible differential settlement forms (Tennekoon & Raviskanthan, 1989). For reinforced concrete frame structures, the *angular distortion* β is important whereas for loadbearing structures, the limiting deformation criterion defined in terms of *deflection ratio* is more important. The deflection ratio means the deflection at the centre of the wall to the length of the wall.

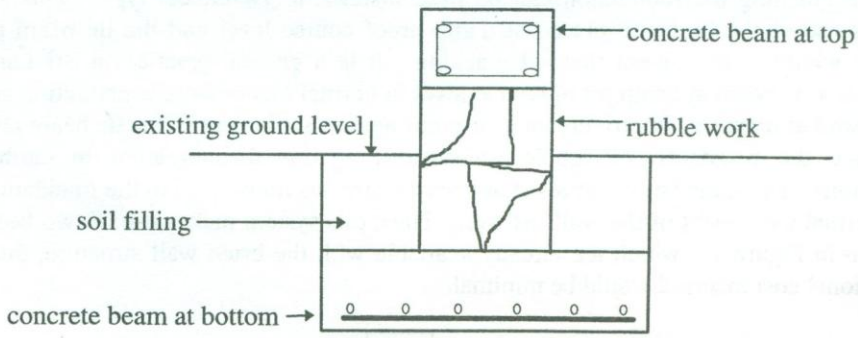

Figure 8: Vierendeel type foundation

For structures constructed with locally available bricks, the limiting deflection ratio for a load bearing structure is estimated as *1/2750* on the basis of a considerable number of actual measurements made on existing structures (Tennekoon & Raviskanthan, 1989). This compares well with the value given by Hendry et. al. (1981) for clayey soils, which is equal to *1/2500*.

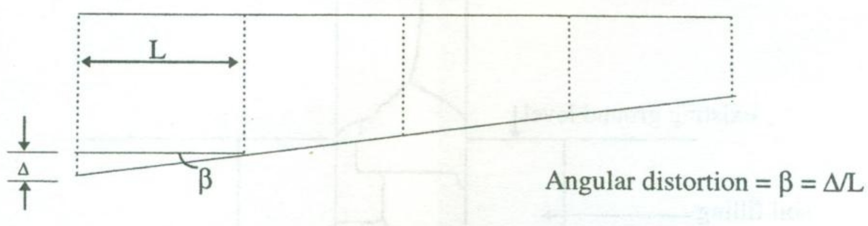

Figure 9: Definition of angular distortion for framed structures

The function of the Vierendeel type foundation is to stiffen the foundation so that it can resist the loads that would arise due to a limiting deflection ratio. As a result, the deflection ratio of the brick wall would be within the limits, and hence it would be possible to prevent cracking of the brickwork.

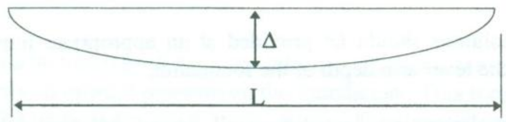

Figure 10: Definition of deflection ratio for loadbearing wall structures

The cost of Vierendeel type foundations can be much more than the normal rubble foundations. It is shown (Jayasinghe, 1997) that a composite reinforced brickwork and rubble foundation system where the brick wall has been given a flexural capacity instead of strengthening the foundation can be used instead of Vierendeel type. This system makes use of the tie beam placed at damp proof course level and the tie beam placed below windows to prevent thermal cracking. It is a general practice in Sri Lanka to provide a tie beam at damp proof course level in normal loadbearing construction since it is viewed as means of improving the resistance against settlement. This tie beam also can enhance the resistance of rubble foundations against disintegration in earthquake situations. The same beam can resist any tensile stresses transferred to the foundation due to thermal movement of the walls as well. Thus, this system makes use of two beams as shown in Figure 11, which are already available with the brick wall structure, thus, the additional cost incurred would be minimal.

