STRATEGIES TO ENHANCE THE CYCLONE RESISTANCE OF SINGLE STOREY HOUSES WITH IMPROVED SUSTAINABILITY

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ABSTRACT

Countries with tropical climatic conditions closer to the equator generally have a significantly high population density. Due to various reasons among such communities, single and two storey houses are still popular than blocks of flats with low to medium rise buildings. One of the reasons may be the favourable climatic conditions that allow people to enjoy the garden spaces around their houses than trapping them to an upper floor of a multi-storey building. However, most of the single and two storey houses may not have sufficient input with respect to structural engineering aspects. Therefore, these structures are prone to disproportionate damages under extreme forces of nature. When such damages occur, it is possible to cause loss of life in addition to loss of property. The need to re-build will also arise which may need the use of building materials based on various natural resources again. This will be an extra burden to the environment in addition to the construction waste that is generated as part of the post-disaster re-construction activities. One of the strategies that can be promoted to improve sustainability is the provision of sufficient degree of disaster resistance as part of the original construction, though this may not be very attractive due to the prevailing perceptions about the extra costs involved.

Thus, development of strategies that will allow enhanced cyclone resistance that can be implemented as part of the original construction in a very cost effective manner will be of significant value as far as sustainable construction is concerned. This paper describes some strategies that have been specifically developed to increase the cyclone resistance of single storey houses built with commonly used building materials available in Sri Lanka to achieve this goal. The implications of strength parameters of locally available materials or locally manufactured walling materials will also be discussed when incorporated with the strategies presented.

***Key words**: Cyclone resistances, building materials, sustainability*

1. INTRODUCTION

During past few decades, the combined effects of world human population and human activities have caused substantial changes to the natural environment. It is predicted that the temperature of the world could rise by 1.2^0 C to 5.0^0 C in the next century due to global warming expected with increased greenhouse gas emissions. Such global temperature rises could bring severe climatic changes in the world. Likely climatic changes in the 21^{st} century include significant melting of mountain glaciers and polar ice-caps. As ice melts and sea water warms and expands, global sea level will rise from 30 cm to 1 m (Abbott, 2008). Another consequence of this is the increased incidence and intensity of tropical cyclones, as witnessed in the recent past. This also can be attributed to global warming since increased sea temperatures increase the amount of water vapor presents in the atmosphere, thus creating favourable conditions for the generation of tropical depressions.

In Sri Lanka, there exists a strong seasonality and localized nature of impacts to the North, North Central and North Eastern parts of the country mainly during the months of November and December (Zubair, 2006). Hence, it is possible to isolate the potential risk of damage from the whole of Sri Lanka. Since the landfall and magnitude can also be predicted very accurately before a cyclone strikes, people will be able to evacuate and moved into safe shelters. However, special care has to be given on cyclone resistant construction aspects to minimize the damage to properties.

Therefore, the provision of sufficient cyclone resistance in all built environments will be of extreme importance. Since the large structures such as multi-storey and large public buildings likely to have sufficient engineering input, the situation could be different with single and twostory houses.

2. OBJECTIVES AND METHODOLOGY

The main objective of this research is to present simple, cost effective and easy to implement strategies that can be adopted for single and multi-storey houses constructed with commonly used building materials in Sri Lanka with improved cyclone resistance. For this research the following methodology was adopted:

1. Questionnaire surveys were carried out and data collected on typical failure and damage mechanisms of low rise masonry buildings due to strong winds
2. Vulnerable elements in a typical building were identified and studied for improvements
3. Various cyclone resistant construction techniques which are already available were studied using literature
4. Few techniques that can be adopted using locally available materials were selected
5. Alternative building materials were tested for their strength characteristics.
6. Strategies were developed with special attention on sustainable construction techniques to enhance the cyclone resistance of single storey houses

3. EVIDENCES FROM CYCLONES

Improper design and poor construction practices, wind borne debris and wind driven surges could mainly trigger damages to structural elements under heavy wind conditions. The roof uplift is the commonest type of damage as indicated in Figure 1.

Figure 1: A house with a clay tiled roof. The roof covering material has completely blown away and some of the roof members have failed during the 24th November, 1978 Cyclone (Datum International)

Other possible types of damages to roofs include breakage of covering sheets, deformations and failures of hook-bolts, buckling or failure of roof truss members, etc. Roof angle also plays a vital role in preventing roof uplift. Generally, high roof angles are preferred.

