GUIDELINES FOR BUILDINGS AT RISK FROM NATURAL DISASTERS

A response to the tsunami of 26/12/2004 &

A contribution to the task of reconstruction

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CONTENTS

1. DESIGN AGAINST NATURAL DISASTERS

1.1. In addition to the normal task of designing a building to not to *fall down* under gravity, buildings must be prevented from being *pushed sideways* and *lifted off upwards* when subjected to cyclones, flooding and earthquakes.

1.2. This calls, in general, for the introduction of *steel reinforcement* into the building envelope. For single storey buildings not subject to cyclones, flooding and earthquakes, the use of steel reinforcement is best avoided, as it not only increases cost, but also introduces the inevitable onset of corrosion in due course.

1.3. In addition, where resistance against cyclones and flooding is concerned, it is desirable to *increase the weight* of structures, contrary to the usual imperative to reduce weight for economic reasons.

1.4. ***Earthquakes*** can occur anywhere, although their intensity is low in Sri Lanka; hence, moderate provision for earthquakes may be sufficient. ***Cyclones*** are frequent on the East Coast; special provisions to resist uplift are essential not only near the coast, but also in the entire Eastern and Northern Provinces. ***Flooding*** considered here is mainly coastal flooding, inclusive of tsunami effects; any building within 500 m of the coastline or 3 m elevation from mean sea level (which we shall call the "Coastal Zone") should be designed according to these guidelines; the above limits should read as "1 km of the coastline or 5 m elevation from mean sea level" for the East Coast.

1.5. The guidelines below are given mainly for single storey construction that may not be based on engineering design calculations. They also relate mostly to conventional building technology; however, the underlying principles, especially in Section 2, are relevant to any technology that is used. Multi-storey construction must be carried out after carrying out proper engineering designs and producing structural drawings – this will facilitate any future assessment of the building (e.g. for change of use or ownership) and add value to it. However, some recommendations for multi-storey building layouts are given in Section 9. Each of the recommendations below is followed by a set of up to 3 letters, where **F** stands for flooding, **C** for cyclones and **E** for earthquakes, emphasizing what the recommendation is for; if the letter is in bold type, that recommendation is very important for resisting the natural disaster corresponding to the letter. Also, the sub-sections titled "Essential requirements (**A**)" are clearly more important than those titled "Desirable features (**B**)".

2. GENERAL PRINCIPLES

2.1. The building must be held down to the foundation. Hence at least 4 reinforced concrete ***columns*** at the four corners of the building are required. These should be of minimum cross section 150 mm x 150 mm, with 4 tor steel bars of at least 10 mm diameter; column stirrups can be 6 mm diameter mild steel at 120 mm intervals. The column should be integral with the walls, to ensure that the walls are not sheared away. The steel reinforcement in the column should have a minimum of 25 mm clear concrete cover. The column can be built in two ways. It can be constructed inside one half of a 200 mm thick hollow block into which concrete is poured after creating a 150 mm x 150 mm space through the block; the through blocks in alternate courses

will then face in mutually perpendicular directions, but will have a common opening 150 mm x 150 mm or so (Fig. 1). Alternatively, the concrete should be poured in after constructing the walls, but GI stirrups should be placed at every 300 mm to 400 mm in the masonry to stick into the column (Fig. 2); or some other technique used to key in the walls to the columns. For wall lengths exceeding 6 m, an additional intermediate column along that wall should be introduced. These columns (and the pad footings described below), are essential for buildings in the Coastal Zone subject to *flooding*, especially from tsunamis. They are also quite important for resistance against *cyclones*, and will considerably improve resistance against *earthquakes* too. [**F**,C,E]

2.2. Below ground level, the column should be of size 200 mm x 200 mm and be connected with a concrete ***pad footing*** of minimum size 750 mm x 750 mm x 150 mm, with the column reinforcement bent at least 300 mm into the footing. The footing reinforcement can be 6 nos. 10 mm tor steel in each direction, i.e. at around 150 mm spacing, with a minimum cover of 40 mm. The formation level of the footing should be at least 1.0 to 1.5 m below ground level (Fig. 3). [**F**,C,E]

2.3. The columns and walls should be connected together, ideally at the roof level. These ***roof beams*** connecting the columns should be at least of depth 200 mm. This will ensure that frame action and load transfer from walls to frames can take place in the presence of columns. The tops of other (internal) walls can be connected to these roof beams using a 100 mm deep ***roof band***. If there are no columns (e.g. for buildings in areas not subject to flooding and cyclones), a continuous horizontal reinforced concrete element can be used to tie all walls together and improve their resistance to a minor earthquake; in such cases, it may be better to use a ***lintel band*** rather than a roof band, since the openings will be confined thereby and since lintels may have to be provided anyway. (If a lintel band is used in place of a roof beam or band, and it is desired to provide some resistance against roof uplift due to cyclones too, this can be achieved by providing vertical ties within the wall from the lintel band to wall plate level). This simple horizontal linking of walls is probably the single most important element for strengthening buildings, as it will provide various kinds of resistance against almost *all natural disasters* (Figs. 4 and 5). [**F**,**C**,**E**]

2.4. The reinforcement from the columns should be anchored to the roof beams, by bending them at least 300 mm into the beams. Threaded 10 mm bars should be cast into the roof beams at around 1.5 m intervals, in order to hold down the wall plate; the bars should have an L-bend of around 100 mm (See also Section 7). The slope of a lightweight ***roof*** should be at least 22-30^{o}, to minimize wind uplift. Roofing sheets should be used in preference to tiles. Such sheets should be fixed to the underlying roof timber at intervals not greater than 1.5 m in both directions. This provision is important for all roofs and especially for those in *cyclone* prone areas. The best roof against cyclones is a concrete roof, provided thermal comfort and watertightness issues are addressed. Columns are essential to support this type of roof, and the roof beams can be cast integrally with the roof. [**C**]

2.5. For *flooding* and *cyclonic* conditions, ***walls*** should be made as heavy as possible; if hollow blocks are used they should be at least 200 mm thick, and if 100 mm thick walls are used, they should be of solid blockwork or brickwork. Such walls would provide a basic level of thermal insulation and rain protection too. Where flooding

and cyclonic conditions do not prevail, minimizing the wall weight is desirable. The sizes of ***openings*** on walls should be such that the aggregate width of openings on any wall do not exceed 50% of the width of that wall. [**F**,C]

2.6. The ***materials*** used should be of good quality too, especially since excessive loads may have to be resisted. For binding mortar, the mix proportions should not be leaner than 1:6 cement:sand. For making cement blocks, the proportions should be 1:10 with cement and sand (or quarry dust); it can be made 1:7:10 using cement, sand and 6-8 mm aggregate chips. Blocks should ideally not be used until least 1 month (or even 2 months) after casting, so that most of the shrinkage is over before the block is placed in the wall. For concrete, the quality should be at least grade 20, which can be achieved by using a 1:2:4 mix of cement, sand and coarse aggregate. (For multi-storey buildings near the coast, a minimum concrete grade of 25 is advisable; this can be achieved by using a 1:1½:3 mix, or using a 1:2:4 mix with around 15% extra cement). [**F**,**C**,**E**]

