EDUCATIONAL BUILDING REPORT 7
UNESCO REGIONAL OFFICE FOR EDUCATION IN ASIA
BANGKOK, THAILAND

CYCLONE-RESISTANT RURAL PRIMARY SCHOOL CONSTRUCTION

– a design guide

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by Ian T. Sinnamon
G. A. van 't Loo

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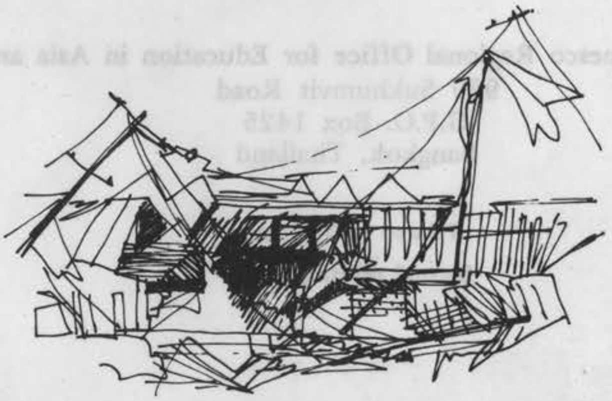

UNESCO REGIONAL OFFICE FOR EDUCATION IN ASIA
BANGKOK, THAILAND, 1977

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Published by the Unesco Regional Office for Education in Asia and the Pacific
920 Sukhumvit Road
G.P.O. Box 1425
Bangkok, Thailand

Printed in Thailand
Second printing 1981

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BKB/81/RRHM/237-300

FOREWORD

Asia is a region in which cyclonic storms, earthquakes, tsunami, flood and fire are fairly common. It is important that schools in the countries subject to disasters of this type be made safe for the children that use them and, moreover, that there be a disaster-resistant building such as a school in every community for use as a place of refuge for people whose homes may have been badly damaged or destroyed.

This document is one of several that have been published by the Unesco Regional Office for Education in Asia dealing with the design of buildings to resist disaster. Education Building Report No 4 in this series, also written by Mr. I. Sinnamon, one of the authors of this Report, provides a useful annotated bibliography on natural disasters and educational building design which will supplement the material in this document. Educational Building Digest No 2 deals with the design of small buildings in earthquake areas and Digest No 7 deals with design against fire in schools.

Close contact with reality is an important thing in writing of disaster. For this reason most of the photographs used to illustrate the text are of Bangladesh very shortly after the 1970 cyclone in which more than 200,000 people were reported to have lost their lives. The Bangladesh photographs were taken by D. Mooij and A. Sikkema, then Unesco Associate Experts and staff members of the Unesco-sponsored Asian Regional Institute for School Building Research, Colombo, Sri Lanka.

The publication contains information concerning wind pressures and strong air currents. The building planner who wishes reference material regarding the normal flow of air and its results in ventilation may wish to order Educational Building Report number 6, "Ventilation of wide-span schools in the hot, humid tropics".

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CHAPTER ONE

INTRODUCTION

Scope

Theory of design against strong wind is still in the development stage, and the working methods and calculations involved in accurate structural design are complicated. The following material attempts to present the results of recent experience in problems of wind and water at a practical level, appropriate for use in relatively simple, low-rise, low-cost structures, which may not be subject to detailed professional design and supervision. The type of building contemplated here is the basic primary school. The material should be no less appropriate for secondary schools or other more complex or ambitious buildings, but it is generally the case that the latter are more likely to be professionally designed and supervised.

In the following notes no particular assumption has been made about the acceptance or rejection of respectively vernacular or industrialized building techniques. In general, a somewhat innocent acceptance of long-standing practices may be detected. The present writers' position in relation to the dichotomy is not firm, but in the light of a number of reports (such as Mackey at al.[1]) an inclusive approach to the question can be expected.

Rationalism, nationalism, regionalism and the international style

The school building may be the first institutional building the child enters. It may be the first building he experiences apart from his own and other houses. It will inevitably communicate some image about the institutions it accommodates and symbolizes; education, political authority, and the individual's role in relation to them.

The role of education is to develop, or process, the learner to a level where he is competent to operate without strain in his existing society. Beyond this basic competence, there is divergence of views about aims and methods.

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[1] S. Mackey, C. Finney and T. Okubo. *Philippines: the typhoons of October and November 1970*. Paris, Unesco, May 1971. (Serial no. 2387/RMO RD/SCE). The authors found very little damage to owner-built houses, even in the squatter belts, compared with concentrations of extensive roof damage in the new high-cost residential areas of Makati and elsewhere.

Frequently a government that sees itself as progressive will insist upon doing things like school building programmes within a framework of assumptions about the necessary symbols of progress: modern technologies, prefabricated structures, new materials, bold statements. Sometimes this is tempered with a regional or nationalistic overlay of symbols derived from traditional forms (for example, round-headed windows), the traditional and essential logic of these shapes often having been lost completely in the altered technology. Further, these symbols almost always acquire a 'morning-after' seediness after a few years of weathering and indifferent maintenance.

It is sometimes overlooked that nearly all populous countries have existing traditions in building which have evolved to fit, very snugly, the general and particular needs for shelter in their immediate region. In a developing country the educational programme may not fit precisely within a previously known formula for physical accommodation but, except in detail, it is unlikely to be completely foreign in its requirements. This suggests that the locally available crafts and building practices should be drawn upon for at least some of the technique employed in school building.

Some of the reasons this is often not done are obscure. Government officials have said that "the people like new things." Other informants have said that the Government officials rather than the people like new things. Experience indicates that the acceptance of innovatory structures varies widely for a number of seemingly sound reasons; that some welcome novelty, others distrust it.

It seems that a further social role that school buildings may be called upon to play is that of introducing novelty to a community in a form that it will not reject. A traditional community may not accept a round plan or a novel material for their own houses, however economical or physically comfortable they may be. Yet if a government considers it to be 'good' for them, it may decide to reduce or divert their rejection by first introducing it in the form of school buildings, which by their nature symbolise beneficial change in developing countries.

This predisposition to accept novelty in school design sets the designer fewer restraints than housing design, and should encourage creativity. It also tends to encourage less stringency in the appraisal of designs.

In the following respects school buildings are likely to present new or unfamiliar physical requirements:

1 Teaching materials, including scientific equipment and audio-visual aids, may present special needs in services, handling, storage and security. A classroom with permanent ventilation openings in the upper walls may occasionally admit heavy rain which will damage expensive equipment.

2 Environments which are protected acoustically or otherwise may be required for special tasks.

3 The school may be called on to serve community functions, particularly in relation to natural disasters such as floods or cyclones. If a school complex is to serve this additional role, it may need to provide for some of the following :

a) If the school serves as a community warning centre for strong winds or other approaching disasters, it will have equipment for broadcasting signals (for example one, two or three blasts, as in the Philippines). It may also be a local weather station [2]

b) In the case of flooding in the area, some high land and/or building space should be provided above flood level. This space (upper floor or school roof) will then need to support considerably-increased live loads, and should also provide emergency supplies of potable water and basic hygiene facilities.

c) If it is a refugee and communications centre for disasters, it may need an indestructible core which will withstand extreme conditions relatively intact. This core would be designed against maximum wind forces, and contain an appropriate range of equipment and space for emergency administration (which may be a generously-scaled headmaster's office).

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[2] As recommended in Mackey, ibid.

CHAPTER TWO

THE NATURE OF WIND AND WATER THREATS

Wind and tropical storms

The nature of wind is complicated and depends among other things on:

- the difference in heating of the surface of the earth by the sun;
- the differences in absorption of this heat by different areas of the earth, especially as between land and water;
- natural obstacles to the free flow of the wind, such as continents and mountains;
- the rotation of the earth.

Figure 1 shows an idealized flow of prevailing winds: because of many local disturbances the real picture will often be quite different. For practical purposes, such as for natural ventilation, this picture may however be kept in mind.

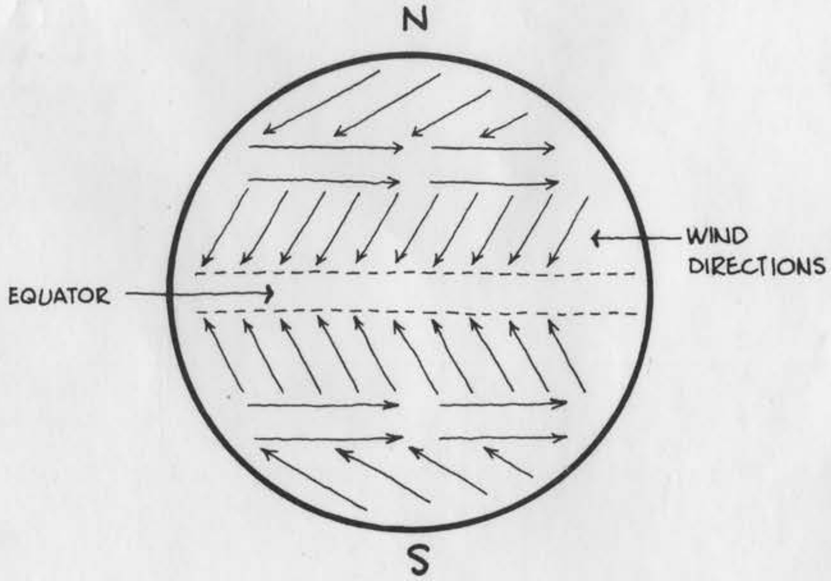

FIGURE 1. THE PHENOMENON OF WIND

One type of local disturbance is called a 'tropical storm'. This publication deals with this kind of disturbance and its effect on educational building design. In order to provide simple guidelines for better design against strong winds, a brief description is given of those characteristics of tropical storms that may have an impact on the design.

Tropical storms are severe cyclonic disturbances of the atmosphere in low latitudes. Their characteristics are not entirely uniform, but depend somewhat on their age and size, and the latitude at which they occur. They are cyclonic whirls, with wind near the centre forming an almost circular vortex, and having a slight, inward motion toward the centre near the ocean surface. As a result of the effect of the earth's rotation, the rotation of the vortex is clockwise in the southern and counter-clockwise in the northern hemispheres.

If the surface winds in such a cyclonic whirl exceed 120 km per hour (64 knots, 75 mph or Beaufort force 12) this storm is called a hurricane in the western Atlantic, a typhoon in the western Pacific, or sometimes just a cyclone (in the Indian Ocean).

All tropical storms develop over water of which the temperature is in excess of 27° C, and in an area of relative low atmospheric pressure. The area in which such storms commonly occur is approximately between latitudes 5° and 30° in both hemispheres. The main areas where tropical storms originate as well as the main tracks they normally follow are shown in Figure 2.

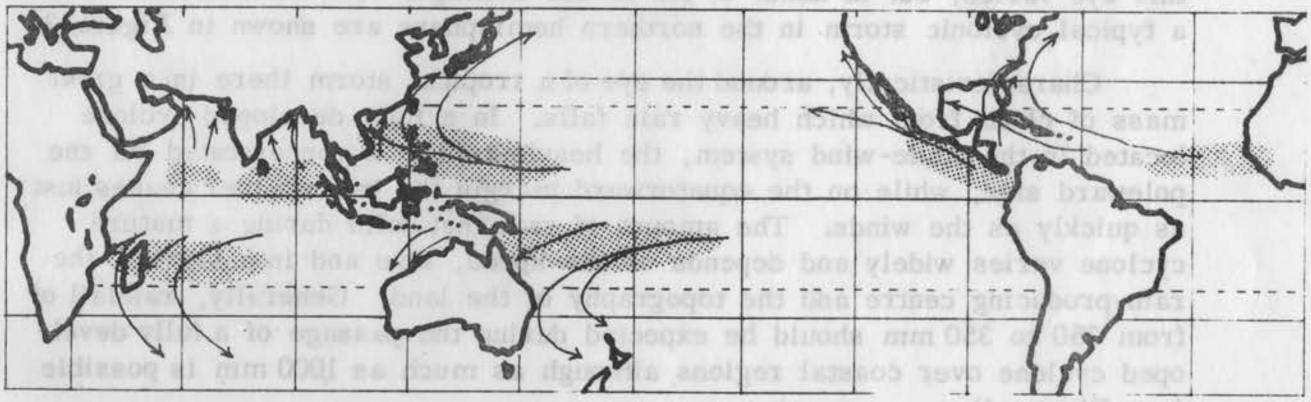

FIGURE 2. MAIN AREAS OF ORIGIN AND MAIN TRACKS OF TROPICAL CYCLONES

The principal cyclone seasons in the northern hemisphere are between July and October and in the southern hemisphere between January and April but storms may occur, although somewhat less frequently, during the rest of the year. The area covered by cyclonic whirls with wind speeds in excess of 120 km per hour may have a diameter of only 15 km when the storm is in its early stage and 80 to 250 km when fully developed. The total area affected by a major storm may exceed 800 km. While the area of a tropical cyclone is small compared with storms outside the tropics, the violence of the weather within the disturbed zone is usually far greater. Sustained winds in excess of 160 km per hour are common near the centre, and winds as high as 320 km per hour have occurred. Storms that have attained maturity usually drift westward with the prevailing trade wind. While the speed of the winds within the disturbance themselves frequently exceeds 160 km per hour, the rate of movement of the disturbances themselves is about 15 to 30 km per hour. Most storms gradually approach the poleward limit of the tropics and come under the influence of the prevailing westerlies when they reach the latitude 30°. Here the cyclones recurve and their speed of forward movement increases rapidly to 80 to 100 km per hour when they reach the polar zone. Dissipation of tropical storms over the tropical oceans is rare. Most disturbances eventually enter middle and high latitudes where they are absorbed into the prevailing westerly circulation of those regions. Tropical storms normally lose intensity when striking land, irrespective of latitude. Even passage over the smaller islands of the tropics can result in great reductions of their strength. Within 24 hours after striking land, the winds of a severe cyclone may have been reduced to approximately 50 km per hour. Over flat land the dissipation is far slower than over rugged country. Within the region of cyclonic winds, the wind speed rises toward the innermost portion of the storm. Very close to the centre of mature cyclones however, the winds drop abruptly from their extreme maximum to light breezes or even complete calm. Clear skies or only thin clouds prevail. This central circular calm area bears the name 'eye' of the storm and the diameter of this eye varies, but is about 25 km on the average. The characteristics of a typical cyclonic storm in the northern hemisphere are shown in Figure 3.

Characteristically, around the eye of a tropical storm there is a great mass of cloud from which heavy rain falls. In a fully developed cyclone located in the trade-wind system, the heaviest rain is concentrated on the poleward side, while on the equatorward margin the bad weather ceases just as quickly as the winds. The amount of rain that falls during a mature cyclone varies widely and depends on the speed, size and intensity of the rain-producing centre and the topography of the land. Generally, rainfall of from 250 to 350 mm should be expected during the passage of a fully developed cyclone over coastal regions although as much as 1,000 mm is possible (see Figure 4).