The low pitched gable roofs will suffer more damage than the high pitched hipped or pyramidal shaped roofs. The "**A**" shaped gable ends and the area along the ridges of low pitched roofs will subject to higher uplift forces than the rest of the roof area. Once this uplift force exceeds the dead weight of the roof structure the roof will blown away (Arya, 2000).

Floating debris such as uprooted trees and debris of collapsed structures are responsible for another considerable portion of damages during high winds.

Once the roof has blown away, the weaken masonry walls could easily collapse due to lateral pressure also suffer from heavy winds due to the loss of restraint provided from the roof at top most level of the walls. Then, the weaken walls will collapse easily due to the lateral pressure induced by wind.

The presence of large openings and poor orientation of them are other reasons for the failures of walls. When openings present, the severe cyclonic winds can blow in through these openings and the consequent sudden increase in internal pressure can induce excessive lateral loads on walls

4. STRATEGIES FOR ENHANCED CYCLONE RESISTANTCE

Many strategies have been developed to enhance the cyclone resistance of houses. Some of the strategies have been discussed in this paper.

4.1 Guidelines for sub – structure

The cyclone storms are invariably accompanied by torrential rain and tidal waves (in coastal areas) resulting in flooding of low lying areas. The saturation of soil can reduce the bearing capacity and the receding tidal surges can cause scouring and liquefaction in sandy soils. This means, a sufficient depth and width should be selected for the foundations. It is also advisable to tie the foundation at plinth level with a tie beam.

4.2 Guidelines for super – structure

4.2.1 Use of Masonry

The commonly used masonry units are burnt clay bricks and cement sand blocks. The stability of walls under lateral wind loads depends on their thickness, height and distance between transverse supports. Less height, larger thickness and fewer spans make them more stable.

It is advisable to provide a damp – proof course at plinth level to stop the rise of pore water into the super structure. In order to prevent the rain water soaking into the walls, make roof projections beyond the walls by about 500 mm. Application of a cement plaster on external and internal faces of masonry walls can also add extra strength to the masonry panels. The walls must be designed to resist the out of plane lateral pressure adequately. For this, suitable walling materials with correct thicknesses and flexural strengths should be selected and the wall should be sufficiently buttressed by transverse walls.

It is shown with an experimental programme that the Compressed Stabilized Earth (CSE) walls also can perform in a similar manner as the traditional burnt clay brick walls when subjected to lateral loads. With low levels of pre-compression, the flexural strength of CSE walls can be considered as approximately 0.25 N/mm^2 or above. These values are comparable with the values given in BS 5628: Part 1: 1992 for walls constructed with burnt clay bricks of having a compressive strength of 5 N/mm^2 and water absorption above 12 %. With the other comparable test results available on compressive strength parameters, it can be stated with confidence that CSE bricks, blocks and rammed earth can be considered as viable and safe alternatives for the single leaf external and internal load-bearing walls of single and two storey houses. Such single leaf walls are generally used for houses in countries with tropical climatic conditions. Due to dimensional stability and the physical appearance of these materials, the walls can be left un-plastered. This will be a great move towards green construction techniques.

A small building enclosure with properly interconnected walls is ideal. Buildings having long walls should be avoided as in Figure 2.

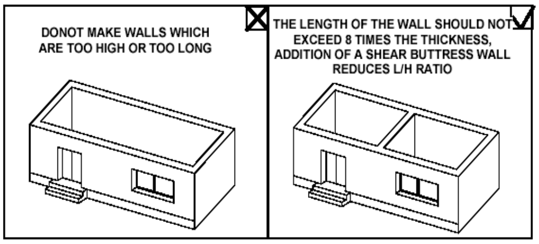

Figure 2: A desirable arrangement for partition walls

4.2.2 Use of reinforced concrete columns

In cyclone prone areas it is advisable to have a minimum of four reinforced concrete columns at four corners of a building, provided that the layouts are symmetrical (i.e. rectangular or square in shape in most cases). In addition to the tie beams at plinth, window sill and lintel levels, both columns and external walls should be again connected together ideally at the roof level using a continuous roof beams to make the structure to behave as a single confined body as shown in Figure 3. Instead of a roof beam, a continuous lintel band can be used since it is having further advantages like confinement of the openings