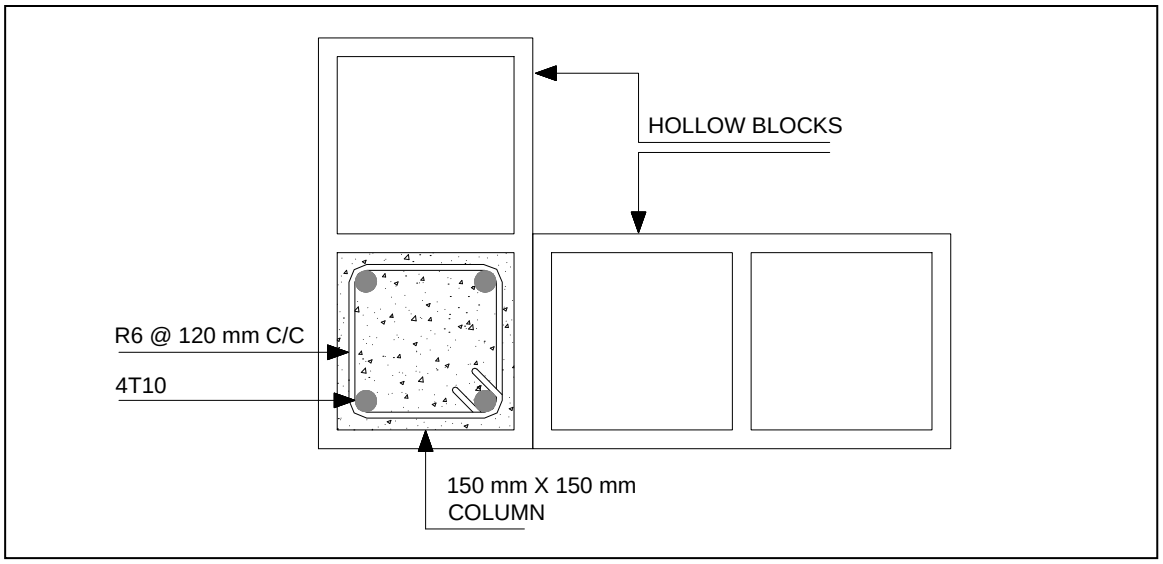


Fig: 1

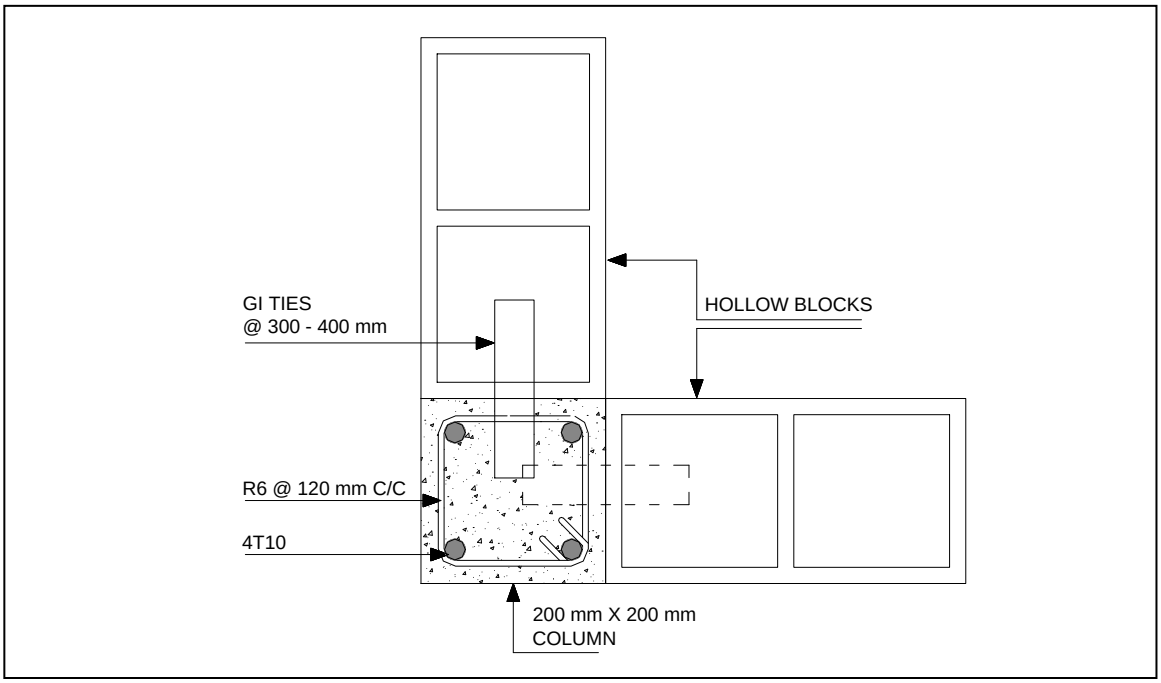

GI TIES
@ 300 - 400 mm
HOLLOW BLOCKS
R6 @ 120 mm C/C
4T10
200 mm X 200 mm
COLUMN

Fig: 2

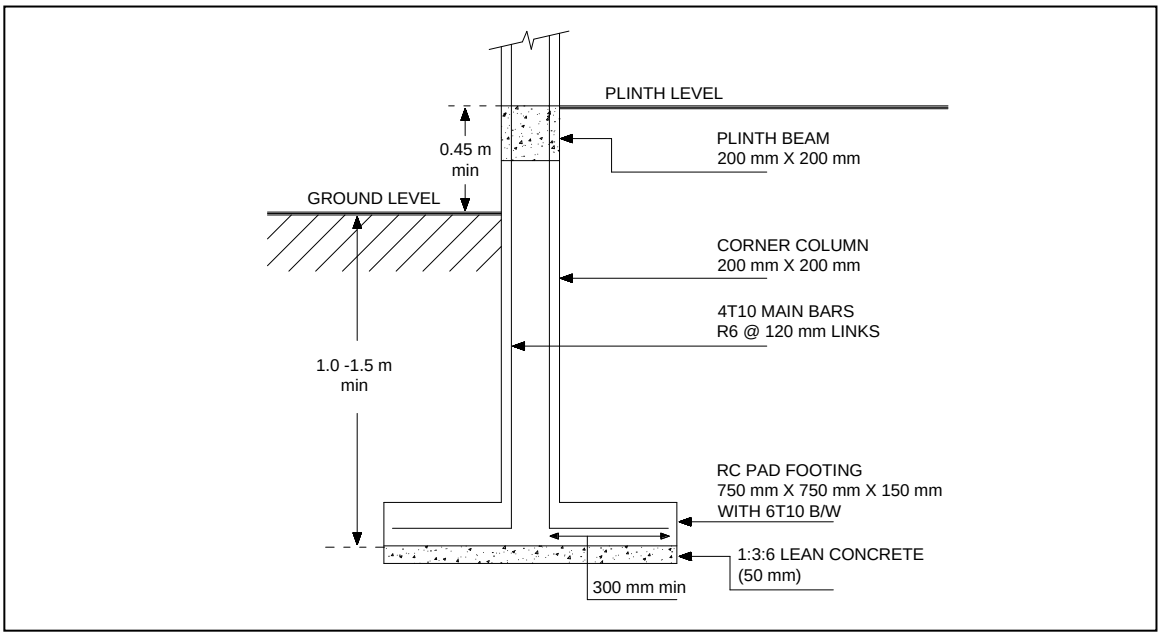

PLINTH LEVEL
0.45 m
min
PLINTH BEAM
200 mm X 200 mm
GROUND LEVEL
CORNER COLUMN
200 mm X 200 mm
4T10 MAIN BARS
R6 @ 120 mm LINKS
1.0 -1.5 m
min
RC PAD FOOTING
750 mm X 750 mm X 150 mm
WITH 6T10 B/W
1:3:6 LEAN CONCRETE
(50 mm)
300 mm min

Fig: 3

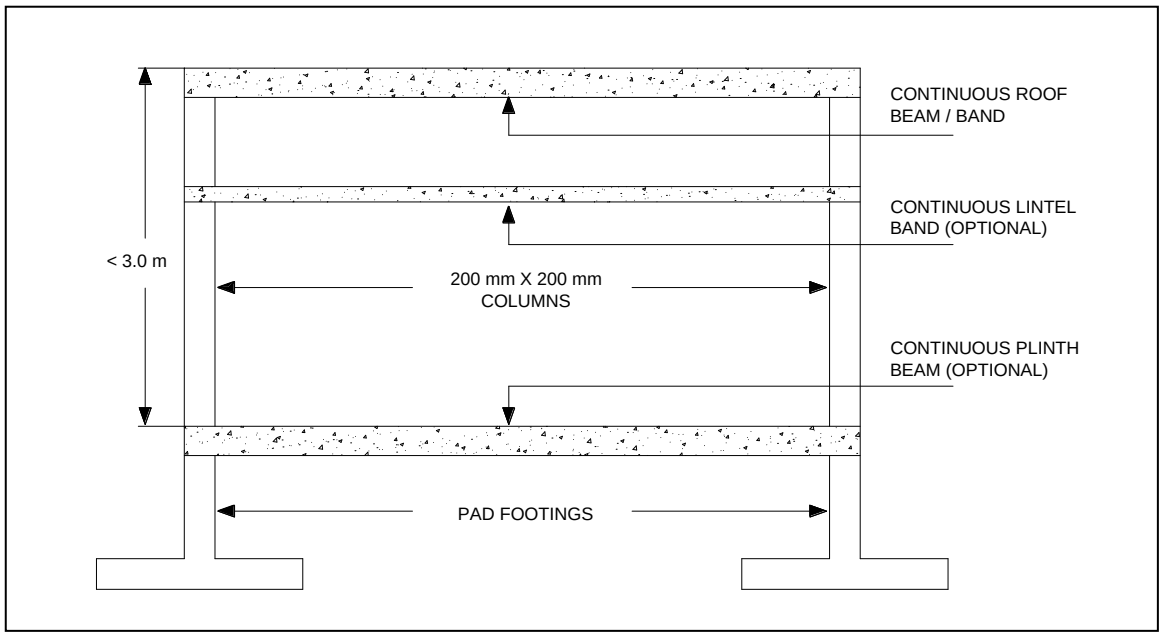

CONTINUOUS ROOF
BEAM / BAND
CONTINUOUS LINTEL
BAND (OPTIONAL)
< 3.0 m
200 mm X 200 mm
COLUMNS
CONTINUOUS PLINTH
BEAM (OPTIONAL)
PAD FOOTINGS