One of the characteristics of a cyclonic storm is its association with a strong reduction in atmospheric pressure. This reduction may be in the order of 60 to 100 millibars with a rise of the water level, called a 'storm surge', as a result. Although this low pressure will not result in a rise of the water level of more than one metre, the combined action of low pressure, the wind driving sea water inland (when the cyclone approaches land), hard-breaking waves and the astronomical tide may result in a rise of water level by as much as 14 metres. A rise of 5 metres is quite common (Figure 5).

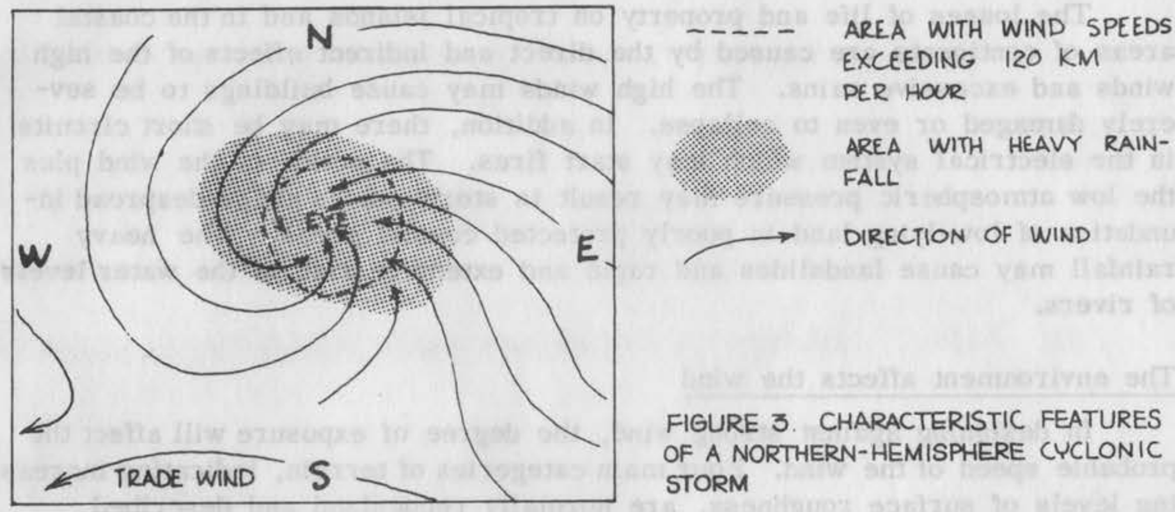

FIGURE 3. CHARACTERISTIC FEATURES OF A NORTHERN-HEMISPHERE CYCLONIC STORM

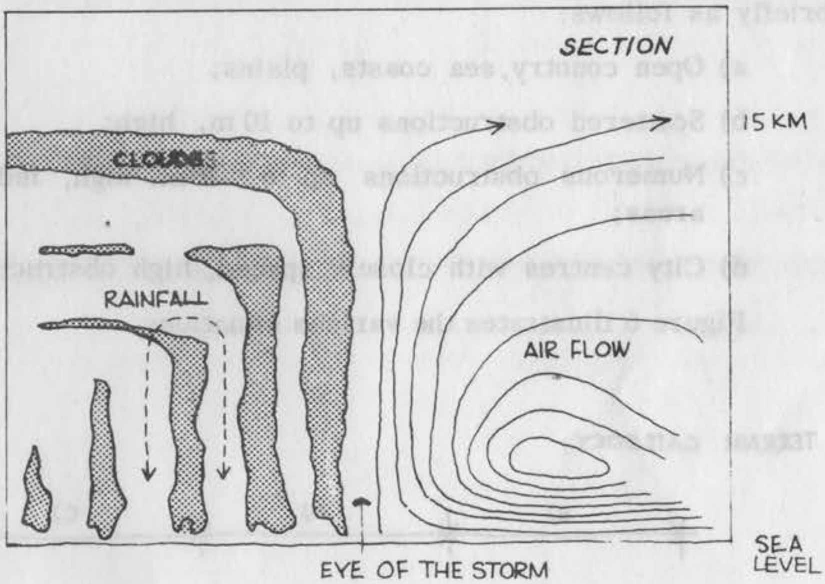

FIGURE 4. RAINFALL AND AIR FLOW IN A CYCLONIC STORM

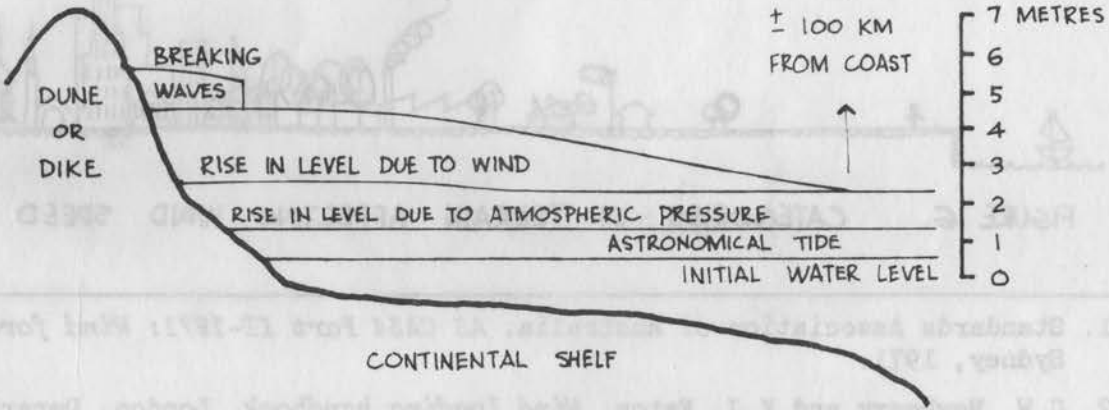

FIGURE 5. RISE IN SEA LEVEL IN A CYCLONIC STORM

The losses of life and property on tropical islands and in the coastal areas of continents are caused by the direct and indirect effects of the high winds and excessive rains. The high winds may cause buildings to be severely damaged or even to collapse. In addition, there may be short circuits in the electrical system which may start fires. The action of the wind plus the low atmospheric pressure may result in storm waves and widespread inundation of low-lying land in poorly protected coastal areas. The heavy rainfall may cause landslides and rapid and extensive rise of the water levels of rivers.

The environment affects the wind

In designing against strong wind, the degree of exposure will affect the probable speed of the wind. Four main categories of terrain, indicating increasing levels of surface roughness, are normally recognized and described briefly as follows:

a) Open country, sea coasts, plains;

b) Scattered obstructions up to 10 m. high;

c) Numerous obstructions up to ± 10 m. high, industrial and wooded areas;

d) City centres with closely spaced, high obstructions.[1], [2]

Figure 6 illustrates the various situations.

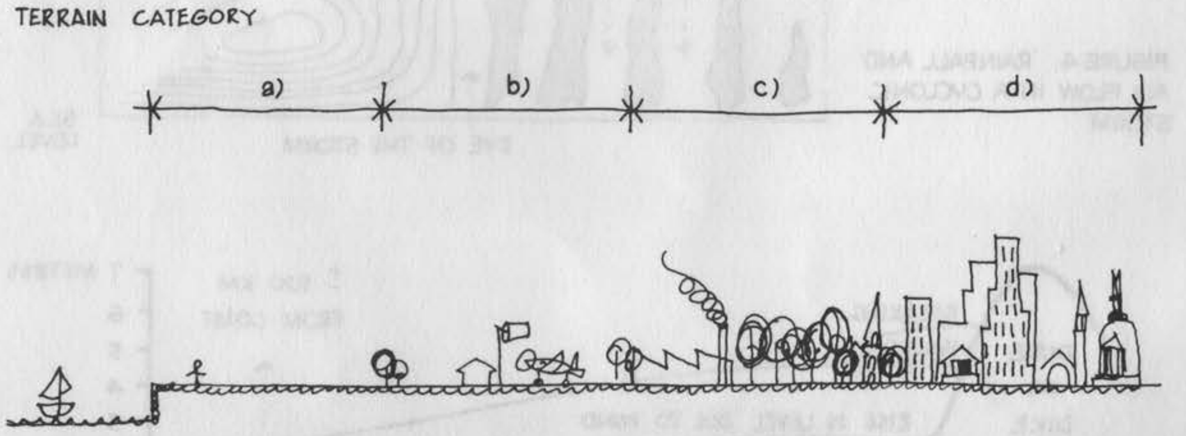

FIGURE 6. CATEGORIES OF TERRAIN AFFECTING WIND SPEED

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[1] Standards Association of Australia. *AS CA34 Part II-1971: Wind forces.* Sydney, 1971.

[2] C.W. Newberry and K.J. Eaton. *Wind loading handbook.* London, Department of the Environment, H.M.S.O., 1974 (Building Research Establishment Report).

Designing for wind loads

Many countries publish Building Codes of Practice and, where available, they should be used. In this chapter a general description of the design procedure common to many of these codes is given. The concepts and the design applications are as follows :

1. Data on maximum, annual, or monthly wind speeds are collected over as many years as possible by meteorological stations at various locations. Usually, maximum wind speeds, averaged over a 1-minute period, and extreme gusts are recorded by so-called quick-run anemometers, located at a height of 10 metres in an open field.

2. Using statistical methods, these data are then analysed and an estimation of the wind speed that is not likely to be exceeded within a certain number of years is made. In many Codes this is commonly taken as a wind speed that would have a 2% risk of being exceeded once in 50 years. For buildings that are very likely to be empty during heavy storms and of which the replacement cost is relatively low, sometimes once in 25 years may be accepted; while, on the other hand, for buildings that represent a hazard to life and property, such as high-rise buildings, once in 100 years is recommended or required.

3. These estimated maximum annual wind speeds may be shown in maps in the form of so-called "isopleths" or lines connecting different locations with the same estimated wind speed. In addition the wind speed at the major cities often is given. To provide an idea of the magnitude of these estimated values :

- In the United Kingdom, with no cyclones, the isopleths range from 38 to 56 m/sec (136.8 to 201.6 km per hour).
- In the United States, isopleths range from 96.5 to 177 km per hour but tornados are excluded.
- In Australia values range from 145 to 209 km per hour but may be multiplied by 1.15 in tropical cyclone areas, thus giving a maximum design speed of 240 km per hour.
- The isopleths on the map of the Philippines, a country that is very often frequented by tropical cyclones, show annual maximum wind speeds at a 50-years return period ranging from 32 to 274 km per hour.

In countries where data on wind speed are not available, the above-mentioned values may be of help in making a reasonable design estimate. As the wind speed varies with height above ground, it will be necessary to adjust the basic wind speed to the height of the building. As velocity increases with height and single-storey schools are usually lower than 10 m, the isopleth values can often be somewhat reduced.

The wind speed is influenced by the roughness of the surrounding area and will decrease as the roughness increases. As the data are obtained in open field conditions, a reduction can be applied in rougher conditions.

A wind gust within the one-minute period over which the wind speed is averaged may have a considerably higher speed than this average value. As a wind gust of only a few seconds duration can cause severe damage, an adjustment must be made; this will increase the isopleth value.

The basic wind load

The wind speed, arrived at after the above mentioned adjustments, is called the basic design wind speed. Using the formula $p = 0.0625\ v^2$, this basic wind speed can be converted into a basic wind load. In this formula 'v' is the wind speed in metres per second and 'p' is the equivalent static load in kg per m^2.

The static load 'p' represents the load in the middle of a large vertical flat surface, perpendicular to the direction of the wind.

Buildings, however, have a wide variety of shapes, and as the wind speed is very much influenced by the shape of a building, the actual wind load acting on different parts of it will also vary with its shape. In order to arrive at the basic design load, a coefficient known as the drag-coefficient, is applied to the actual wind load. Several Codes give extensive figures and tables indicating the value of this coefficient, based on wind tunnel tests as well as on measurements in the field. Other factors which have to be considered include :

- Channelling of wind where two buildings are located close together; the drag-coefficient may have to be increased for two walls facing each other;
- Internal pressure, depending on the area of openings in the walls;
- Parapets as suction-reducing elements;
- Courtyards.

CHAPTER THREE

FACTORS INFLUENCING THE SELECTION AND USE OF THE SITE

General

Only in a minority of cases will selection of the site be a matter of of choice, but some of the following influences might be significant.

The school will normally be situated within walking distance of its population (in the Philippines about a two-kilometre maximum radius for primary schools). Ideally the site will contain variegated types of terrain, including flat ground for playing fields, small rises and hillocks to provide shelter from strong winds, vegetation of various kinds including wooded areas and, if possible, windbreaks sheltering the site from bad weather.

If the school serves a flood-prone area, and is intended as a community refuge during floods, it should clearly be situated as high as possible. If there is no high ground, consideration might be given to earth works (which should be relatively cheap) designed to raise the general ground level, or a critical part of it to whatever height is feasible. These elevated areas could be supplemented over time by supervised filling with building debris and (selected) refuse.

Such earthworks can serve several functions:

1. They would offer outdoor spaces for teaching or drama by creating 'amphitheatre' spaces in the vicinity of the school buildings;
2. They would reduce the tendency for schools to be situated in bleak, undifferentiated flat areas without identity or human scale;
3. They could relate to outdoor gardening and nature study programmes;
4. In flood conditions they would provide some outdoor high ground convenient to school buildings;
5. If properly located in relation to strong prevailing winds they would deflect some winds without interrupting beneficial breezes. (As cyclones may blow from any direction, the earthworks will only provide partial shelter, at least from cyclonic winds).
6. Ventilation in normal conditions is better if buildings are raised on mounds than if they are at ground level.[1]

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[1] Unesco. Regional Office for Education in Asia, Bangkok. *Induced air movement for wide-span schools in humid Asia.* Bangkok, 1976. (Educational Building Digest No. 9).

Vegetation

Although the study of the Darwin cyclone (December 1974) reported many uprooted trees and advocated pruning of large trees before the cyclone season,[2] the observations of a mission to the Philippines indicated little damage to trees compared to the devastation of buildings and other man-made objects.[3] Plate 1 shows trees in Bangladesh, substantially undamaged after the major 1970 cyclone.

In general, trees which are blown down are of the large, older types having shallow or restricted root structures. Trees of softer wood which have little bending resistence lose some of their limbs. Coconut palms, stands of bamboo and small banana orchards survive with very little damage. At a rough guess, possibly 25-30% of large trees are uprooted but these, in turn, represent quite a small proportion of all tree growth in the areas observed. It is suggested that the planting of groves of trees of an appropriate kind may reduce wind speeds and provide some sheltering effect without seriously risking further damage by their own destruction, or even impeding gentle winds. The educational value of trees for biological and general studies is, of course, undisputed, as is their value in creating more pleasant external spaces, and shading buildings and grounds against thermal excesses.

Plate 1. Trees in Bangladesh, substantially undamaged after the major 1970 cyclone.

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2. Australia. Department of Housing and Construction. *Report on cyclone "Tracy" and effect on buildings,* by George R. Walker, Vol 3, Canberra, 1975.