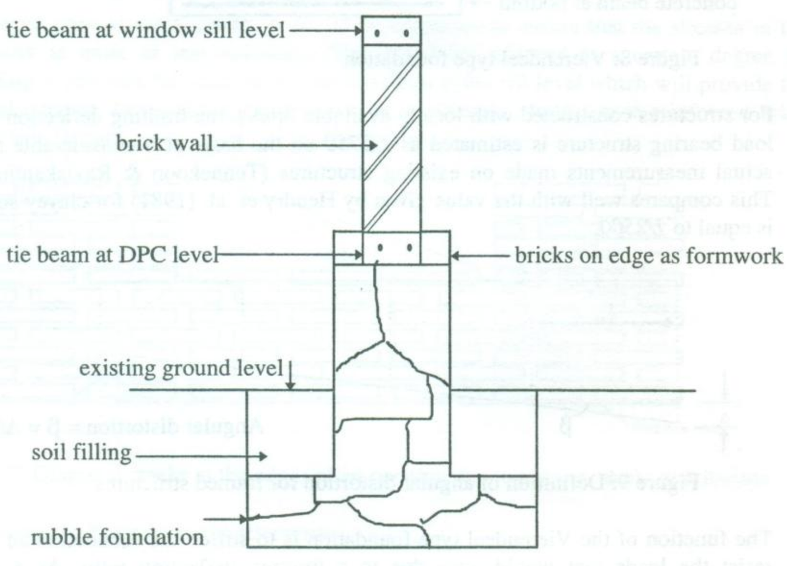

Figure 11: Rubble foundation with tie beams at DPC and window sill levels

In this composite system, it is important to prevent the flexural and shear failures. The calculation technique is presented with a case study in Jayasinghe (1997). In this case, the reinforced brickwork is used to resist flexure.

COST INCREASES DUE TO EXTRA TIE BEAMS

One of the key factors that discourage the owners of buildings in adopting robust building construction techniques is the high cost associated with such techniques. The tie beam introduced at window sill level is a departure from the normal construction practice in Sri Lanka and hence its adoption will depend on the extra cost involved. Thus, a cost calculation has been performed for a typical case where the cost of constructing a brick wall of length 3.0 m and height 2.7 m have been evaluated with a tie beam at lintel level and without it.

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 4300/=*
c.	Cost of $1m^2$ of shuttering	= *Rs 300/=*
d.	Cost of *1 Tonne* of reinforcement	= *Rs 48,000/=*

These rates include the cost of labour and materials.

Case 1:	Cost of brick wall of size *3.0m* x *2.7m*	= Rs *4455/=*
Case 2:	Cost of $0.04730m^3$ of concrete	= Rs *203/=*
	Cost of *0.0018* Tonnes of reinforcement	= Rs 86/=
	Cost of $0.45\ m^2$ of shuttering	= Rs *135/=*
	Cost of *3.0 m x 2.625 m* of brick work	= Rs *4331/=*
	Total cost of Case 2	= Rs *4755=*
	Cost increase is Case 2	= Rs *300/=*

If there is a length of about 60.0 m in an average house (about 100 m^2 at ground floor), the cost increase will be Rs 6000/=. With the present day costs, a house of 200 m^2 will at least cost Rupees one million and hence the cost increase due to providing an additional tie beam at window sill level will be in the range of 0.6% of the total cost.

CONCLUSIONS

It is practically possible to construct loadbearing brick wall structures which would not show any signs of defects in the form of cracking, by taking adequate precautions. 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 actions to prevent the occurrence of undesirable cracking which often impair the serviceability of the brick wall structures.

The precautions that have been explained in detail in this paper 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 so that the soil will be able to regain its natural 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 a trial pit where the soil samples are inspected to identify the type of soil at every *0.3m* depth up to a depth of about *1.5 m - 2.0 m*, 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 beam which will connect all the internal and external wall are highly recommended.

4. The brick walls should be constructed with bricks of length *200 mm*, width *100 mm*, and a height of *50 mm*, since the use of smaller bricks will give higher number of mortar joints, thus increasing the tendency for shrinkage cracking. 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 at the window sill level to prevent the occurrence of vertical thermal cracking close to the middle of windows. These tie beams can also act in composite with the tie beam provided at the foundation level to resist settlement cracks.

6. 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.

7. 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.

The loadbearing brick wall structures constructed by taking all these precautions have performed quite satisfactorily in Sri Lanka, without showing any cracks or distress.

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