Fig: 4

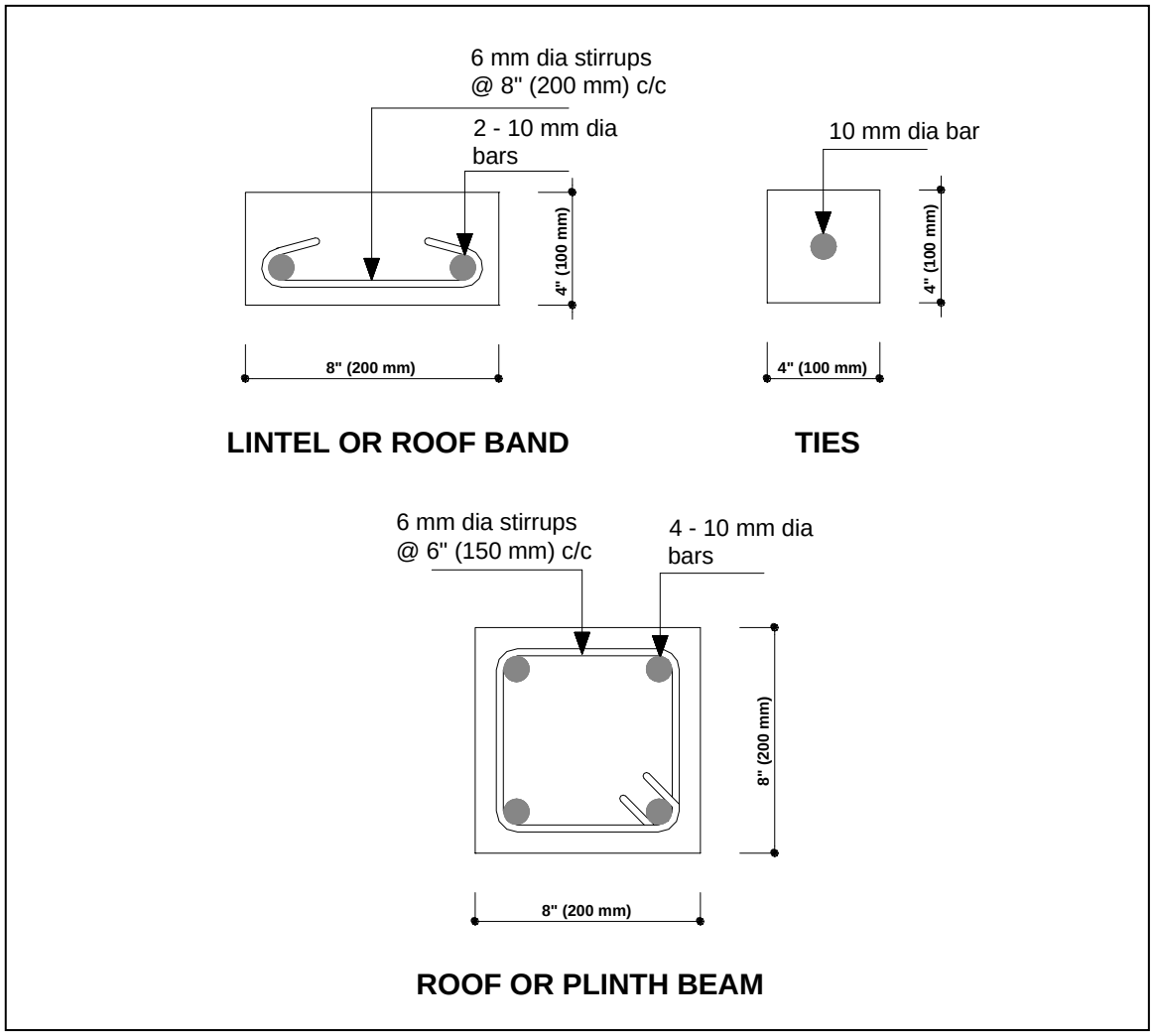

6 mm dia stirrups
@ 8" (200 mm) c/c
2 - 10 mm dia
bars
4" (100 mm)
8" (200 mm)
LINTEL OR ROOF BAND
10 mm dia bar
4" (100 mm)
4" (100 mm)
TIES
6 mm dia stirrups
@ 6" (150 mm) c/c
4 - 10 mm dia
bars
8" (200 mm)
8" (200 mm)
ROOF OR PLINTH BEAM

Fig: 5

3. SITING OF BUILDINGS

3.A. Essential Requirements

3.A.1. Buildings should not be constructed on the shore itself. [**F**,C]

3.A.2. Buildings should not be constructed in areas that are below sea level, especially within the Coastal Zone. [**F**]

3.A.3. Buildings should be located via stable foundations on soil strata having no susceptibility for liquefaction due to flooding. [**F**]

3.B. Desirable Features

3.B.1. Areas behind mounds (Fig. 6) or vegetation (Fig. 7) are preferred in order to provide natural shielding; however dwellings should not be constructed too close to large trees, in case the uprooting of trees during a cyclone causes disproportionate damage. [F,C]

3.B.2. The Coastal Zone may suffer from flooding due both to storm surges and tsunamis. Site selection should avoid areas likely to be submerged. It is desirable to locate the site such that it is: [F]

a. At least 100 m from the shore (200 m on the East Coast)
b. 3 m above Mean Sea Level (5 m above MSL on the East Coast)

3.B.3. The sites need to be close to the original settlement. It should preferably be within a distance of 1 km from the original settlement so as to facilitate the schooling of children and the livelihoods of fishermen.

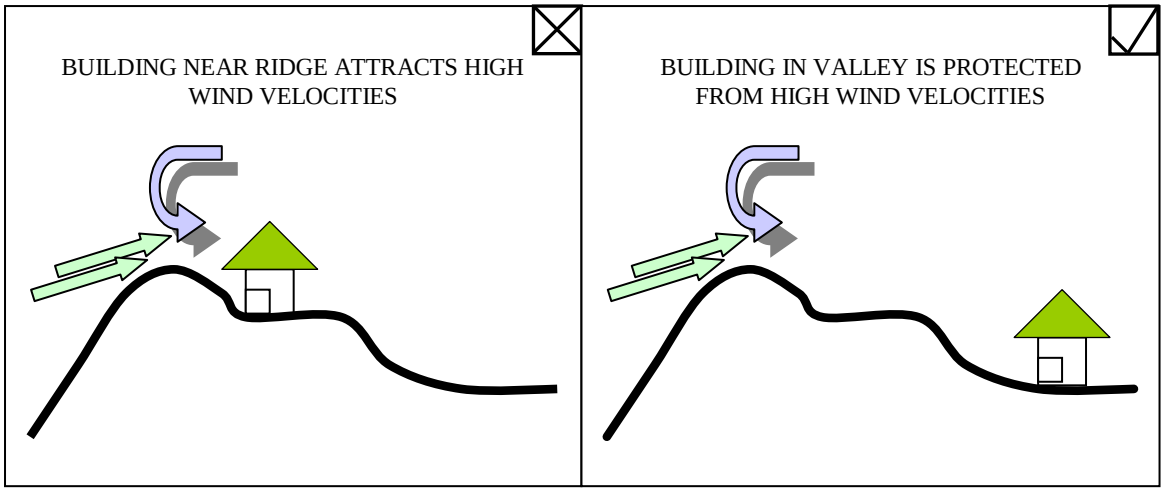


Fig: 6

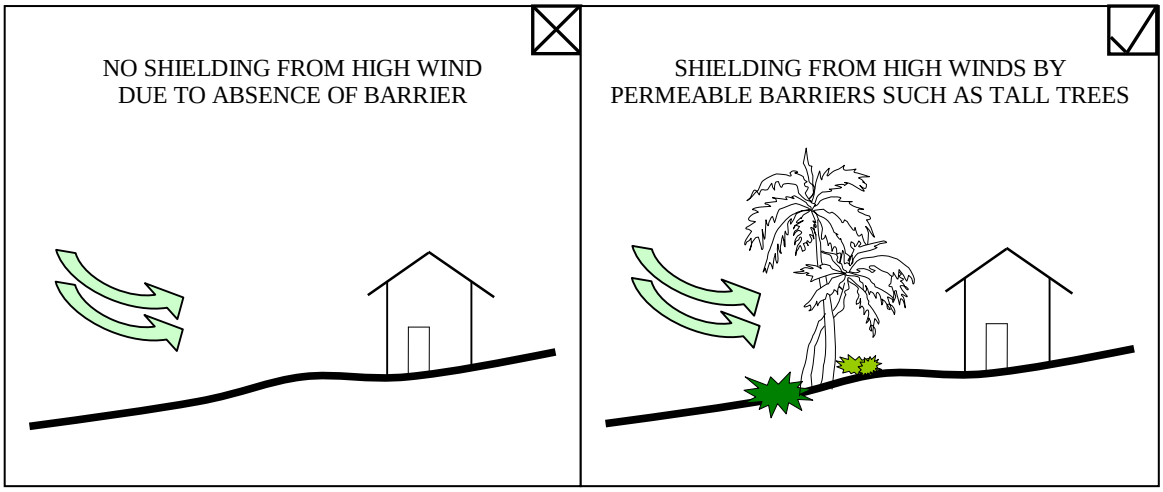

NO SHIELDING FROM HIGH WIND
DUE TO ABSENCE OF BARRIER
SHIELDING FROM HIGH WINDS BY
PERMEABLE BARRIERS SUCH AS TALL TREES

Fig: 7

4. PLANNING ASPECTS

4.A. Essential Requirements

4.A.1. The plinth area of each dwelling unit should be at least 28 sq.m. (300 sq.ft.) but preferably 37 sq. m (400 sq.ft.).

4.A.2. Wherever possible sea facing walls should be braced by cross walls, so that the length of unsupported wall does not exceed 3 m (Fig. 8). [**F**]

4.A.3. Openings in the building will permit flooding and also weaken the wall. Hence large openings on the seaward side should be avoided. [**F**]

4.B. Desirable Features

4.B.1. For individual buildings, a circular or polygonal plan shape is preferred over rectangular or square plans, but from the viewpoint of functional efficiency a square or rectangular plan form is desirable. [F,C,E]

4.B.2. A building that is symmetrical about both axes with a compact plan form is more stable than one with a zigzag plan, having empty pockets. The latter is more prone to cyclone, flooding and earthquake related damage (Fig. 9). [F,C,E]

4.B.3. The buildings should be oriented in such a manner that the shorter span length of the wall faces the sea (Fig. 10). [F,C]

4.B.4. The aspect ratio of the building (length to width ratio of the building) should not be greater than 3. [F,E]

4.B.5. Ornamental architecture involving vertical or horizontal cantilever projections, fascias etc. should be avoided. [F,C,E]

4.B.6. In the case of locating a group of buildings, a cluster arrangement should be chosen in preference to row type buildings for resistance to cyclones; the opposite would be true for flood waters and tsunamis, which would be diverted through the gaps between rows (Fig. 11). Also, clear paths should be identified for evacuation to high ground or to a community building. [F,C]

4.B.7. If possible, buildings should be constructed so that a corner rather than a wall faces the sea (Fig. 12). [F]