3. Mackey, Finney and Okubo. *Philippines: the typhoon of October and November 1970,* op. cit., p. 3.

Wind breaks

In the case of normal prevailing strong winds, the logical procedure for protection is to present the minimum area of building towards the wind, to shape it in such a way as to reduce strains in the building fabric, and to protect it with windbreaks of whatever kind. In the case of cyclone-prone areas, this is not so easy, since the cyclone, while following a general path which may be relatively straight and predictable, may blow strongly in virtually all directions within a small area.

By the same token, although a site may have good and bad aspects from the viewpoints of prevailing winds, breezes, sun and other factors, a cyclone will render the careful layout in relation to these considerations largely irrelevant. One cannot provide shelter against wind from all directions without discarding the important benefits of cooling breezes in normal times.

Nevertheless, it may be possible for strong winds to be mitigated by either permeable or shaped obstructions that cause less interference with gentle winds. Some experiments suggest that this may be done, but there seem as yet to be few conclusions from detailed study of the problem.

Buildings and trees as wind-breaks

A rudimentary wind-break occurs when one building is erected on the windward side of another. The detailed effect this has on wind movements is complicated, and seldom entirely beneficial. Depending on the height of the wind-break, there is a considerable blocking of wind from buildings on the leeward side. See Figure 7, (a) and (b). Angling the blocks in plan, or staggering them as shown in the adjoining diagrams, causes only minor differences in the amount and direction of wind penetrating beyond the wind breaks. Olgyay [4] claims that the arrangements shown in Figure 7(c) and (d) result in good breezes to all units. If the successive rows of buildings are spaced

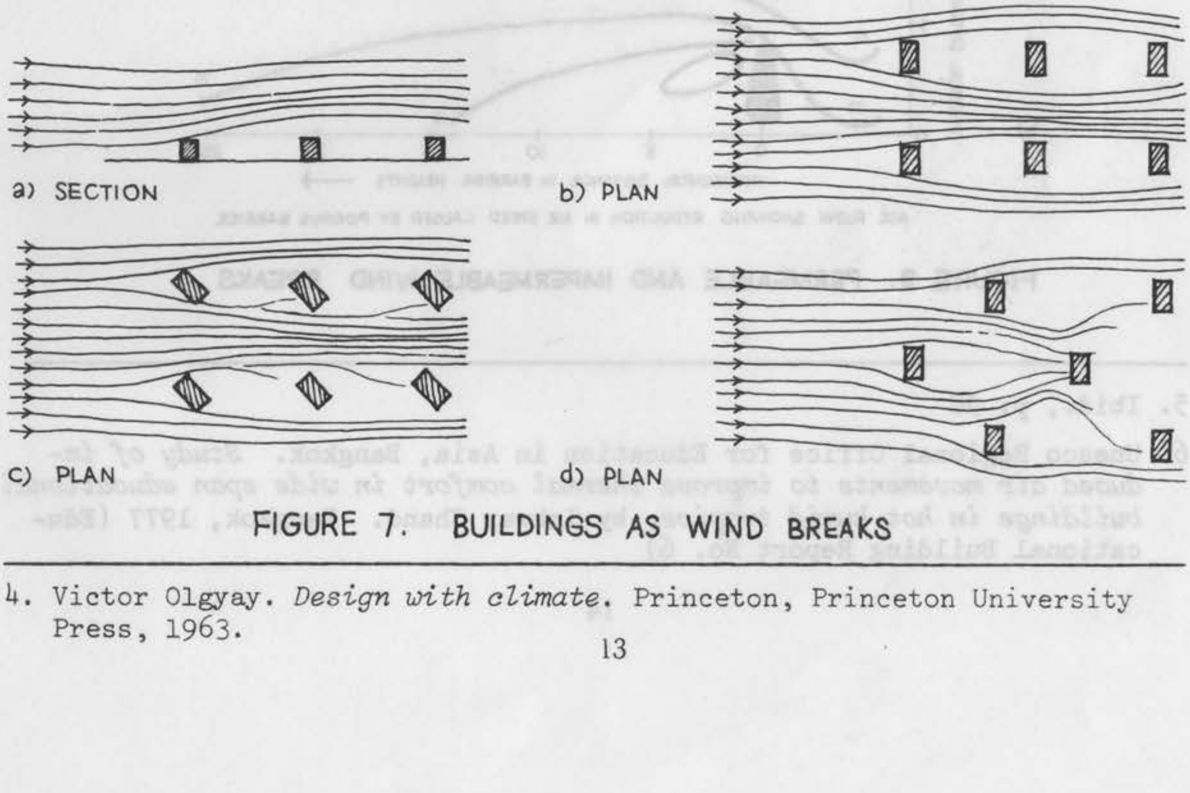

FIGURE 7. BUILDINGS AS WIND BREAKS

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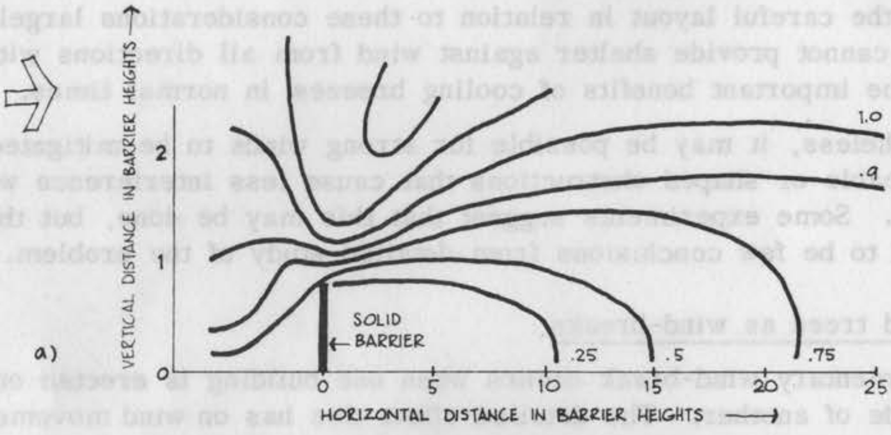
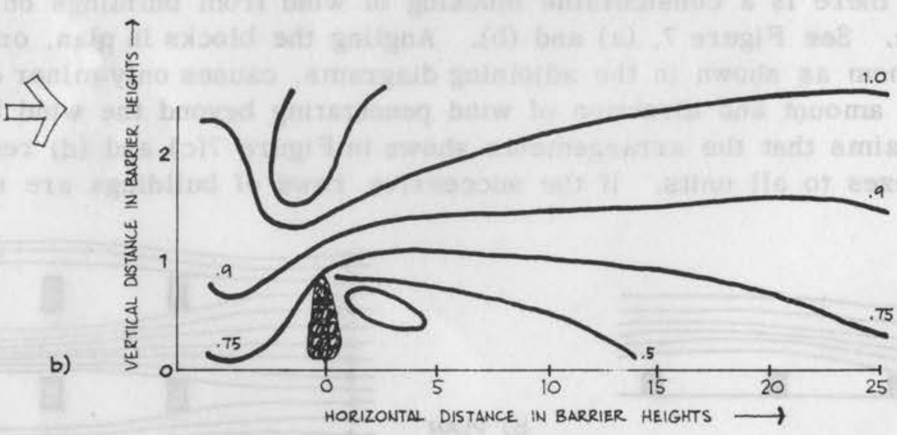
[4] Victor Olgyay. *Design with climate.* Princeton, Princeton University Press, 1963.

at about seven times their height apart, the wind movement will not be seriously diminished; at a closer spacing some wind protection is afforded.

Wind-tunnel tests have been made of wind-breaks of various kinds[5/], [6/]. The type of wind-break has some effect on the result; solid windbreaks - for example, walls - cause eddies over the top which reduce their value (Figure 8a). Permeable barriers such as belts of trees are more effective in some ways because, while not reducing wind velocities as markedly as solid barriers, there is a greater depth of protection (Figure 8b).



AIR FLOW SHOWING REDUCTION IN AIR SPEED CAUSED BY SOLID BARRIER



AIR FLOW SHOWING REDUCTION IN AIR SPEED CAUSED BY POROUS BARRIER

FIGURE 8. PERMEABLE AND IMPERMEABLE WIND BREAKS

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5. Ibid., p. 98

6. Unesco Regional Office for Education in Asia, Bangkok. *Study of induced air movements to improve thermal comfort in wide span educational buildings in hot humid tropics*, by Ishwar Chand. Bangkok, 1977 (Educational Building Report No. 6)

The air bleeding through a permeable wind-break tends to reduce the formation of leeward eddies (Plate 2).

Plate 2. Trees seem to have reduced wind speeds sufficiently to prevent damage to these flimsy buildings

The permeability of different kinds of trees and other barriers can be varied (Figure 9). The optimum porosity of the barrier is in the range 30-to-50 per cent.[7] A lower figure will cause a greater reduction in wind speeds, but the more open barrier will be effective for a greater distance.

The performance of different types of permeable barriers - boarded fences, dense belts of trees, thinner belts of lighter texture trees - will produce considerable differences for the first five to ten times or so of their height, in horizontal distance from the barrier, after which the differences diminish. At about 30 height units there is no appreciable effect, and not much at 20.

It should be remembered that, as well as affording protection, wind-breaks divert wind to other places. This can have a beneficial or adverse effect. Similarly, in using trees to reduce wind speeds in a particular area, the effect in other locations will probably be to increase speeds (for example, immediately above and below the foliage).

Seasons

Many school buildings are in use for only some parts of the day and year. Ideally, the long school vacation would coincide with the months of

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[7] Newberry. *Wind loading handbook,* op. cit. p. 34

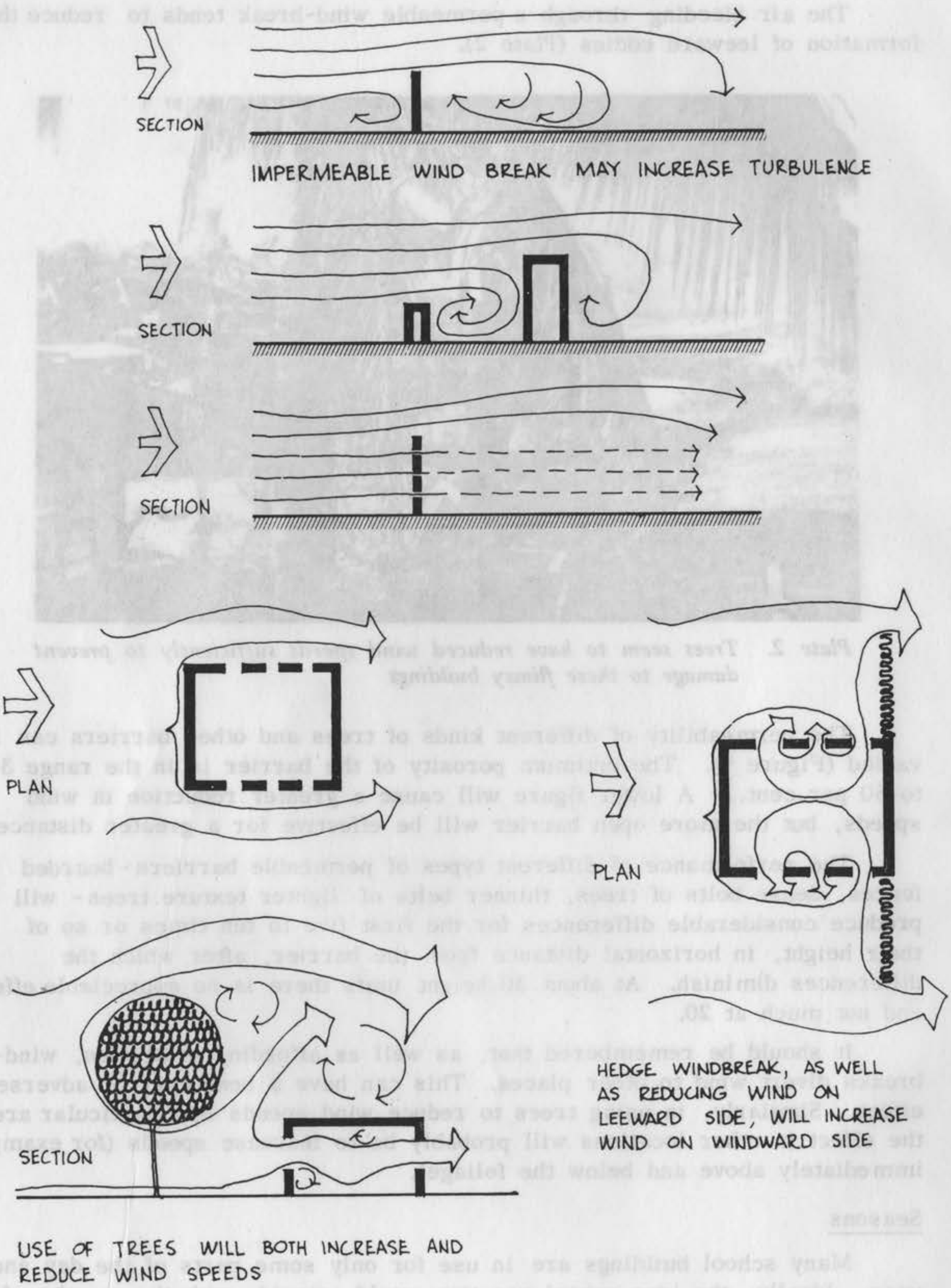

FIGURE 9. WIND FLOW

cyclones or other bad weather. Some parts of the school do not need as much protection as other parts, and some parts may be able to shelter other parts from unfavourable winds.

Flooding and storm-surge

When a history of flooding exists, there are probably locally evolved building practices in which some adjustments have been made to meet flood problems. For example, earth-block construction may have evolved with additives such as cement or asphalt which are more resistant to still or turbulent floodwater. Local observations about scouring and the dynamics of flood water will be valuable.

There is a proposal for small flood shelters, community-built on raised earth platforms, for Bangladesh. These shelters will give minimum protection against an 8 metre storm surge, which is a fairly extreme surge height. The shelters are capable of construction by voluntary community labour (Figure 10).[8]

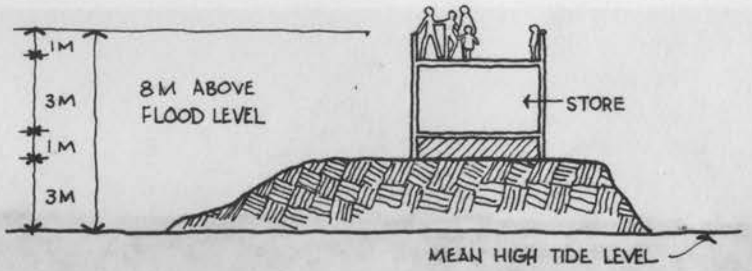

FIGURE 10. STORM SHELTER WITH ROOF REFUGE

A more commodious shelter of this type is being provided in Bangladesh through the school-building programmes.