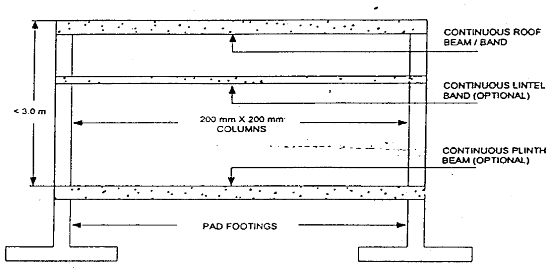

Figure 3: The preferred locations for tie beams

4.2.3. Orientation and size of openings

The total length of all the openings located between two consecutive supports should be limited to 50% in case of single storey, 42% for two storey and 33% for three storey houses (National housing development authority, 2005). In addition, these should have proper or strong locking mechanisms. Otherwise, a failure of any door or window on windward side can multiply the positive wind pressure inside the building

4.2.4. Layout and orientation of the building

A symmetrical building about both axes with a compact plan-form shown in Figure 4 is more stable than a zigzag plan, having empty pockets. The building should be oriented in such a manner that the shortest span length of the wall faces the windward direction as in Figure 5.

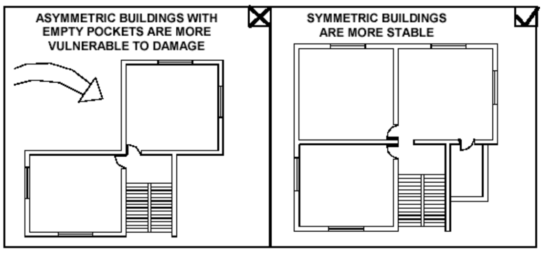

Figure 4: Effect of building layout

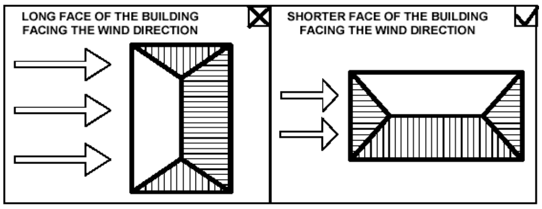

Figure 5: Desirable orientations for buildings

4.2.5 Shutters for openings

Failure of any door or window on windward side may increase the positive pressure inside. Therefore, all the openings should have strong closing / locking arrangements, all glass/wooden panels be securely fixed and all door/window frames should be fixed into walls through holdfasts. Use of smaller panel sizes is another good practice to minimize the damages from excessive pressure and wind borne debris. Glass panes can be further strengthened by pasting a thin plastic films or paper strips.

4.3 Guidelines for roof-Structure

The commonest type of roofing material is the cement fibre sheets. The dead weight of a cement fibre sheet roof with a timber structure (0.3 kN/m^2) is less than that for a clay tile roof with a timber structure (0.4 kN/m^2) (Chandrakeerthy 1996 & 1997). Since the cement fibre sheeted roofs suffer more damage from roof uplifting than the clay tiled roofs, effective means of increasing the dead weight of roof structure and anchoring mechanisms are of high priority.

Use of concrete or masonry strips above the roof covering material can also increase the roof dead load. Further, the use of tie beams and stub columns are two economical and effective ways of holding down the roof structure.

The uplifting forces will be a minimum when the roof angles are higher. The preferable roof angles for various roofs covering materials are shown in Table 1 (Clarke et al., 1979). However the slope of a light weight roof should be at least 22-30 degrees, to minimize wind uplift.

Table 1: Preferable roof angles with roof covering materials (Clarke et al., 1979)

Roof covering material	**Preferable roof angle (degrees)**
Calicut clay tiles	20 or steeper
Corrugated asbestos cement sheets	10 or steeper
Corrugated galvanized iron sheets	10 or steeper

When light weight (Galvanized iron or Cement fibre sheet) roof covering materials are used in low–pitched roofs, they should be strongly held down to joists, with fastenings not exceeding 1.5 m spacing in both directions. Also joists should be properly tied to rafters (as in Figure 2) and the rafters to the wall plate (as in Figure 3).