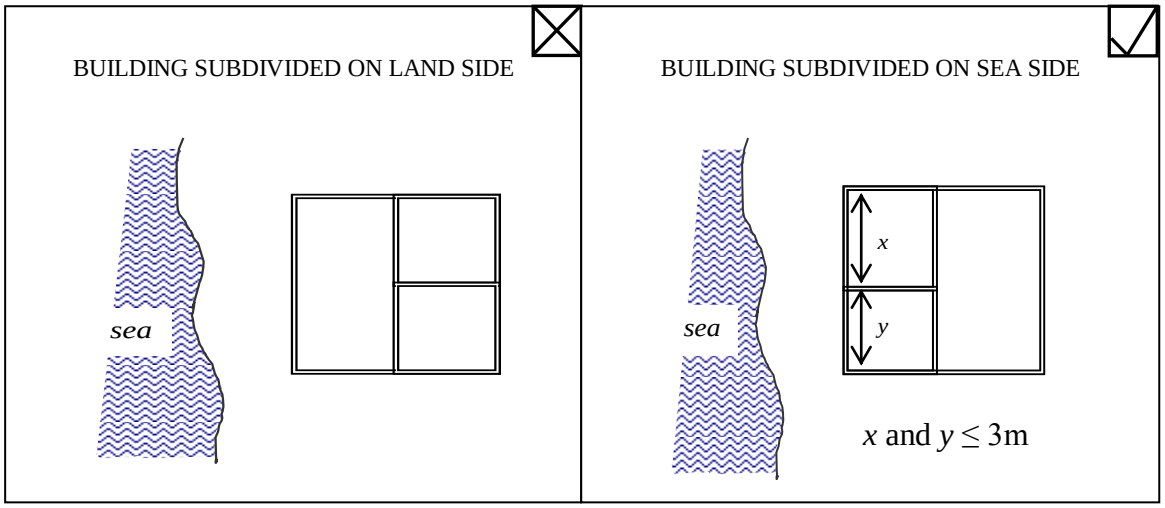


Fig: 8

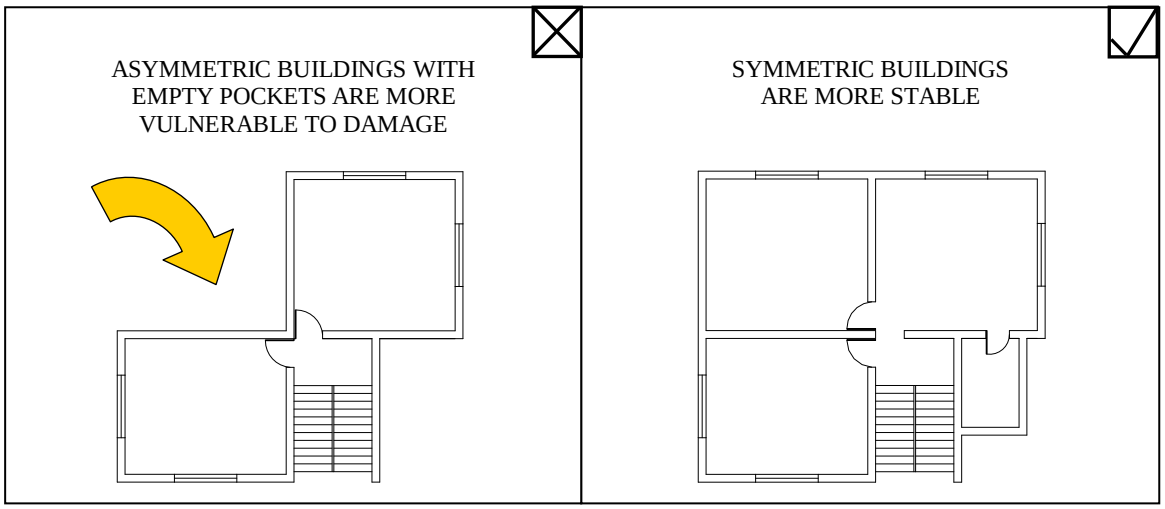


Fig: 9

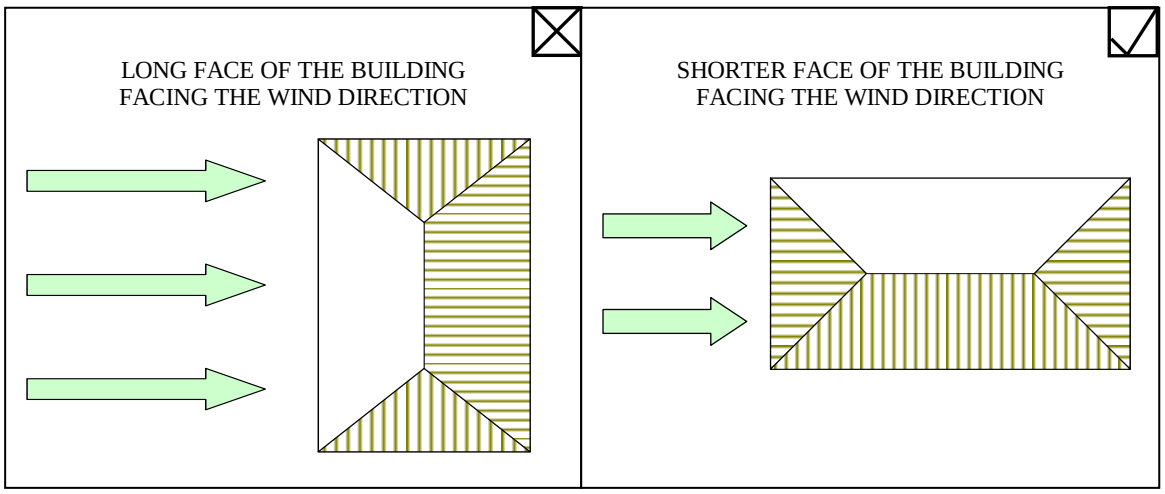


Fig: 10

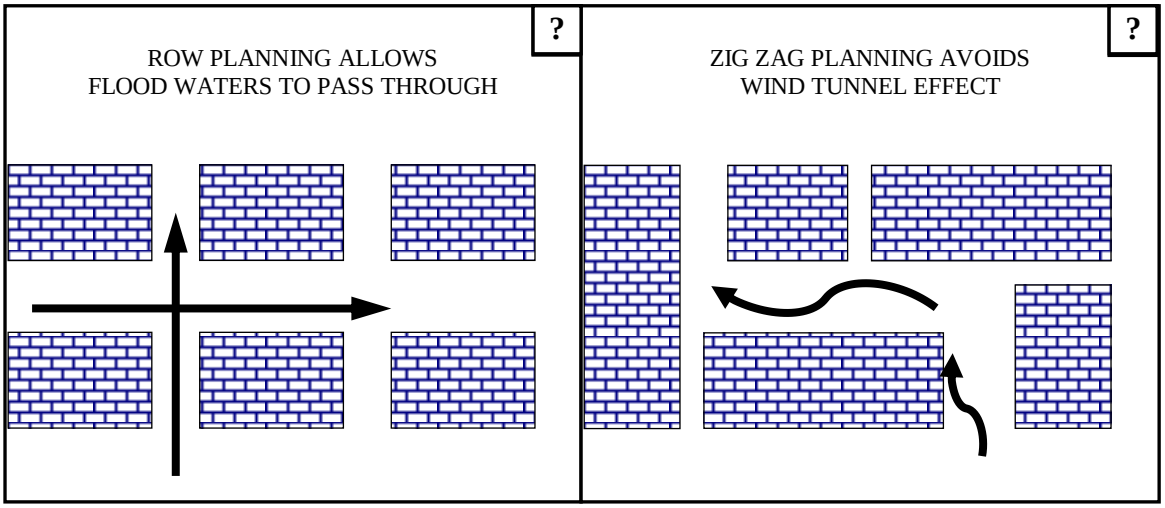

?
ROW PLANNING ALLOWS
FLOOD WATERS TO PASS THROUGH
?
ZIG ZAG PLANNING AVOIDS
WIND TUNNEL EFFECT

Fig: 11

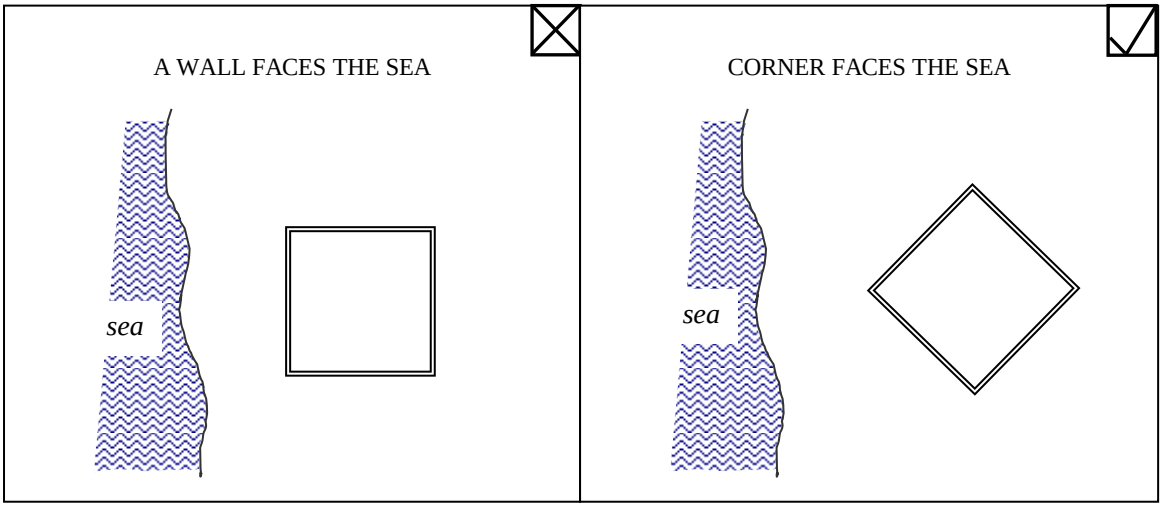

A WALL FACES THE SEA
sea
CORNER FACES THE SEA
sea

Fig: 12

5. FOUNDATIONS

5.A. Essential Requirements

5.A.1. Buildings can have shallow foundations on stiff sandy soil. [**F**]