Important site considerations which have a bearing on storm-surge are these

1. The history of storm surge from cyclonic disturbance, i.e., the probability of severe storms and therefore the likely height of water over normal sea level;
2. Tide level at the time of arrival of the storm;
3. Land configuration and wind direction;
4. Elevation of site (natural and constructed);
5. Distance from body of water, characteristic ground cover resisting surge;

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[8] Stephen A. Liment. *Housing in extreme winds report.* Washington, D.C., National Bureau of Standards, Center for Building Technology, Office of Federal Building Technology, 1973, p. 20.

The last two are capable of being varied by an anti-flood policy. A recommendation by the Institute of Engineers, Pakistan, discouraged the construction of permanent buildings within a belt of one-and-one-half miles of the sea coast and of estuarial rivers, and proposed a one-quarter mile belt of afforestation within that area, and coastal embankments along the sea coast and estuarial rivers to exclude saline water (Plate 3), the outside area to be cultivated with planned afforestation. A further recommendation was that all public buildings, including schools, should be of double-storeyed masonry construction. [9] This last recommendation was the subject of further work resulting in specific proposals for schools as cyclone shelters. These proposals include the following:

1. Floors above storm-surge level;
2. An accessible roof;
3. Sanitary facilities;
4. Drinking water storage facilities. [10]

Plate 3. Part of the embankment along the coast and estuaries of Bangladesh. The cyclone of 1970 resulted in a storm surge which raised water over the embankment, washing away the part shown in the foreground.

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[9] Pakistan. Institute of Engineers. *Report of Institute of Engineers, Sub-Committee on Cyclone Disasters in East Pakistan.* Dacca, 1962, p.26.

[10] Asian Regional Institute for School Building Research, Colombo. *The Primary School Building Programme, East Pakistan with special reference to cyclone affected areas.* Colombo, 1968, p. 30.

CHAPTER FOUR

STRUCTURAL PRINCIPLES IN SCHOOL BUILDING DESIGN : ROOFS

General

Wind may cause direct damage to the building through :

1. Under-design of the frame or structural members;
2. Defects in materials or workmanship;
3. Deterioration of materials.

Common experience in developing countries points to (b) and (c) as being the most frequent causes of damage, but (a) is not uncommon.

Roofs commonly fail through :

1. Inadequate strength of components;
2. Inadequate fixing of sheeting, or lack of continuous tying down of ridge-sheeting-purlins-trusses or rafters-wall-footing;
3. In humid climates, deterioration of metal sheeting and fixing, also loosening of fixings from wood shrinkage over a long period. Influencing factors include roof shape, roof slope, proximity of other elements, size of cantilevered eaves or overhangs, construction of trusses or rafters, use of posts or walls, and the use of ceilings inducing pressure under the roof.

Slope and shape of the roof

A reasonable generalization would hold that modern buildings tend to have low-pitched or even flat roofs, compared to the relatively steep pitches of traditional types. In considering the loading caused by winds, a relatively steep pitch produces a more manageable and predictable load. Pitches higher than about 30° will tend to give positive loads (pressure) on the roof surface, except at ridge and eaves where a negative pressure (suction) will occur (Figure 11). If the building itself is permeable to wind, a further pressure may well be applied to the under surfaces of the roof. If both pressures on the upper and lower surfaces are upward, there is an increased chance of the roof failing from these sometimes unexpected forces (Plate 4).

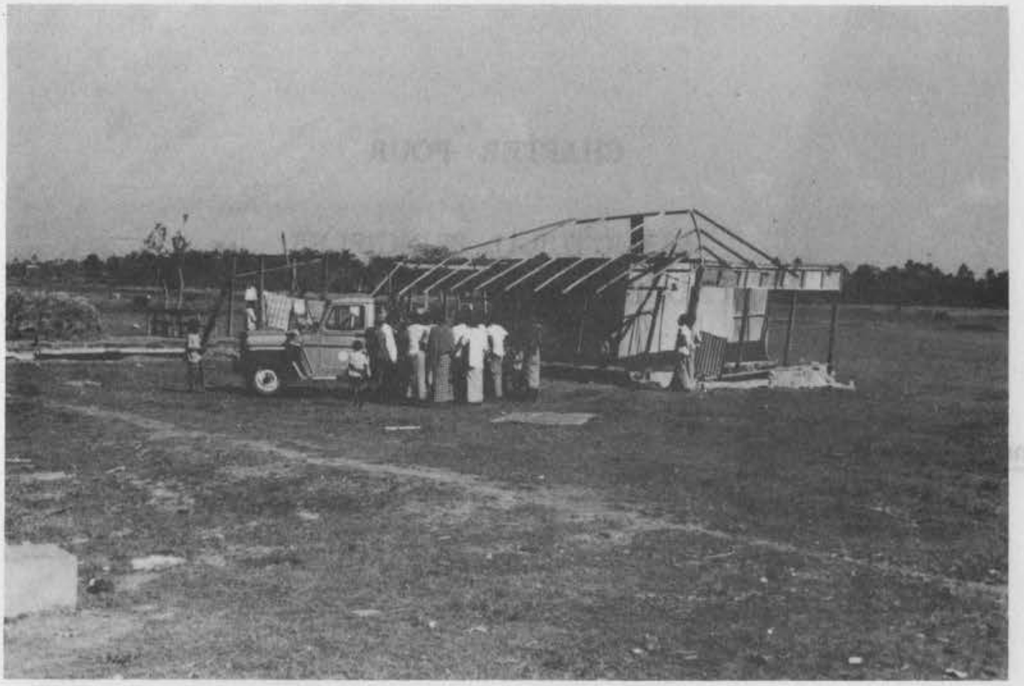

Plate 4. External negative pressures combined with internal pressures have blown this roof away out of sight.

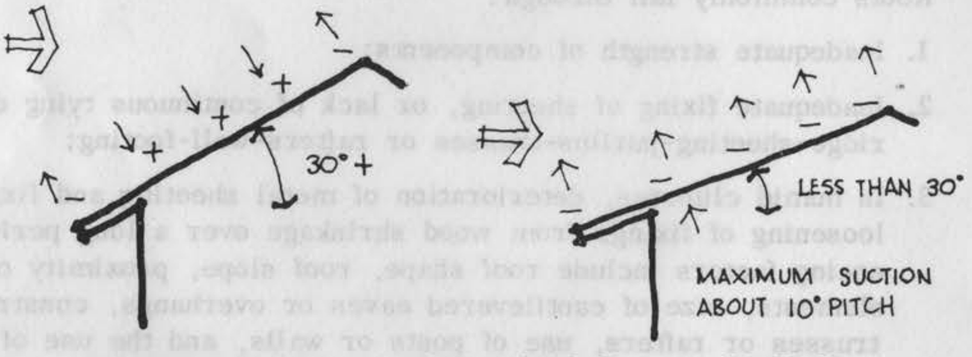

FIGURE 11. EFFECT OF ROOF SLOPES ON WIND PRESSURE

Modern building procedures tend towards repetition of factory-assembled building units, such as roof trusses. This results in obvious benefits in uniformity of structural strength, ease of inspection and quality control. It also tends to produce a gable roof of standard slope, (Figure 12a) which is often a relatively low pitch. The reasons for this low pitch are obscure, but two suggest themselves :

1. A low pitch lends itself to extension over a verandah or covered way without endangering head height;
2. Prefabrication methods were developed at a time when low-pitched roofs were symbols of modernity, despite the greater structural and economic logic of a slope of 30° or more.

The commonly-seen gabled-roof school building, while economical in many ways, has some shortcomings:

1. It presents a relatively large flat area to the wind. The gable end has often failed in strong wind, (though it need not do so) through its tensile weakness and lack of adequate connection to the roof structure;[1]
2. The gabled roof may shelter the two long sides of a rectangular building very well, but it leaves unsheltered the two high (and expensive) end walls and any openings in them;
3. Poorly designed gabled roofs are frequently inadequately braced diagonally. Bracing, in both the sloping plane of the roof and the horizontal plane of the ceiling, is usually of the greatest importance in imparting rigidity to the structure as a whole.

The more common traditional shape is the 'hipped' roof (Figure 12b). It does not lend itself quite so readily to prefabrication (although it could certainly be prefabricated) but it presents some advantages:

1. It reduces the area and cost of the outside wall;
2. It protects the walls better than the gabled roof;
3. It provides some inherent bracing to the roof by reason of its shape;
4. It presents a smaller obstruction in the path of strong winds.

Possible disadvantages in the use of a hipped roof include the potential weakness to penetration involved in cutting and shaping sloped sheets, and the associated 'flashing'.

Another obscure disadvantage appears in the event of inundation of the building, when the hipped roof may tend to trap air when the water rises, thus imposing strong up-thrust on the roof and its fastenings to the wall (Figure 12c). A recommended practice for flood-prone buildings is to ensure ventilation openings high in the walls to permit rising water to escape. This recommendation might extend to the hipped roof. Alternative suggestions include the 'gabled hip' which (in theory) allows ventilation of the roof space and would overcome the problem referred-to above (Figure 12d).

Ridge ventilation also allows warm air to escape and permits slightly cooler air to enter the building by convection (Figure 12e).

<ins>Flat roofs</ins>

In strong winds, there is a very strong suction effect on the outer, windward edges of a flat roof. In the case of a flat, metal-clad roof, this frequently causes the roof to peel off. Fixing of the ends by means stronger than normal is possible, but this will result in increasing the cost of the

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[1] Newberry, *Wind loading handbook*, op. cit.

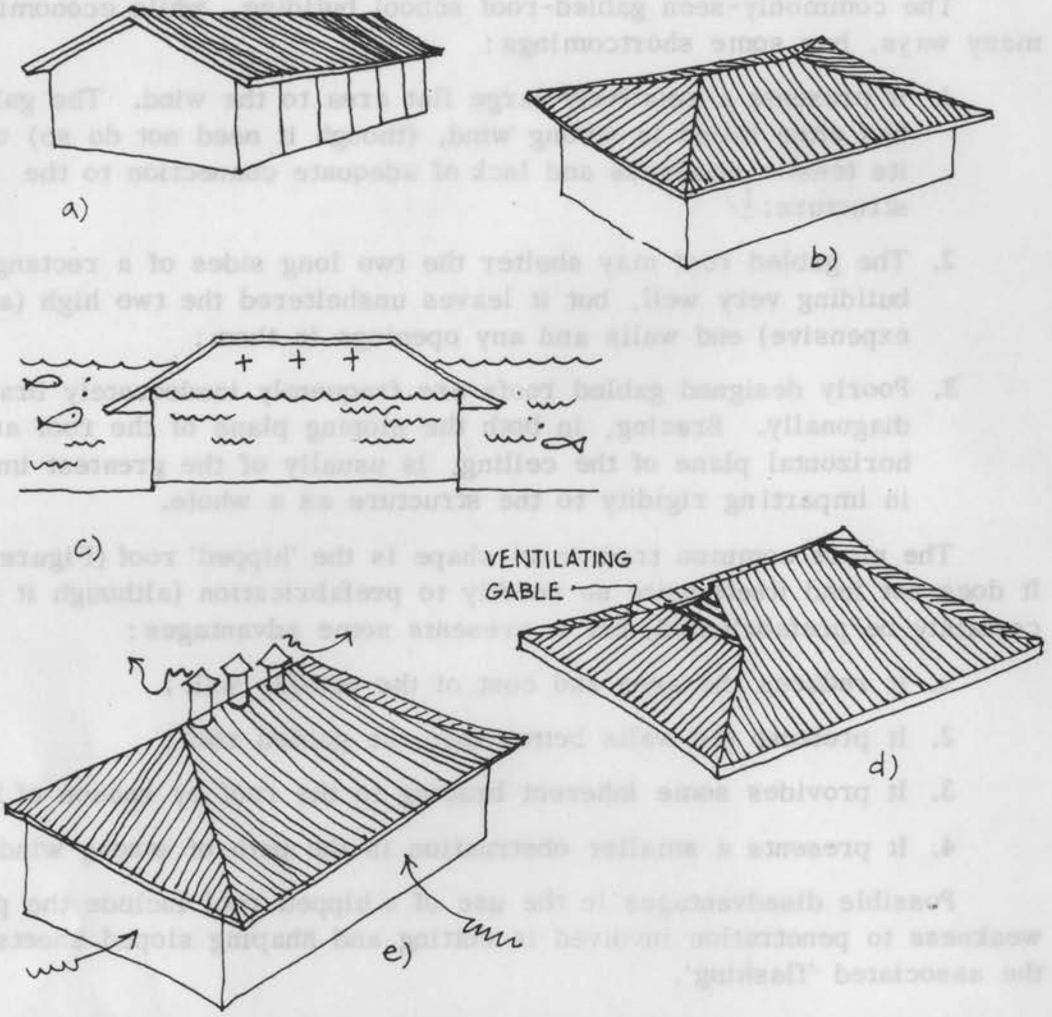

FIGURE 12. WIND AND THE SHAPE OF THE ROOF

building. In the case of flat roofs, common for example in Bangladesh, the inherent strength of the construction is normally sufficient to withstand the suction and buffeting effects, particularly if the roof is designed (as recommended) for a high live load, because of its emergency functions of accommodating refugees during floods.

Roof overhangs and canopies

Cantilevered and overhanging eaves are universally condemned by writers reporting on wind damage. But it is the protection of a generous roof that gives many buildings their functional and emotional appeal.

A roof carried down over a verandah space mediates between the small scale of the interior and the infinite external space. It serves a similar function in modifying the harsh contrast in light levels between inside and outside on a bright day. It also provides partial shelter in inclement weather, and usable space of intermediate quality between the uncontrolled exterior and tightly defined interior.

The experience of the 'Marcos' prefabricated school buildings in the Philippines showed increasing caution in the structural design of succeeding models. The cantilevered, steel-framed overhang was reduced from about 2.258 metres to about 1.20 metres and reduced again in the latest timber-framed (Bagong Lipunan) model. The earliest of the prefabricated series, the 'army' type, also in timber, had a generous overhang on one side, supported on posts. All of the above types have failed in various typhoons, with the exception of the most recent, which is, at the time of writing, only a prototype, and designed for 140 mile-per-hour winds (225 k.p.h.) as compared with 100 m.p.h. for the earlier models. Previous failures have variously been attributed to design and workmanship. As many of the schools are erected in remote areas by 'self-help', through parents and teacher associations without central supervision, workmanship shortcomings are to be expected. In reducing the overhang by more than half, the usefulness of the building is impaired. Some study of the detailed reasons for roof failures is justified and the following notes and sketches attempt to discuss the matter further.

There is always a negative pressure on the windward edge of the roof (Figure 13).