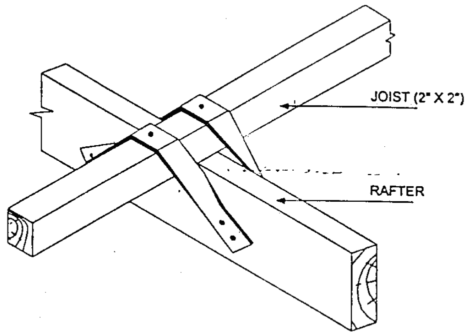

Figure 2: Joists should be fixed to the rafters

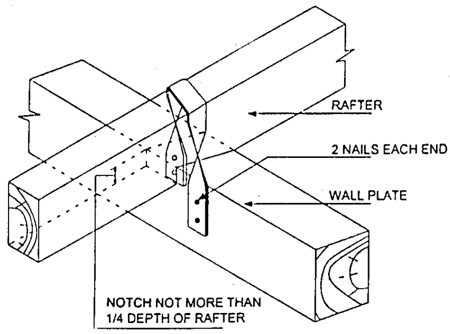

Figure 3: Rafters should be fixed to the wall plate

The best roof against cyclone is undoubtedly a concrete roof. A minimum thickness of 100 mm and minimum grade 20 concrete can be used. This can also prevent water ingress associated with conventional roof covering materials in heavy wind situations. Columns are essential to support this type of roof, and a roof beam can be easily cast integrally with the roof. In addition, a concrete slabs will be helpful in providing adequate indoor thermal comfort as well.

The reinforcement bars should be extended from the columns to the tie beam at the roof level with a roof beam of at least 200 mm in depth as shown in Figure 4. This can be achieved by bending the reinforcement at least 300 mm into the beams. In order to provide sufficient anchorage to the wall plate, 10 mm diameter threaded bars can be cast into the roof beams in about 1.5 m intervals with an L-bend of about 100 mm as shown in Figure 4.

However, these precautions could lead to the uplifting of the whole roof as one unit unless properly fixed to the walls. One of the best defenses against uplifting is to anchor the roof beam with stub columns to the lintel beam. The normal practice in Sri Lanka is to curtail the internal walls at ceiling level. Therefore, it would be essential to raise the walls above the ceiling level sufficiently so that the roof structure can be properly anchored with the weight of the wall.

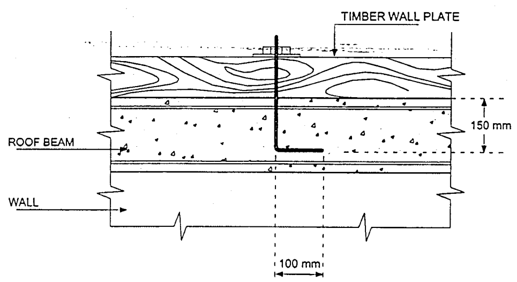

Figure 4: Anchoring of roof skeleton to the continuous roof beam

A design study has indicated the following minimum heights for different types of commonly used cement sand blocks and burnt clay bricks

1. Hollow cement sand blocks of 100 mm thickness = 1.74 m
2. Hollow cement sand blocks of 150 mm thickness = 1.16 m
3. Hollow cement sand blocks of 200 mm thickness = 0.87 m
4. Solid cement sand blocks of 100 mm thickness = 0.95 m
5. Solid cement sand blocks of 150 mm thickness = 0.63 m
6. Half brick thick walls (130 mm thickness) = 0.81 m
7. One brick thick walls (240 mm thickness) = 0.44 m

Gable walls can also be strengthen by raising the internal partition walls up to the gable wall height. These walls can then partition the gable walls into few panels thus ensuring adequate lateral support to the walls. With high roof angles, these supports can be stepped to achieve sufficient heights.

In this paper qualitative assessments of some simple remedial measures have been presented with special attention on cyclone. Although they appear as straightforward techniques, ignorance of such simple measures have often led to major failures. This can be easily achieved at a relatively low cost by mixing the available sand with laterite soil and re-compacting. Thus, the adoption of such simple and cost effective solutions should be strongly encouraged and may also form the basis for survival of masonry houses with more deliberately implemented disaster resistance enhancement features.

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