5.A.2. When there is risk of scouring due to flooding, a minimum foundation depth of around 1.0 m below natural ground level should be provided in the Coastal Zone. In other regions it can be around 0.6 m to 0.75 m (Fig. 13). [**F**]

5.A.3. Where a building is constructed on stilts, these stilts should be properly braced in both the principal directions. This will provide stability to the complete building under lateral loads. Knee braces are preferred to full diagonal bracing so as not to obstruct the passage of floating debris during a tidal surge or tsunami. [**F**]

5.A.4. The wall foundation should have a width of two and half times the thickness of wall (and not less than 0.6 m). Footings should be constructed in stone or solid cement blocks, and not in brickwork (Fig. 14). [**F**]

5.A.5. The plinth height should be not less than 0.45 m above natural ground level and as per topography requirement, for buildings at risk from flooding (Fig. 3). [**F**]

5.A.6. The columns should be founded on pad footings (Fig. 3). [**F,**C,E]

5.B. Desirable Features

5.B.1. If possible, the individual reinforced concrete column footings should be connected by means of reinforced concrete beams at plinth level. These beams will intersect at right angles and thus create an integral housing unit. The plinth beam should be at one level throughout and be connected continuously (Fig. 4). A plinth beam is an essential requirement for multi storey structures. [F,E]

5.B.2. Continuous reinforced concrete footings are considered to be the most effective, not only for earthquake resistance, but also to avoid differential settlements under normal vertical loads. They offer better resistance to scouring and loss of soil contact during flooding too. Hence they are preferable, cost permitting. Plinth beams can be omitted if such footings are used. [F,E]

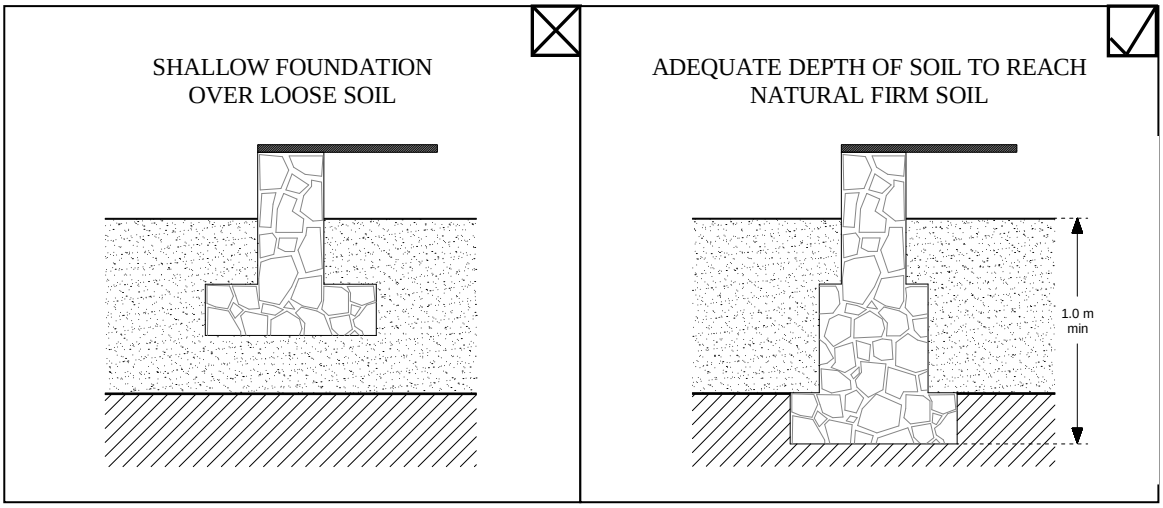

SHALLOW FOUNDATION
OVER LOOSE SOIL
ADEQUATE DEPTH OF SOIL TO REACH
NATURAL FIRM SOIL
1.0 m
min

Fig: 13

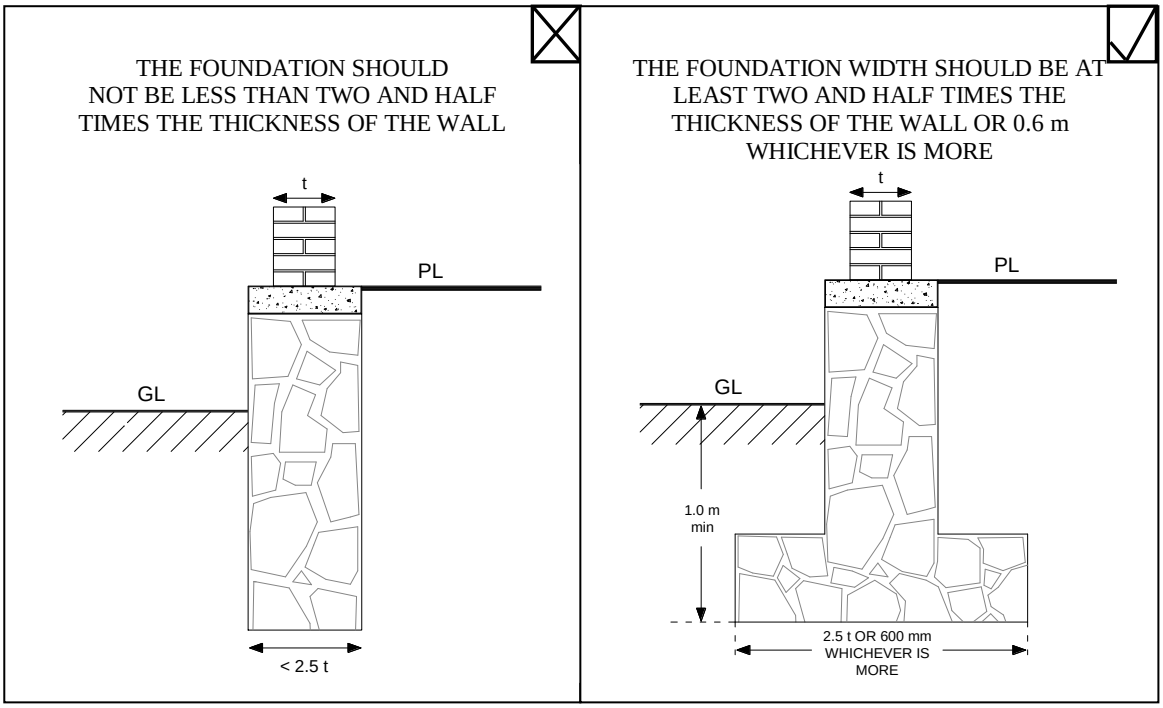

THE FOUNDATION SHOULD
NOT BE LESS THAN TWO AND HALF
TIMES THE THICKNESS OF THE WALL
t
PL
GL
< 2.5 t
THE FOUNDATION WIDTH SHOULD BE AT
LEAST TWO AND HALF TIMES THE
THICKNESS OF THE WALL OR 0.6 m
WHICHEVER IS MORE
t
PL
GL
1.0 m
min
2.5 t OR 600 mm
WHICHEVER IS
MORE

Fig: 14

6. WALLS

6.A. Essential Requirements

6.A.1. All external walls or wall panels must be designed to resist the out of plane lateral pressure adequately. For this, the walls should be sufficiently buttressed by transverse walls. [**F**,C]

6.A.2. A small building enclosure with properly interconnected walls is ideal. Buildings having long walls should be avoided (Fig. 15). [**F**,C,E]

6.A.3. It is necessary to reinforce walls by means of at least one horizontal reinforced concrete band or beam (Figs. 4 and 5). [**F**,**C**,**E**]

6.A.4. The thickness of the external walls should ideally not be less than 200 mm; other walls can be 100 mm thick. If external walls are 100 mm thick, they must be of solid blockwork or brickwork. [**F,**C]

6.A.5. Since tensile and shear strengths are important for lateral resistance of masonry walls, use of mud or very lean mortars should be avoided. A mortar mix leaner than 1:6 cement: sand should not be used. [**F**,**C**,**E**]

6.A.6. For achieving the full strength of masonry, the usual bonds specified for masonry should be followed so that the vertical joints are broken properly from course to course (Fig. 16). [**F**,**C**,**E**]

6.A.7. Concrete columns founded on pad footings must be provided at least at the four corners of the building. These columns should be connected by a continuous roof or lintel beam/band (Figs 3 and 4). [**F**,C,E]

6.A.8. The wall height should be not greater than around 3 m. [**F**,**C**,**E**]

6.B. Desirable Features

6.B.1. In addition to the roof beam and corner columns, a continuous plinth beam and lintel band can be considered (Figs. 4 & 5), on external and even internal walls. This will make the building act as an integral unit under lateral forces. [F,E]

6.B.2. Reinforcing ties can be introduced at wall intersections and jambs of openings. These should be surrounded by concrete of size 100 mm x 100 mm (Fig. 5). The anchorage should extend from the plinth beam to the roof beam. All bars should have an L bend length of 300 mm. This is mainly for earthquake resistance. [E]

6.B.3. Although plastering is best avoided to save material, it may be useful to improve the strength and weather resistance of external walls, especially if they are made of only 100 mm thick masonry. [F,E]