The buffeting effect is increased by the eaves projecting far beyond the building wall. A common effect is the attempted flexure upwards of the overhanging surface (Figure 14). This is known as the Monroe effect.[2]

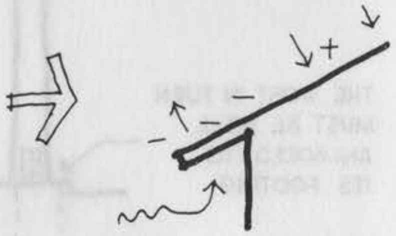

FIGURE 13. NEGATIVE PRESSURE ON THE WINDWARD EDGE OF THE ROOF

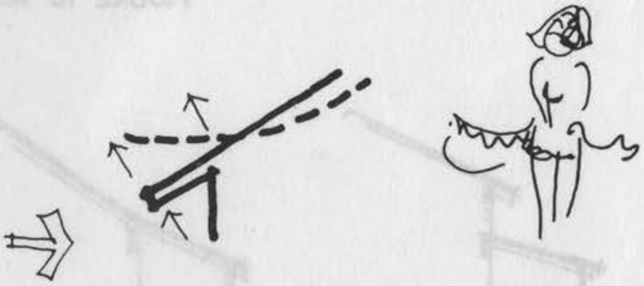

FIGURE 14. THE MONROE EFFECT

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[2] Ambrosio R. Flores, "Design methods for wind effects on building and structures." *Philippine Architecture, Engineering and Construction Record"*, April 1972.

An essential precaution is to tie down the leading edge of the roofing securely, if necessary, by a batten on top of the sheeting, which is bolted or screwed through (Figure 15).

The use of a post to support and secure the outer edge will tend to control this movement (Figure 16).

An alternative method of protecting a verandah space is the use of a separate roof, or a different slope over the verandah. Sometimes this may be a flat roof (Figure 17).

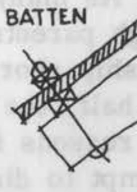

FIGURE 15. SECURING THE ROOF EDGE

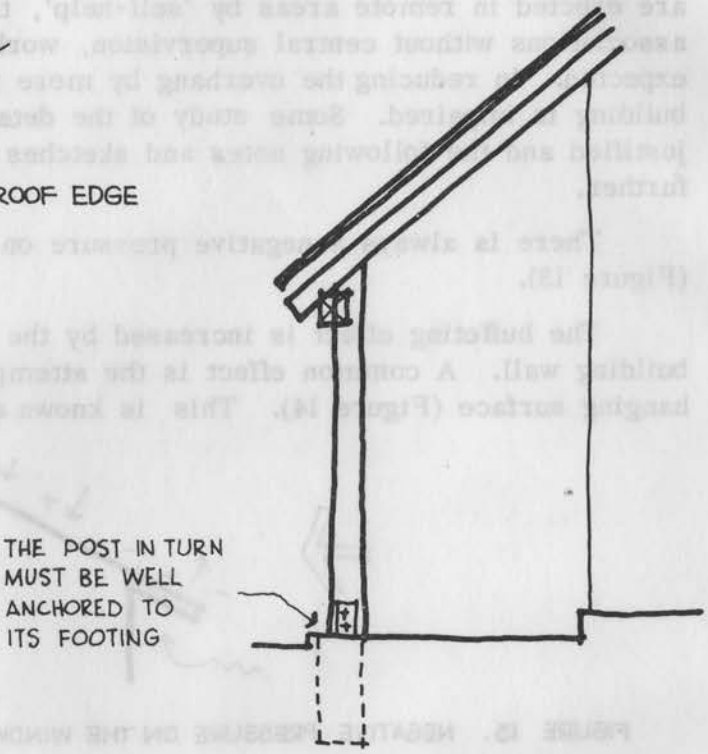

FIGURE 16. HOLDING DOWN THE OVERHANG

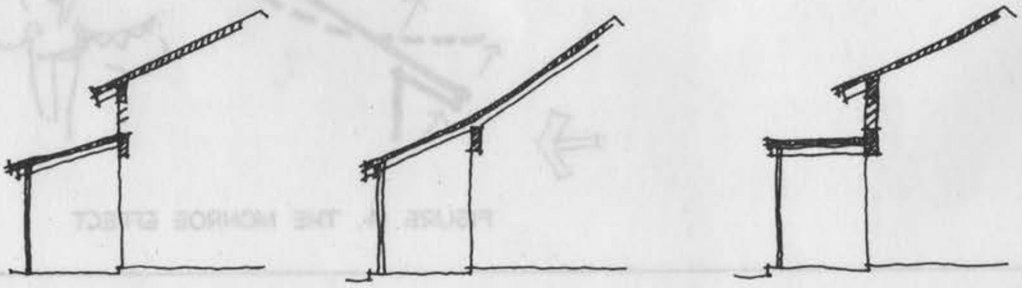

FIGURE 17. VERANDAH ALTERNATIVES

When there is a continuous solid canopy over an opening, it produces an undesirable flow pattern inside, directing air flow upward, away from the interior of the building.[3] (Figure 18a)

When there is a slot between canopy and wall, external pressures are equalized and the pattern of air flow is better (Figure 18b).

This suggests that the desired movement of air inside the building can be promoted by giving the verandah a 'covered way' type of roof, possibly flat, separated slightly from the wall of the school building (Figure 18c).

This type of verandah roof has advantages and disadvantages :

Advantages

1. It separates the vulnerable overhang section of the roof from the main roof. The verandah roof may be of lighter construction;
2. It may promote penetration of light and ventilation into the room in a controllable way, both above and below the roof level.

Disadvantages

1. Radiant heat may be reflected up into the building through the high wall openings;
2. Another roofing process is involved.

If the purpose of the verandah is shade rather than shelter from rain. it can be roofed with permeable material, e.g. split bamboo held on a stretched wire frame - cheap, light and renewable. Intermediate degrees of weatherproofing could be provided by thatch, growing vines or other variants (Figure 18d).

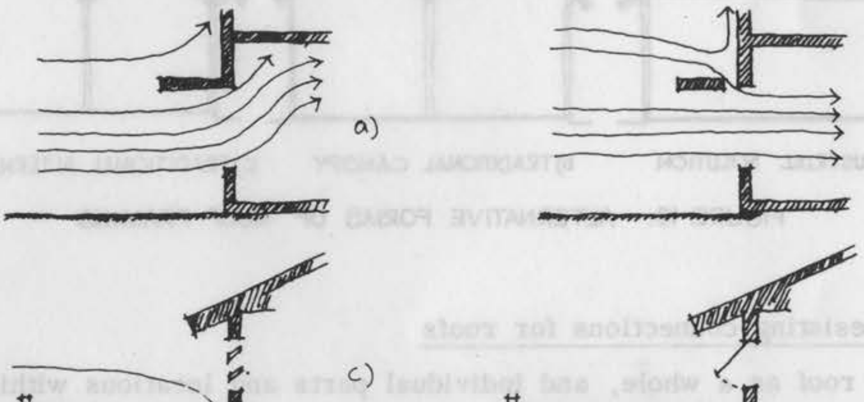

FIGURE 18. EFFECT OF WIND ON CANOPIES

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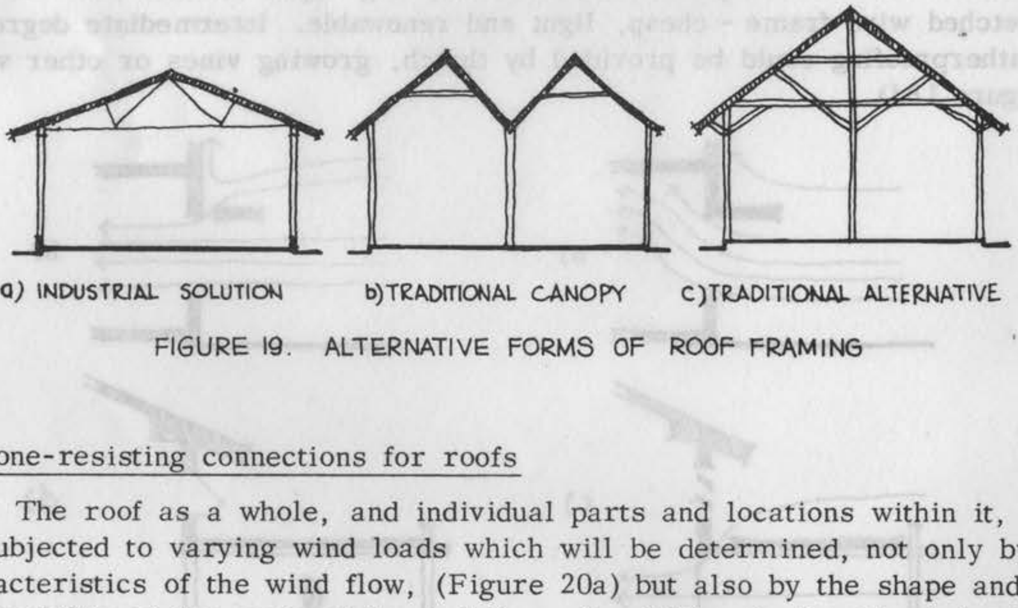
[3] Unesco, *Study of induced air movement*, by Ishwar Chand, op. cit.

Timber framing

The development of prefabricated building components has frozen the development of some lines of design. For example, the characteristic shape of many buildings is now the gabled roof rectangle of about 8 metres in width, resulting in fairly wide spans, uninterrupted by supporting posts inside the building (Figure 19a).

Undeniably, it is often convenient not to have posts within the building, but it is not such an essential that no alternatives can be contemplated. It is in relatively minor differences like this that the break between conventional building practices and industrialized building first appears. The indigenous carpenter is well able to construct a very sound house using traditional techniques, but cannot handle an 8-metres clear span. Therefore the work must be done by the urban technocrats. The traditional way to achieve a large space in a house is to use the same timber sizes and spans, but using multiple bays supported by intermediate posts (Figure 19b). Diagonals are usually employed to brace and strut the structure and reduce spans, in both horizontal directions, whereas the repetition of roof trusses at structural bays does not, by itself, produce lateral strength.

It could be maintained that the breaking up of the internal space, both at working level and overhead, creates a more intimately scaled environment and, indeed, an inherently educational one (Figure 19c).



a) INDUSTRIAL SOLUTION b) TRADITIONAL CANOPY c) TRADITIONAL ALTERNATIVE

FIGURE 19. ALTERNATIVE FORMS OF ROOF FRAMING

Cyclone-resisting connections for roofs

The roof as a whole, and individual parts and locations within it, will be subjected to varying wind loads which will be determined, not only by the characteristics of the wind flow, (Figure 20a) but also by the shape and permeability of the parts of the building. In addition to the direct loading on the upper surface of the roof, which may be a positive or negative pressure (Figures 20b and c), there may be further loading on the lower surface of the roof, caused by the varying penetration of the wind into the interior of the building and below the eaves, and the permeability of the building elements and membranes constituting the roof and roofing. Although it is common for school buildings to have unlined eaves, and frequently no ceiling, there will be other cases where a number of barriers occur between the wind pressure below the eaves construction or ceiling and the underside of the roofing material (Figure 20d). The permeability of these barriers (which may also include such things as doors) will affect the additional load imposed on the roof from below (Figures 20e and 20f).

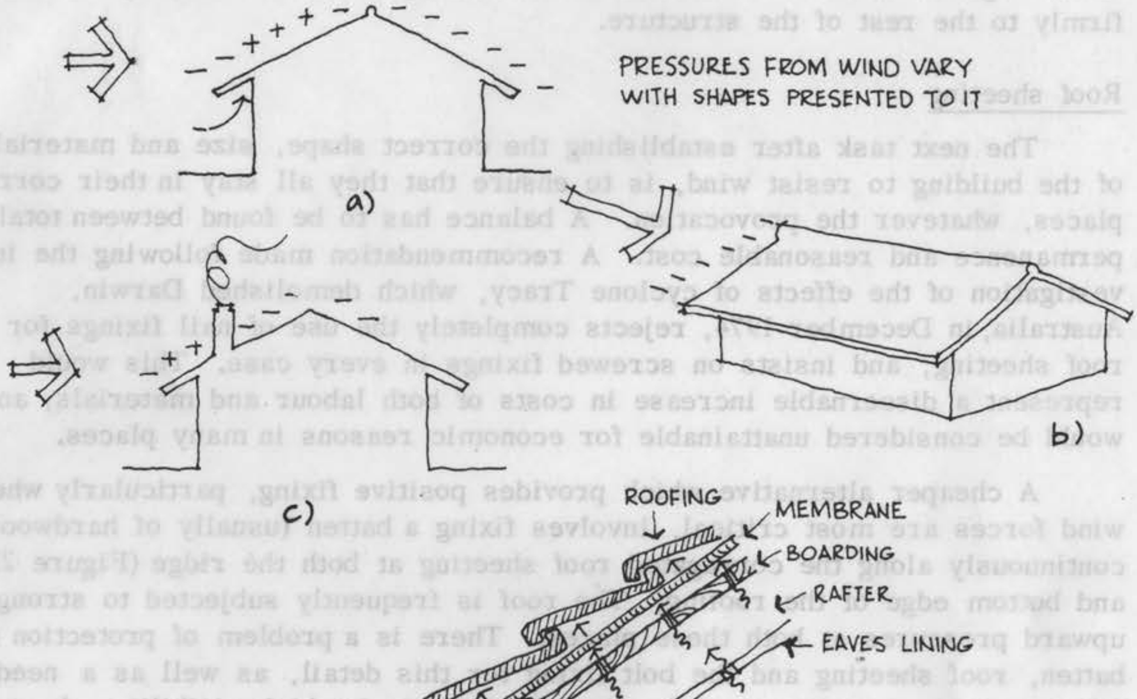


FIGURE 20. ROOFS IN A CYCLONIC STORM

Sometimes minor or partial damage to the roof (e.g. the dislodging of a few tiles) will quickly stabilize the roof loading, by equalizing internal and external pressures. This can be dangerous: where a number of layers, such as wood, insulation, waterproofing elements and the like form a combined barrier to the wind, there is an increased possibility that the entire roof may be lifted off, intact. The prevention of partial, self-adjusting failure against wind loads thus calls for extra precautions in tying the roof firmly to the rest of the structure.

Roof sheeting

The next task after establishing the correct shape, size and materials of the building to resist wind, is to ensure that they all stay in their correct places, whatever the provocation. A balance has to be found between total permanence and reasonable cost. A recommendation made following the investigation of the effects of cyclone Tracy, which demolished Darwin, Australia, in December 1974, rejects completely the use of nail fixings for roof sheeting, and insists on screwed fixings in every case. This would represent a discernable increase in costs of both labour and materials, and would be considered unattainable for economic reasons in many places.

A cheaper alternative which provides positive fixing, particularly where wind forces are most critical, involves fixing a batten (usually of hardwood) continuously along the corrugated roof sheeting at both the ridge (Figure 21) and bottom edge of the roofing. The roof is frequently subjected to strong upward pressures at both these places. There is a problem of protection of batten, roof sheeting and the bolt fixing for this detail, as well as a need for inspection and maintenance. An advantage is its high visibility. Its presence or absence can be checked visually without difficulty, and replacement in the event of deterioration is also simple.