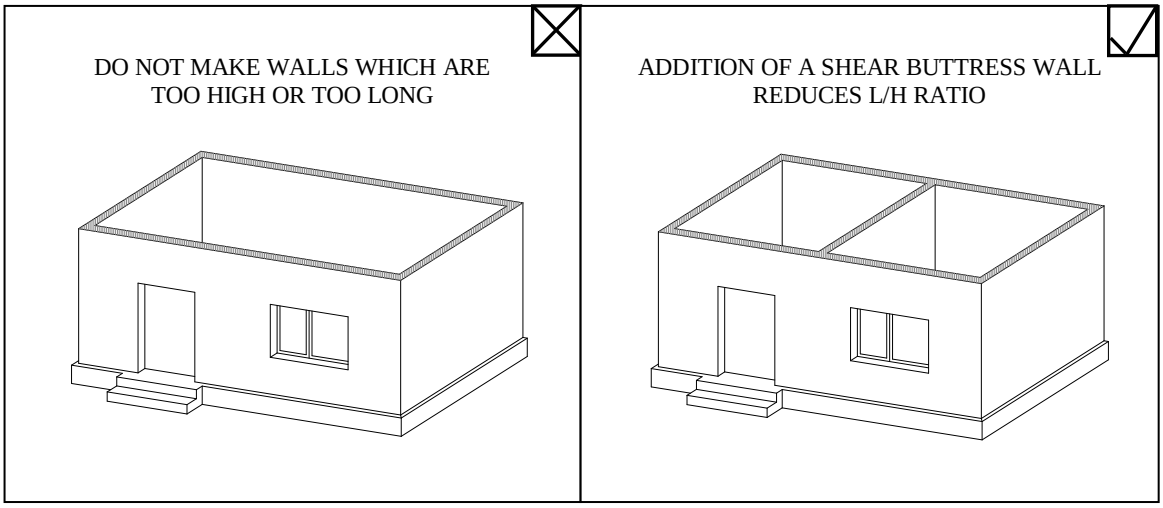

DO NOT MAKE WALLS WHICH ARE
TOO HIGH OR TOO LONG
ADDITION OF A SHEAR BUTTRESS WALL
REDUCES L/H RATIO

Fig: 15

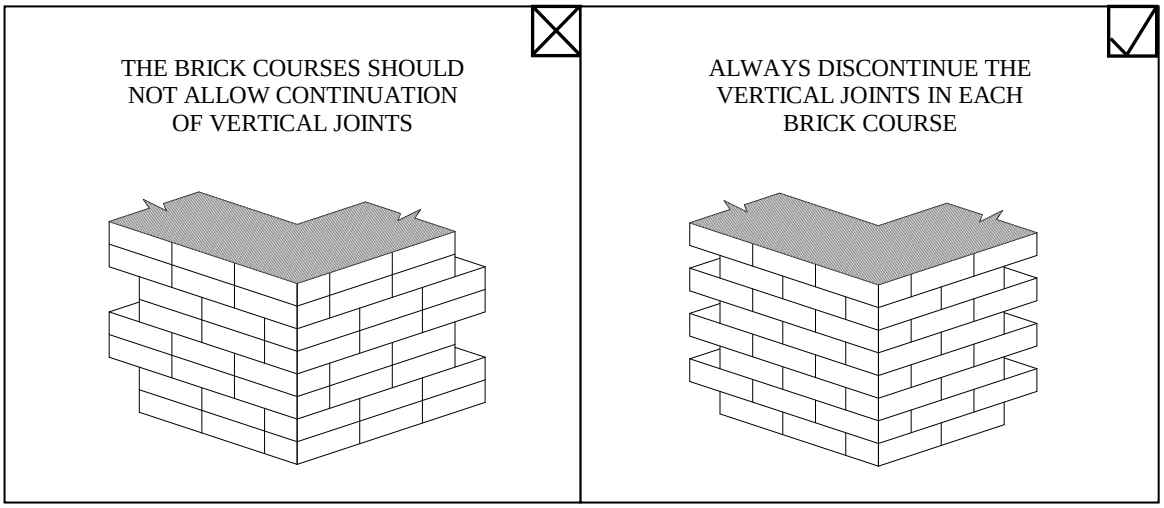

THE BRICK COURSES SHOULD
NOT ALLOW CONTINUATION
OF VERTICAL JOINTS
ALWAYS DISCONTINUE THE
VERTICAL JOINTS IN EACH
BRICK COURSE

Fig: 16

7. ROOFS

7.A. Essential Requirements

7.A.1. Light weight (G.I. or Asbestos sheet) low-pitched roofs should be strongly held down to joists, with fastenings not exceeding 1.5 m spacings in both directions (i.e. along and across slope). [**C**]

7.A.2. Similarly, joists should be tied to rafters and the rafters to the wall plate (Fig. 17). [**C**]

7.A.3. The wall plate should be held down by 10 mm threaded bars cast into the roof beams at around 1.5 m centres; the bars should have an L-bend of around 100 mm (Fig. 18). If the threaded bars are to be anchored in vertical ties, the straight anchorage length should be around 250 mm. [**C**]

7.A.4. Pitched roofs with slopes in the range of 22º to 30º, i.e. pitch of 1/5 to 1/3.5 of span, will reduce suction on roofs and facilitate quick drainage of rainwater. [**C**]

7.B. Desirable Features

7.B.1. The above essential requirements are mainly for buildings in cyclone prone areas. However, they are desirable features for buildings in other areas too.

7.B.2. Gabled walls and simple double pitch roofs should be avoided except for very small structures. It is better to have hipped roofs with wall plates on all four sides. [C]

7.B.3. A flat reinforced concrete roof is preferable to the lightweight roofs discussed above. A minimum thickness of 100 mm and minimum grade of 20 should be used. A gentle slope provided for the flat roof (e.g. 1 in 100) will enable quick drainage of rainwater. Vertical reinforcement bars from the columns should be tied and anchored in the roof beams that will be monolithic with the slab. [C]

7.B.4. If cantilevers cannot be avoided, they should be well anchored to protect them from earthquake damage (Fig.19). [E]

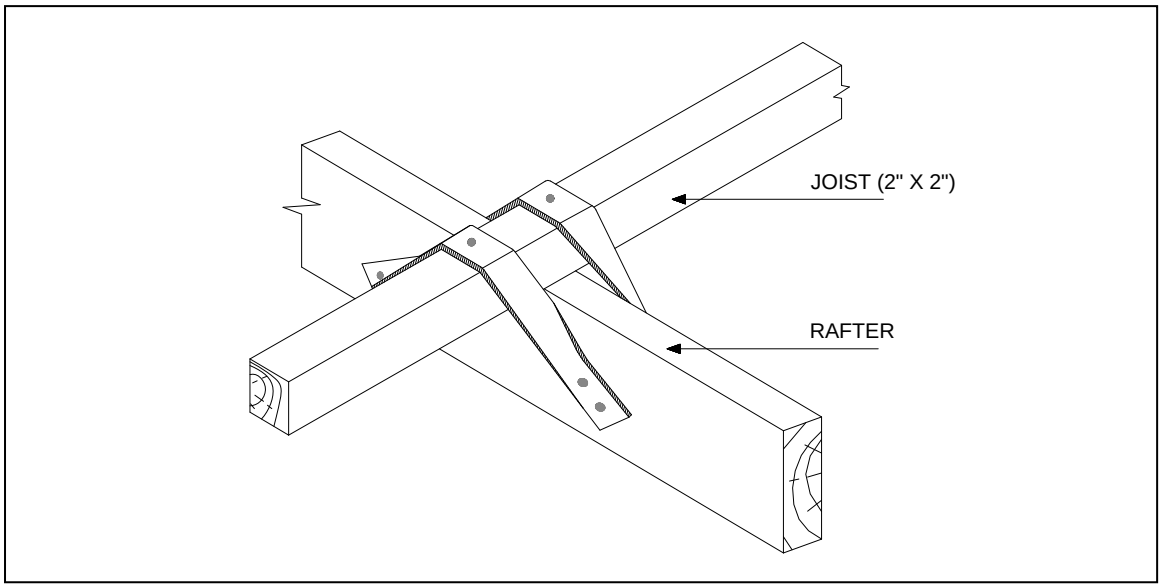


Fig: 17(a)

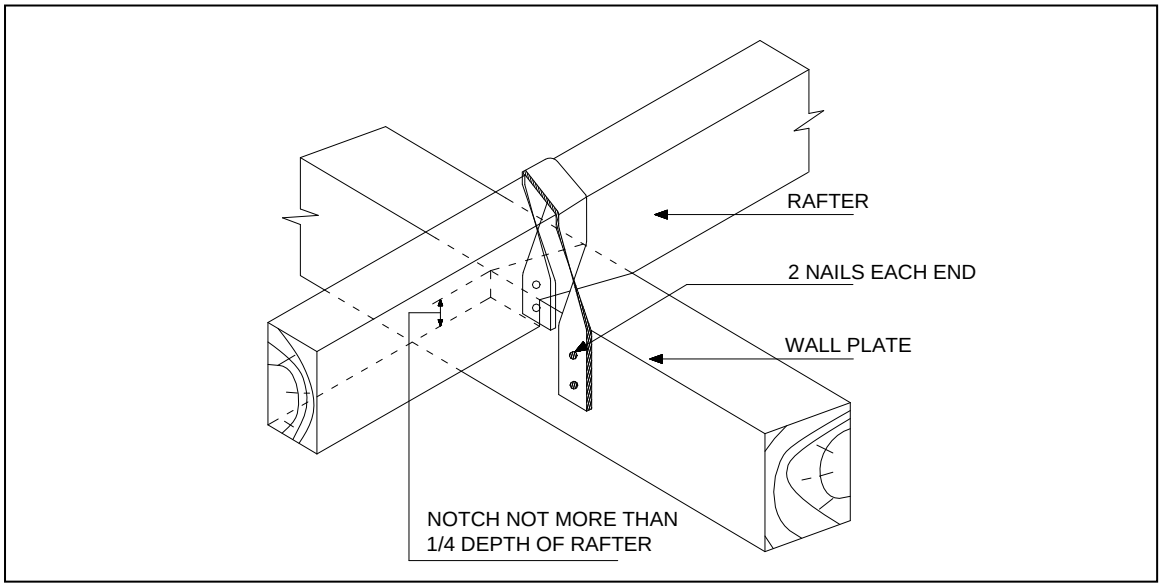


Fig: 17(b)