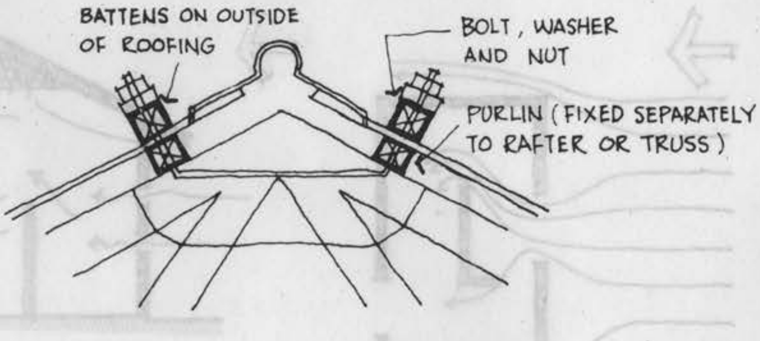


FIGURE 21. CORRUGATED SHEETING-FIXING AT THE RIDGE

Common practices in fixing metal roof sheeting to purlins include the following:

1. The practice of riveting a sheet-metal strap to the sheeting and bending it to run down one side of the purlin would be improved if straps were doubled so that fixing to the purlin would be symmetrical (Figure 22). The riveting point is another potential weakness and the tendency of light gauge sheeting to tear away at this point should be considered.

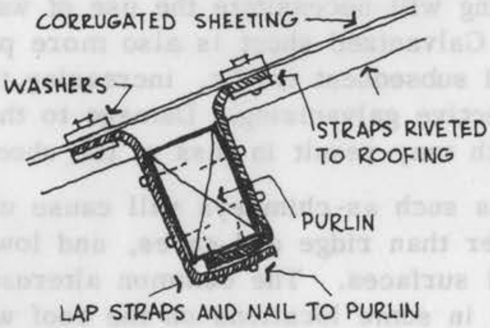


FIGURE 22. CORRUGATED SHEETING—FIXING TO PURLINS WITH STRAPS

2. Another method is to puncture the corrugated sheeting (at the top of the corrugation) and pass a wire through the two perforations, tying the wire underneath the purlin (Figure 23).

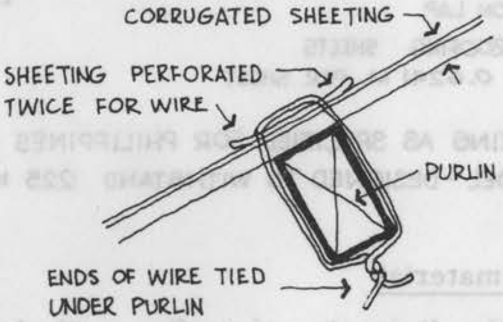


FIGURE 23. SYMMETRICAL FIXING TO PURLINS BY WIRE

Both these examples show the importance of joints avoiding torsion, by using symmetrical connectors or pairs of connectors if necessary.

Both can also be subject to corrosion unless precautions are taken. The use of non-galvanized connections to galvanized sheeting speeds up the loss of galvanizing protection in the presence of moisture. The possibility of water penetrating to the structural timber through a faulty connection, thereby causing not only further loosening of the connection but further deterioration of the timber, must also be avoided.

If the parts of the building subject to special loading (ridges, eaves) are treated to withstand strong upward pressures in high wind, intermediate sheets should be fixed according to recommended practice. Roof fixing to prefabricated school buildings in the Philippines is intended to withstand wind speeds of 225 k.p.h. Zinc-coated roof nails are used (Figure 24).

There are several further points to remember concerning workmanship. Light galvanized sheeting will necessitate the use of washers as an extra area of support at fixings. Galvanized sheet is also more prone to incidental damage in handling and subsequent traffic, increasing the probability of deterioration of the protective galvanizing. Damage to the edge of sheets causes wind entry which may result in loss of the sheets.

Other obstructions such as chimneys will cause unusual pressures (suctions) in areas other than ridge and eaves, and low-pitched roofs will produce suctions on all surfaces. The common alternation between positive and negative pressures in some locations on the roof will amplify and increase any looseness in fixings. The use of screws rather than nails for joining sheets may be desirable in some locations (as suggested for Darwin [4/]).

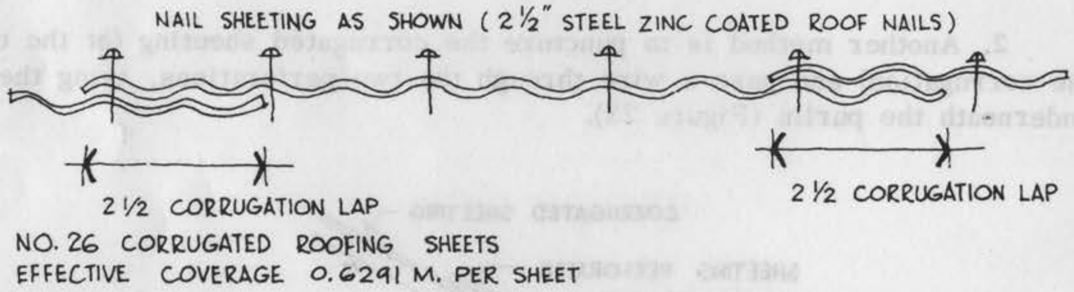


FIGURE 24. ROOF FIXING AS SPECIFIED FOR PHILIPPINES PRIMARY SCHOOLS 1975 MODEL - DESIGNED TO WITHSTAND 225 K.P.H. WIND VELOCITY

Fixing of other roofing material

Although most of the discussion of roofing methods has concerned corrugated sheet-metal roofs, other roofing materials are common; for example, thatch, slate, shingle, tile, mud, concrete, and asbestos-cement sheet.

Thatch is relatively resistant to both wind and water, but is not discussed here. Where thatching is a local practice it will have adapted to the peculiarities of the locality. Where it is not already a practice, it is unlikely to be introduced. The same applies to mud or unburnt clay roofing.

[4/] Australia. Dept. of Housing and Construction. *Report on cyclone "Tracy"*, by G.R. Walker, op. cit.

Slates, tiles and shingles share roughly similar fixing techniques. The manufactured unit in general gives a better-fitted joint, and tends to result in a relatively lighter roofing load, although concrete tiles, for example, are more uniform (and heavier) than terra-cotta tiles (which may be warped). When dislodged in heavy wind these materials are no less dangerous than corrugated sheeting, but their flight paths tend to be shorter and more predictable.

There is a tendency for tiled roofs to be inadequately fastened to battens. Not infrequently entire roofs are virtually unfixed, the tiles being merely laid on the battens. Normal recommended practice in many places is to fasten every second tile - or every second row - to the battens by wire ties. At ridge and eaves this should be done to every tile.

Corrugated asbestos-cement sheeting is susceptible to puncture by flying debris, or fracture by flapping of the entire roof. Danger from puncture can be reduced by the use of a light wire netting fixed beneath the sheets. Asbestos-cement is sometimes subject to condensation in humid climates, a defect which cannot be relieved by ventilating the ridge without increasing risk of damage in wind and rain.

Purlins and trusses

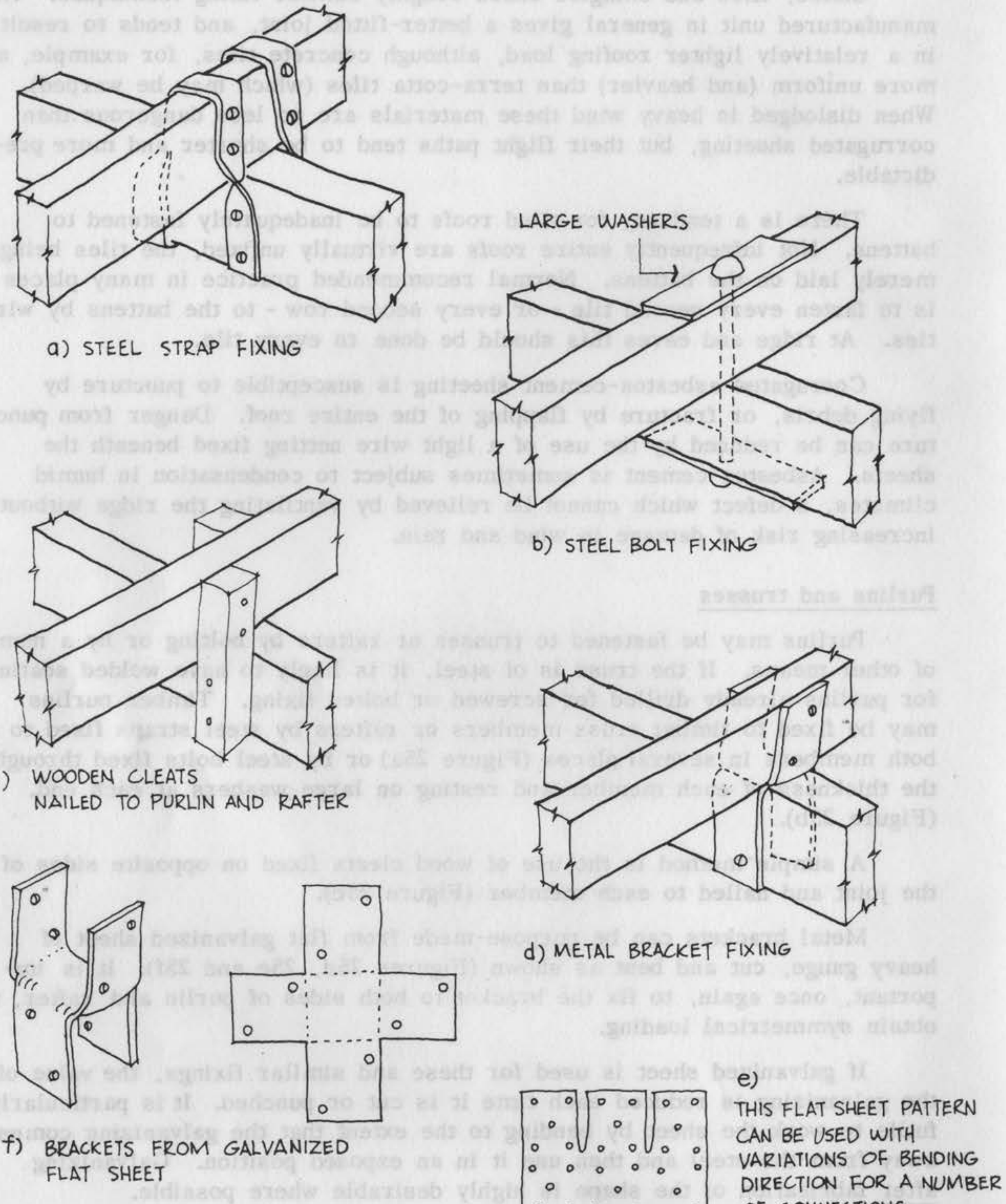
Purlins may be fastened to trusses or rafters by bolting or by a number of other means. If the truss is of steel, it is likely to have welded seatings for purlins already drilled for screwed or bolted fixing. Timber purlins may be fixed to timber truss members or rafters by steel straps fixed to both members in several places (Figure 25a) or by steel bolts fixed through the thickness of each member and resting on large washers at each end. (Figure 25b).

A simple method is the use of wood cleats fixed on opposite sides of the joint and nailed to each member (Figure 25c).

Metal brackets can be purpose-made from flat galvanized sheet of heavy gauge, cut and bent as shown (Figures 25d, 25e and 25f). It is important, once again, to fix the bracket to both sides of purlin and rafter, to obtain symmetrical loading.

If galvanized sheet is used for these and similar fixings, the value of the galvanizing is reduced each time it is cut or punched. It is particularly futile to work the sheet by bending to the extent that the galvanizing comes away from the steel and then use it in an exposed position. Galvanizing after fabrication of the shape is highly desirable where possible.

The various members of timber trusses, normally in the same plane, are usually connected by truss plates for light construction (Figure 26) or split rings for heavy construction. Other framing anchors for various purposes are constructed commercially, providing compact fastenings in a number of directions at timber joints (Figure 27).



a) STEEL STRAP FIXING

b) STEEL BOLT FIXING

c) WOODEN CLEATS
NAILED TO PURLIN AND RAFTER

d) METAL BRACKET FIXING

e)
THIS FLAT SHEET PATTERN
CAN BE USED WITH
VARIATIONS OF BENDING
DIRECTION FOR A NUMBER
OF CONNECTIONS

f) BRACKETS FROM GALVANIZED
FLAT SHEET

FIGURE 25. FIXING PURLINS TO TRUSSES

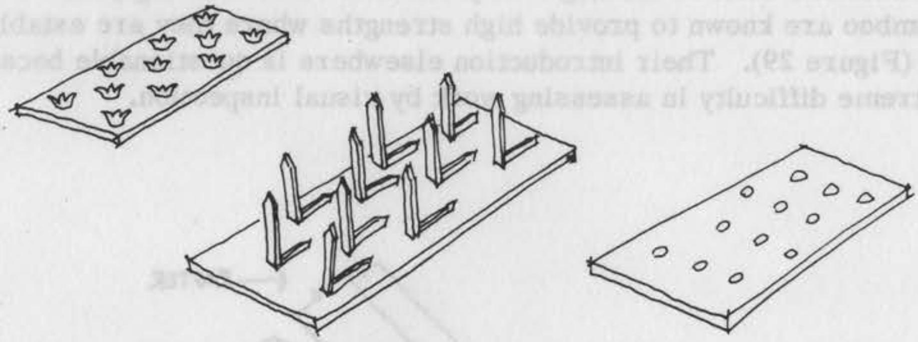


FIGURE 26. PUNCHED METAL TRUSS PLATES

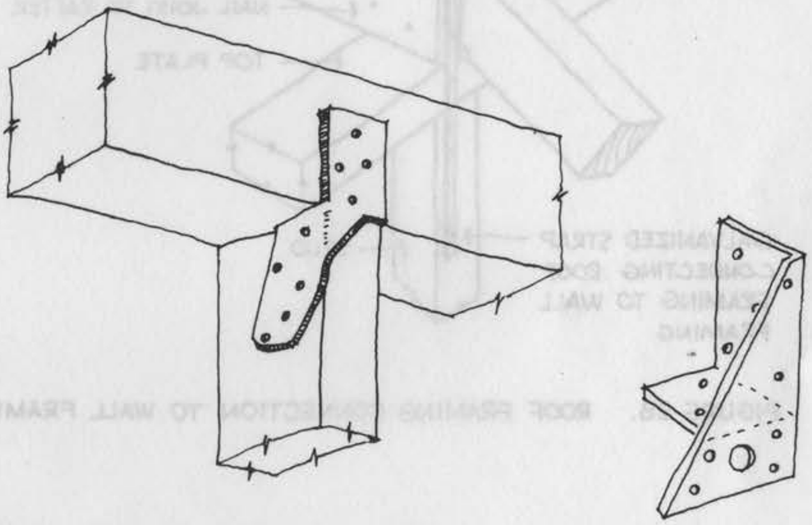


FIGURE 27. EXAMPLES OF PROPRIETARY METAL FRAMING ANCHORS

Roof to wall

The practice of installing 'cyclone bolts' to give tensile continuity to the structure from roof to foundation is discussed in Chapter Five. A simple expedient recommended for lower-cost construction is the provision of a galvanized strap (perhaps 800 mm in length), fixed along the wall stud and ceiling joist, which is then securely nailed to the rafter (Figure 28).

It should be mentioned that the 'cyclone-bolt' device is similar to the recommendation for earthquake-resistant masonry construction [5] and is particularly applicable where both hazards exist.

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5. Unesco, Regional Office for Education in Asia. *Primary and village school buildings and teachers' houses,* a report to H.E. The Minister of Education of the Republic of Afghanistan, Bangkok, 1973. p. 128.

Practices such as lashing roof joints and other framing joints with cane and bamboo are known to provide high strengths where they are established crafts (Figure 29). Their introduction elsewhere is questionable because of the extreme difficulty in assessing work by visual inspection.

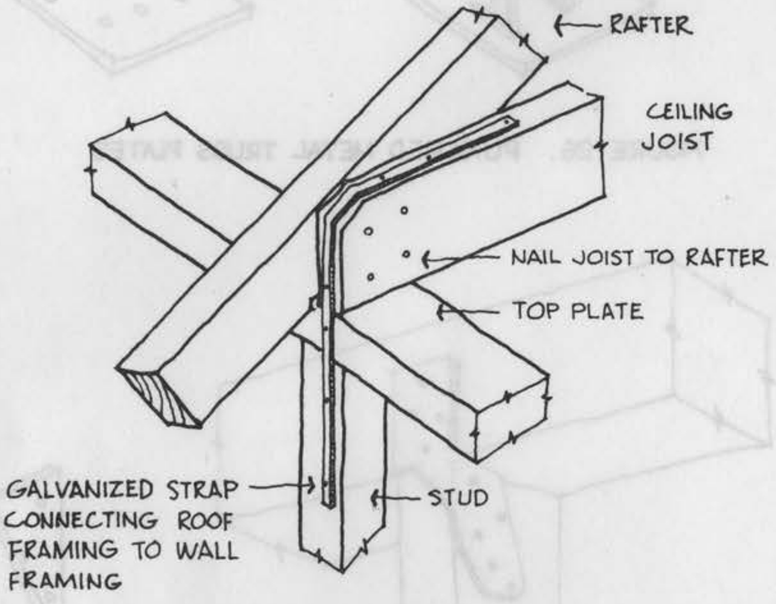


FIGURE 28. ROOF FRAMING CONNECTION TO WALL FRAMING

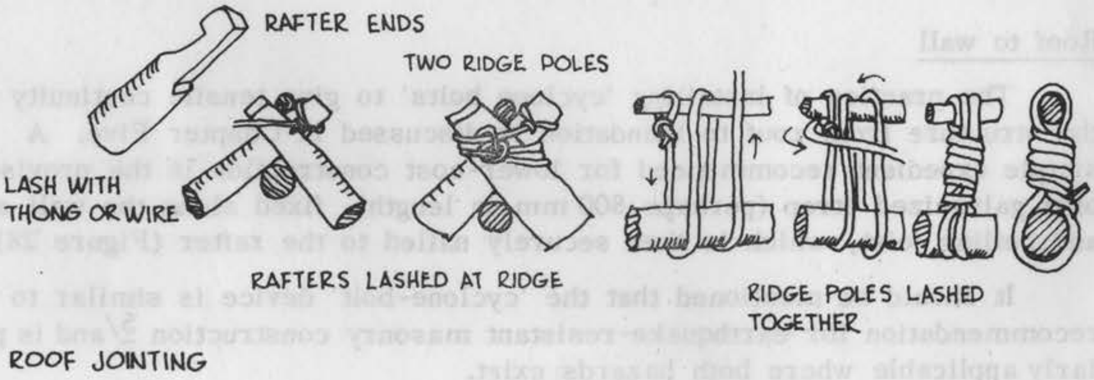


FIGURE 29. LASHED ROOF MEMBERS

CHAPTER FIVE

STRUCTURAL PRINCIPLES IN SCHOOL BUILDING DESIGN : WALLS AND FOUNDATIONS

General

The tendency for small buildings to collapse or disintegrate in strong winds follows certain patterns. For example, modern gabled trussed roofs frequently come off intact, particularly when wind suddenly penetrates the building and exerts an upward pressure from within (Figure 30a). If the building is set on sub-walls or piers which are inadequate to withstand shear, these lower supports may fail and the building be dislodged laterally (Figure 30b). A common recommendation is to provide solid, wind-proof foundation walls both to ensure adequate stiffness to the base and exclude possible upward pressures in strong wind. Unless this base is firmly anchored to the frame of the building, it may still fail at floor level in a strong wind (Figure 30c). In areas of very strong wind, many of these problems can be

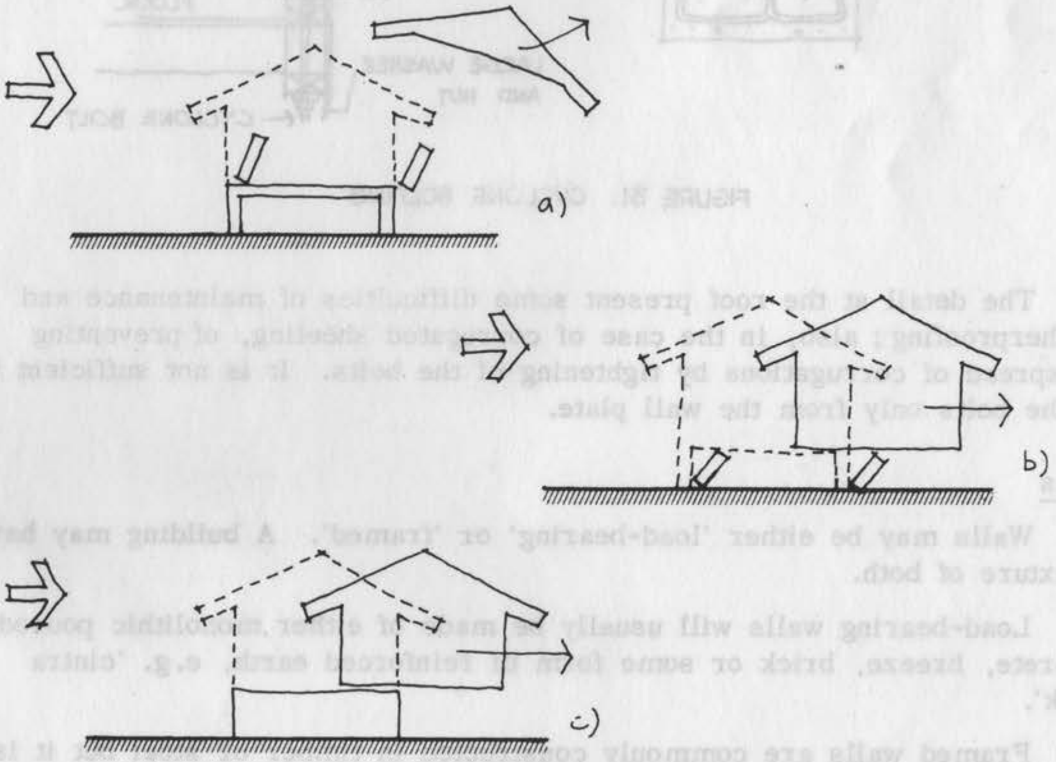


FIGURE 30. MODALITIES OF COLLAPSE IN WIND

overcome by imparting structural continuity to the building (thus giving it maximum tensile strength) through the use of ties from roof to ground. This is sometimes done by providing vertical cyclone bolts continuously through the main structural framing of the building. Unless they are properly anchored, cyclone bolts may impose strain on weaker elements of the construction; hence it is important that they be firmly anchored and supported (Figure 31).

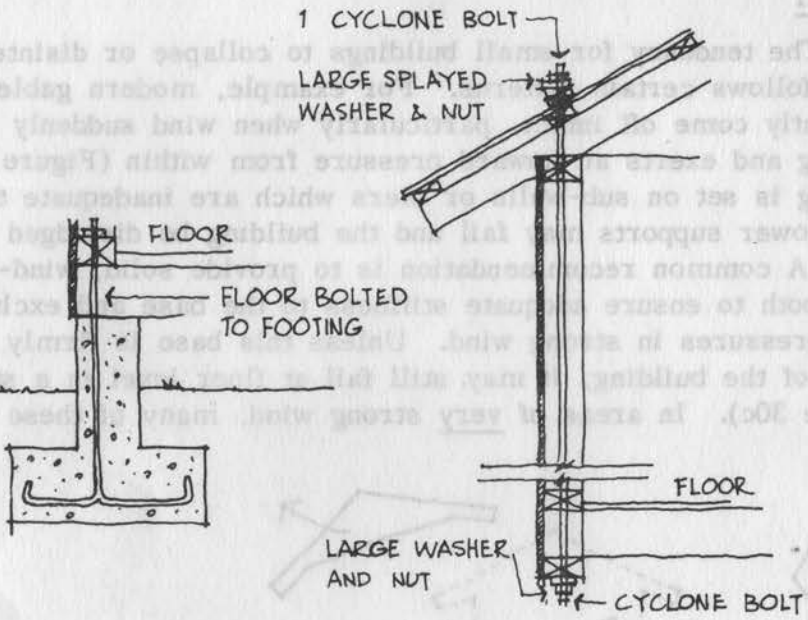


FIGURE 31. CYCLONE BOLTING

The detail at the roof present some difficulties of maintenance and weatherproofing; also, in the case of corrugated sheeting, of preventing the spread of corrugations by tightening of the bolts. It is not sufficient to fix the bolts only from the wall plate.

Walls

Walls may be either 'load-bearing' or 'framed'. A building may have a mixture of both.

Load-bearing walls will usually be made of either monolithic poured-concrete, breeze, brick or some form of reinforced earth, e.g. 'cintra block'.

Framed walls are commonly constructed in timber or steel but it is not uncommon, for example, to have a timber-framed structure with masonry in-fill panels; e.g. 'brick nog', or reinforced-concrete frames with

CHAPTER FIVE

STRUCTURAL PRINCIPLES IN SCHOOL BUILDING DESIGN : WALLS AND FOUNDATIONS

General

The tendency for small buildings to collapse or disintegrate in strong winds follows certain patterns. For example, modern gabled trussed roofs frequently come off intact, particularly when wind suddenly penetrates the building and exerts an upward pressure from within (Figure 30a). If the building is set on sub-walls or piers which are inadequate to withstand shear, these lower supports may fail and the building be dislodged laterally (Figure 30b). A common recommendation is to provide solid, wind-proof foundation walls both to ensure adequate stiffness to the base and exclude possible upward pressures in strong wind. Unless this base is firmly anchored to the frame of the building, it may still fail at floor level in a strong wind (Figure 30c). In areas of very strong wind, many of these problems can be

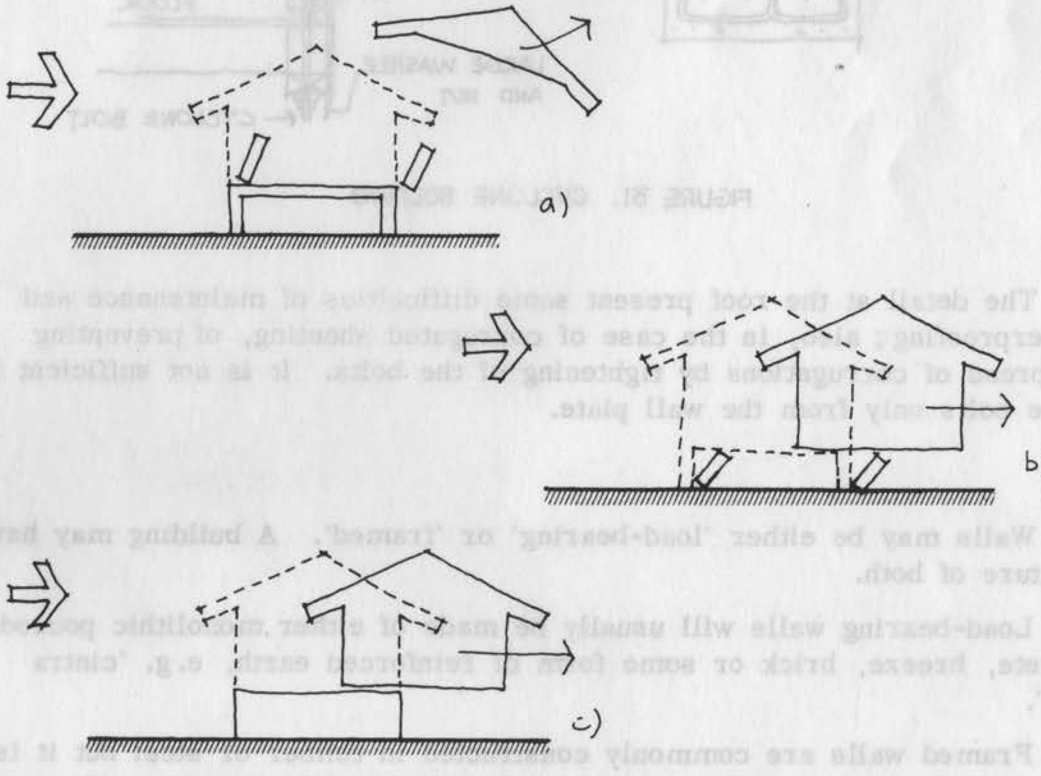
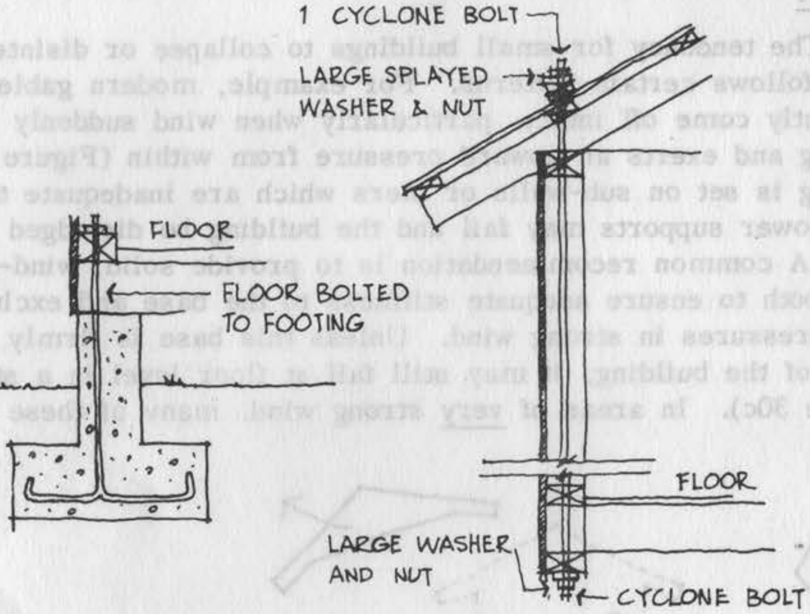


FIGURE 30. MODALITIES OF COLLAPSE IN WIND

overcome by imparting structural continuity to the building (thus giving it maximum tensile strength) through the use of ties from roof to ground. This is sometimes done by providing vertical cyclone bolts continuously through the main structural framing of the building. Unless they are properly anchored, cyclone bolts may impose strain on weaker elements of the construction; hence it is important that they be firmly anchored and supported (Figure 31).