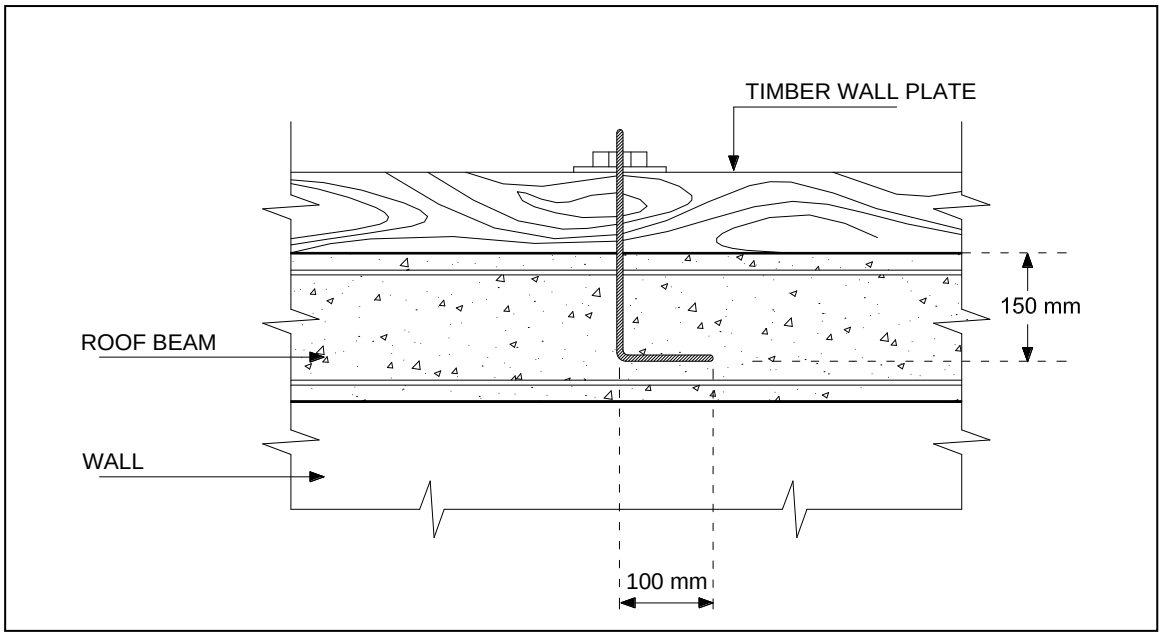

TIMBER WALL PLATE
150 mm
ROOF BEAM
WALL
100 mm

Fig: 18

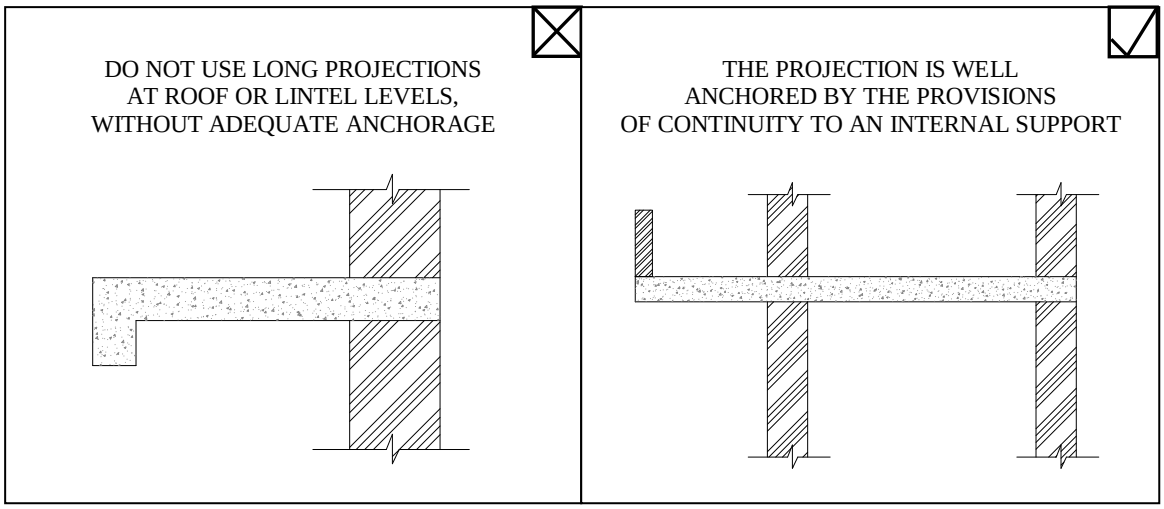

DO NOT USE LONG PROJECTIONS
AT ROOF OR LINTEL LEVELS,
WITHOUT ADEQUATE ANCHORAGE
THE PROJECTION IS WELL
ANCHORED BY THE PROVISIONS
OF CONTINUITY TO AN INTERNAL SUPPORT

Fig: 19

8. OPENINGS

8.A. Essential Requirements

8.A.1. Openings should be avoided or minimized in walls facing the sea. [**F**]

8.A.2. The total length of openings should not exceed 50% of the length of the wall between consecutive cross walls in single storey construction (Fig. 20). (This percentage should be reduced to 42% in two storey construction and 33% in three storey buildings, where loadbearing masonry is used). [**F**,**C**,**E**]

8.A.3. Openings should be located away from the corners by a clear distance equal to at least 25% of the height of opening or 600 mm, which ever is more (Fig. 21). [**F**,**C**,**E**]

8.A.4. The horizontal distance (pier width) between two openings should be not less than 50% of the height of the shorter opening but also not less than 600 mm (Fig.21). [**F**,**C**,**E**]

8.B. Desirable Features

8.B.1. It is desirable to provide reinforced bands (horizontal) and ties (vertical) around the openings (Fig. 5). [F,E]

8.B.2. The frames should be well anchored in the walls (Fig. 22). [F,C,E]

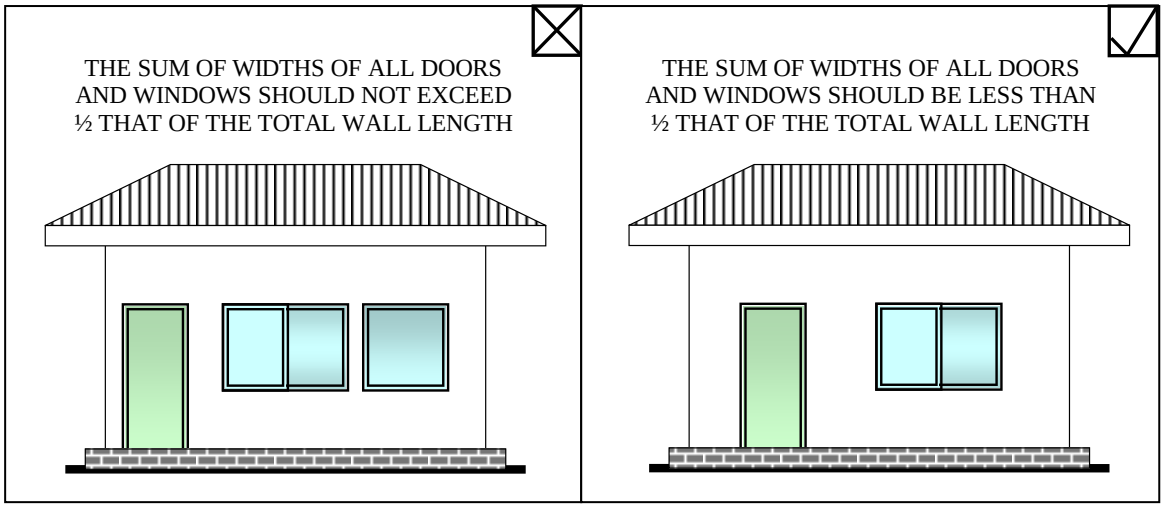
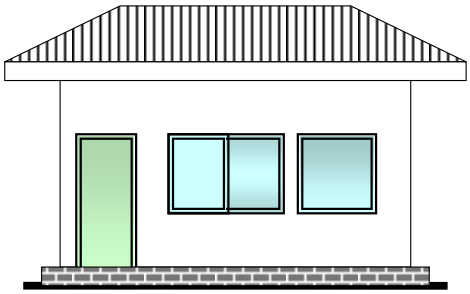


Fig: 20

DO NOT USE TOO MANY DOORS AND WINDOWS IN WALLS AND KEEP THE MINIMUM DISTANCE OF 600 mm BETWEEN THEM



KEEP AT LEAST 600 mm DISTANCE IN BETWEEN DOORS AND WINDOWS AND FROM THE EDGE OF THE WALL. IF NOT POSSIBLE, USE A CONTINUOUS 100 mm BAND OF REINFORCED CONCRETE ABOVE THE DOORS AND WINDOWS

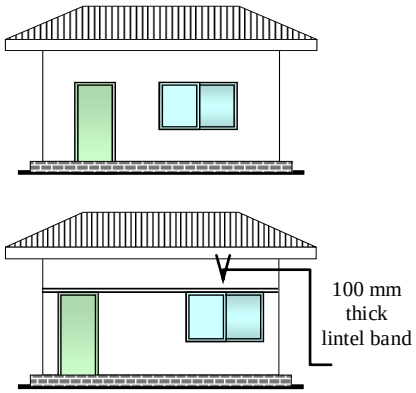
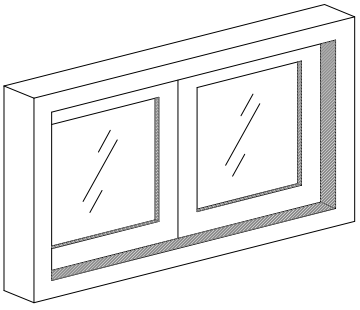


Fig: 21

INADEQUATE ANCHORAGE OF DOOR AND WINDOW FRAMES



ADEQUATE ANCHORAGE OF DOOR AND WINDOW FRAMES WITH HOLDFASTS

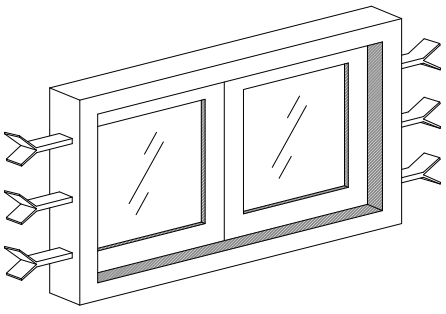


Fig: 22

9. LOW RISE MULTI-STOREY BUILDINGS

9.A. Essential Requirements

9.A.1. The building must have a concrete frame structure and not depend only on a loadbearing masonry, especially if there is risk of flooding and attendant scouring. Loadbearing masonry can be used in areas not prone to flooding and cyclones; here too, it should be restricted to two storey buildings, unless carefully designed. [**F**,C,E]

9.A.2. A plinth beam that connects all columns is essential. [**F**,**E**]

9.A.3. The concrete frame should be braced by a sufficient number of infill walls in two mutually perpendicular directions. Multi-storey buildings in excess of around 4-5 storeys may require concrete shear walls. [**F**,**E**]

9.B. Desirable Features

9.B.1. Corner footings that are prone to scour should be deepened to around 2 m below ground level. Expected scour depths for various soils, as a percentage of tsunami inundation depth (H), are given below. (This recommendation and the ones that follow are related mainly to flooding, and hence to buildings within the Coastal Zone.) [F]

Soil type	Scour Depth (% of H)
Loose sand	80%
Dense sand	50%
Soft silt	50%
Stiff silt	25%
Soft clay	25%
Stiff clay	10%

9.B.3. Scouring at building corners should be resisted by using aprons that are well constructed. Soil improvement can also be considered, such as by grouting or soil stabilization (using lime or cement), or by using geotextiles. [F]

9.B.4. Some redundancy should be provided especially in sea facing edges, so that beams are not merely simply supported at two ends, but also at (an) intermediate point(s). [F]

9.B.5. Infill walls in two mutually perpendicular directions should be provided at building corners too, so that a foundation undermined by scouring can be supported by the rest of the structure without collapse of the end bay. [F]

(See Fig. 23 for a layout view of some of the above features)

9.B.6. If possible, the ground floor of buildings in the Coastal Zone should have an open plan and be used only for activities with short term human habitation (e.g. as a meeting hall, open storage space or even a classroom). This will reduce vulnerability to flooding and also allow flood waters to pass through without loading the structure too much. However, some strong elements must be provided, in order to guard against

impact loading from flood borne debris or a "soft storey" effect in the event of a minor earthquake. Quick access to upper floors will also allow such a building to function as a safe haven in the event of flooding. Hence, upper floors should be designed for imposed loads of 3 to 5 kN/m^2 (Fig. 24). [F]

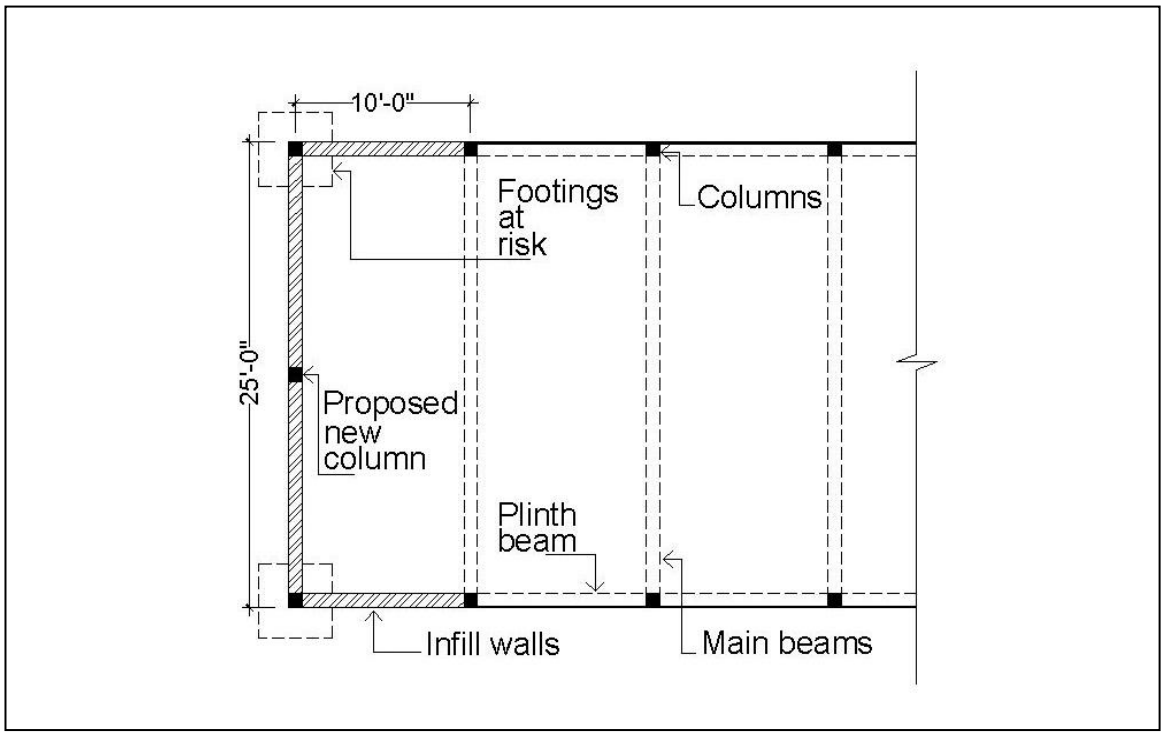


Fig: 23

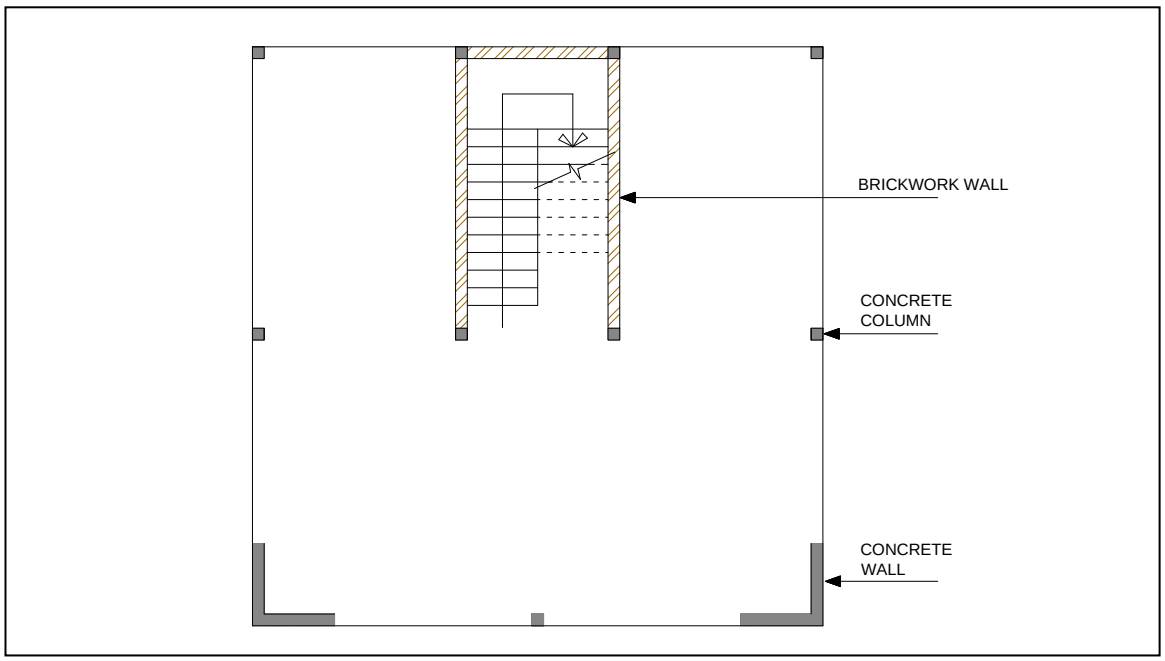


Fig: 24

SOURCES AND RESOURCES

Design of Buildings for High Winds, Ministry of Local Government, Housing and Construction, 1980

This document was produced with Australian assistance after the East coast cyclone of 1979. It has many practical and useful guidelines, many of them ignored in practice. Our guidelines have drawn from this document mainly for design against cyclones.

Guidelines for Reconstruction of Houses affected by tsunami in Tamil Nadu, www.tn.gov.in/tsunami,2005

Our guidelines have drawn heavily from this document, not only in content and graphics, but also in style – i.e. the combination of "Essential requirements" and "Desirable features" for various categories. These Tamil Nadu guidelines have been adapted for Sri Lankan practice.

Coastal Construction Manual (3 vols.), 3rd edition (FEMA-55), Federal Emergency Management Agency, Jessup, MD, November 2003.
www.fema.gov/pdf/hazards/nhp_fema55.pdf

The scour depth estimates in our guidelines are drawn from this document. This document is a valuable source of information for engineering design of buildings. It is therefore essential for the design of multi-storey buildings.

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