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Load-bearing walls will usually be made of either monolithic poured-concrete, breeze, brick or some form of reinforced earth, e.g. 'cintra block'.

Framed walls are commonly constructed in timber or steel but it is not uncommon, for example, to have a timber-framed structure with masonry in-fill panels; e.g. 'brick nog', or reinforced-concrete frames with breeze block infill. A further variation is to use concrete blocks in load-bearing thickness for main walls, (with or without additional reinforced-concrete framing, such as bond beams at roof level) and thin blocks which provide no appreciable structural value, for minor walls.

Load-bearing wall construction is prevalent in many areas where usable timber is in short supply. Although vaulted forms are perhaps stronger in masonry construction, this discussion will be restricted to straight-line forms.

Structural strength in bending and compression will vary greatly between the various types of masonry unit. Tensile strength in every case is negligible, except for reinforced masonry. For this reason, few load-bearing masonry walls are strong enough to withstand strong winds (Plate 5) unless they are specially bonded together by reinforcing, or are held within a frame of superior tensile properties.

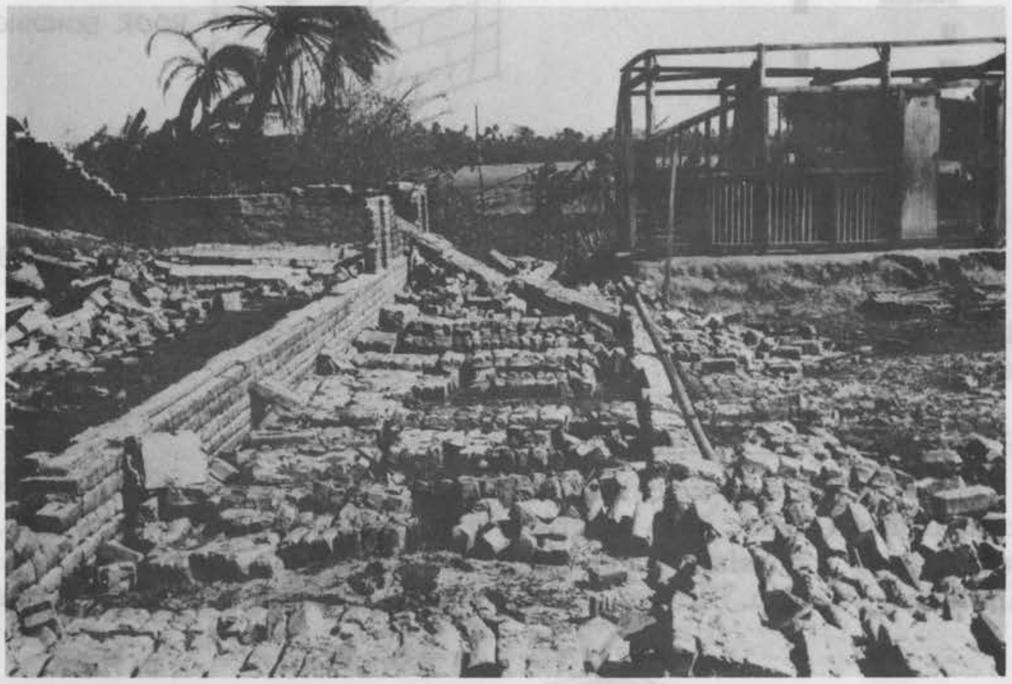


Plate 5. Masonry wall of a school building that failed in the Bangladesh 1970 cyclone. The angle of the trees suggests the wall collapsed due to negative pressures.

Because of the weakness of free-standing masonry slabs, it is essential that, if unsupported by other structural members, they take structurally strong shapes; e.g. angle or "U"-shapes (Figure 32). It is also essential that the individual arms of these shapes be properly bonded together at the junctions and that an adequate mortar be used. Some kind of continuous tensile material (such as 'chicken wire') laid in alternate horizontal joints will provide further horizontal continuity and, for most situations, vertical rods will also be needed for vertical continuity.

A recommended practice for extreme cyclonic conditions is continuous cyclone bolting from roof to ground; if this is to be accomplished with load-bearing walls, it is probable that vertical rods will pass through masonry walls and be anchored into footings and to the wall plate or roof truss at the top.

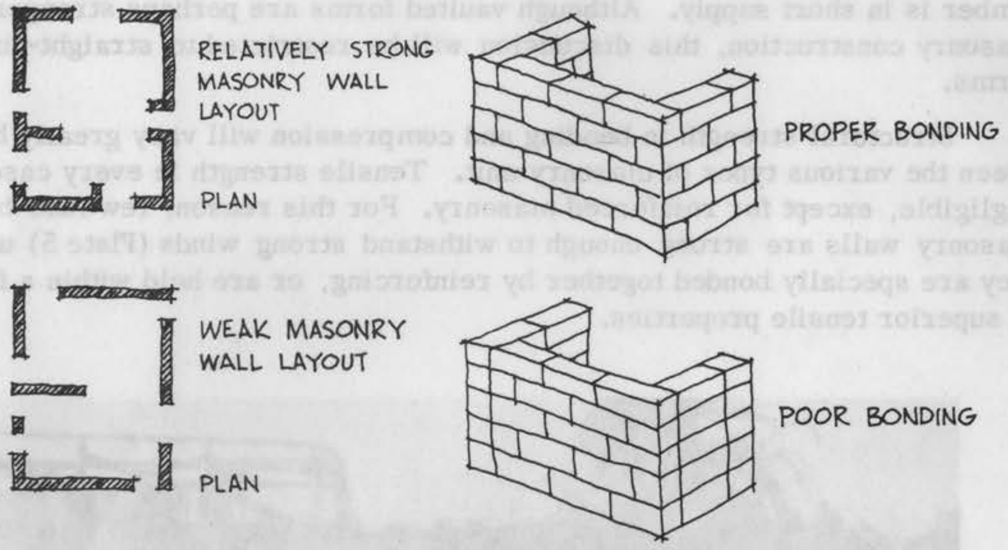


FIGURE 32 . STRENGTH IN MASONRY WALLS

A further alternative, well worth consideration, is to construct walls with honeycomb brickwork so that the wind may blow freely in one side of the building and out the other. This will prevent collapse from a pressure build-up on the wall.

Bonding and reinforcing masonry walls

Masonry walls of calculable strength can be constructed of hollow concrete masonry (Figure 33). If properly manufactured and constructed, this material gives a consistent and highly durable building fabric with great compressive strength. It has no appreciable strength in tension, however,

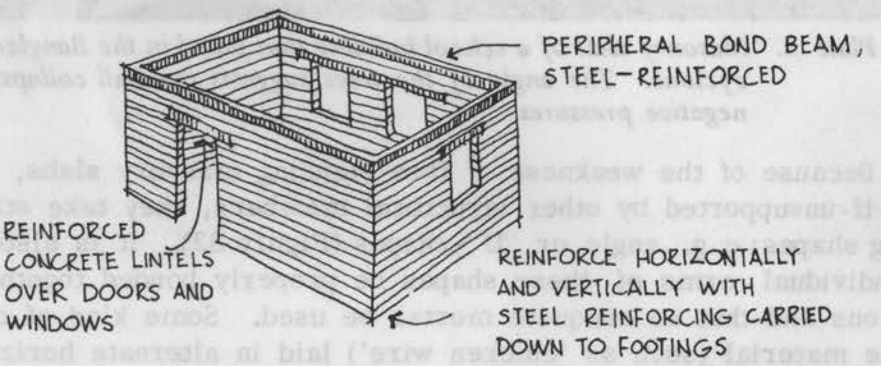


FIGURE 33. STRENGTHENING LOAD-BEARING CONCRETE MASONRY

so its use in thin columns, particularly when 'eccentrically loaded', contradicts its structural purpose (even a strong wind will cause eccentric loading). It is common, however, for concrete block masonry to be reinforced with steel to enable it to withstand reasonable tensile forces.

The tendency for concrete to continue shrinkage even after curing, as well as its tensile weakness which tends to crack a wall which is in contradiction (after heat expansion during the day for example), means that the dimensions of walls that can be built without construction joints are limited. (In a ten-metre length of wall there should be a continuous vertical construction joint at about mid-point). Particularly in high wind conditions, it is desirable to hold concrete masonry construction together by added tensile steel at the top of the wall using a 'bond beam' or 'collar beam' (Figure 34).

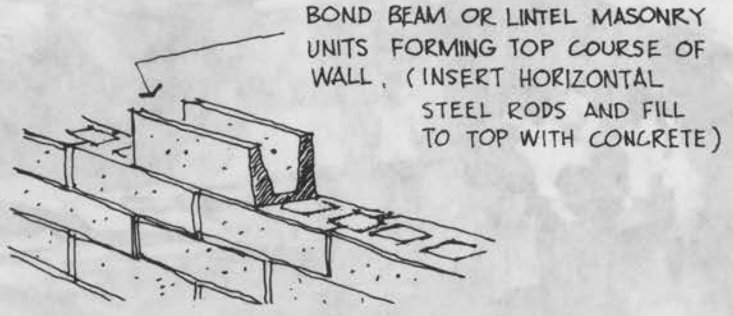
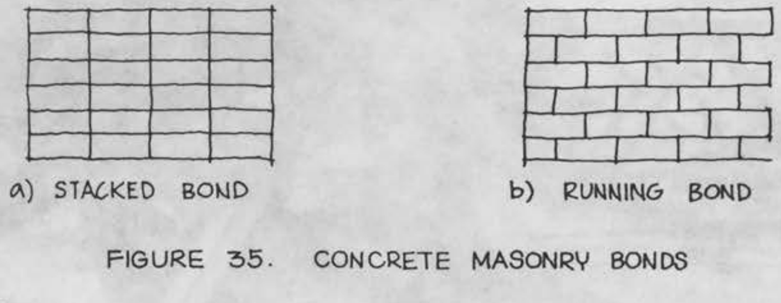


FIGURE 34. BOND BEAMS FOR MASONRY

If lintels and bond beams are cast as a unit, the result will be added rigidity and strength. Also, for strong winds (and for good practice generally) there should be networks of horizontal and vertical steel reinforcement within the wall. Recommended practice in the United States of America is to use joint reinforcement in alternate courses in 'stacked-bond' construction (Figure 35a) and every third course in 'running-bond' construction (Figure 35b). Ties for this purpose vary from light, welded steel-rod reinforcement to chicken wire.


a) STACKED BOND

b) RUNNING BOND

FIGURE 35. CONCRETE MASONRY BONDS

Framed walls

Buildings framed with reinforced-concrete are commonly used for schools, including those where a reinforced-concrete frame is poured for the structural columns and beams, integrally connected to the general 'in-fill' block walls which help to provide formwork for pouring the structural concrete. In low-rise buildings the structural sizes, produced both by block thickness and convenience of handling, tend to give a reasonable margin of safety to the structure (provided the reinforcing steel is not omitted), and the building should have adequate rigidity against strong winds - this caused partly by its own mass.

On the other hand, failures are common in timber- and steel-framed buildings exposed to strong winds (Plates 6 and 7).

Plate 6. Timber frame failure from strong wind.

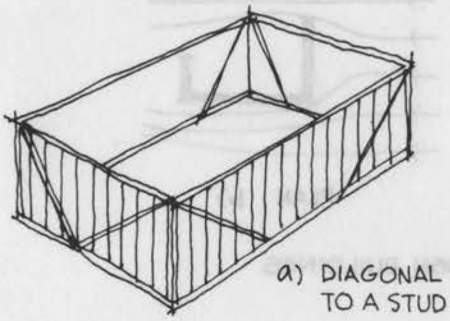
Plate 7. Steel frame failure from strong wind.

The basic requirement of a framed wall is that it be braced within its own plane (assuming that it is supported laterally by return walls (Figure 36a).

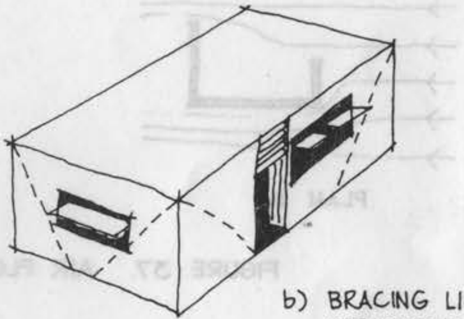
The simplest form of bracing is diagonal bracing at each corner. If the wall is, for example, a timber-stud-framed wall, braces should be at about 45°, fixed firmly to top and bottom plates and to each stud. Commonly such a brace would be about 8 cm x 2 cm, and let into plates and studs to give a flush outside face.

The need for door and window openings in the walls may complicate this requirement, but a close approximation should be aimed at (Figure 36b).

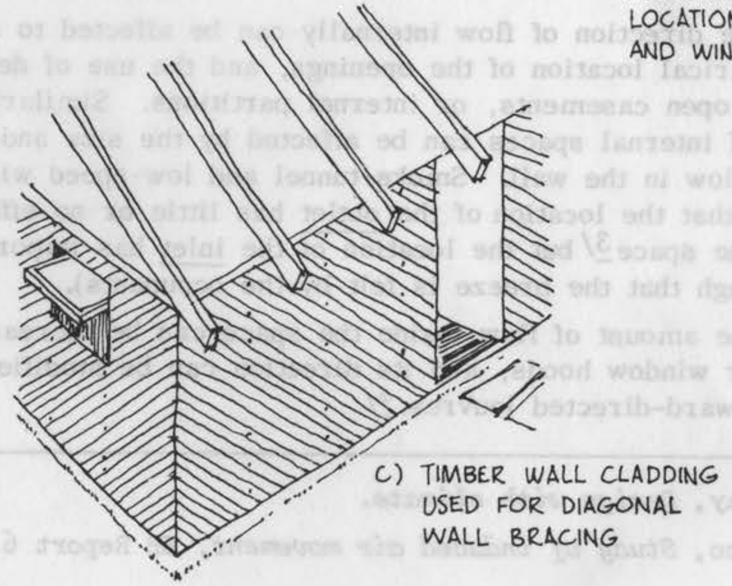
In locations where walls are reasonably sheltered from normal rainfall, the timber wall sheeting can be fixed at the diagonal to provide a highly effective bracing pattern (Figure 36c). Driven rain will tend to lodge in the joints, and conceivably penetrate the wall, but particularly durable species of timber will withstand this without serious deterioration. Other species should be treated against deterioration, or not used in vulnerable positions.



a) DIAGONAL BRACING TO A STUD WALL



b) BRACING LIMITS THE STRUCTURALLY DESIRABLE LOCATIONS FOR DOORS AND WINDOWS



c) TIMBER WALL CLADDING USED FOR DIAGONAL WALL BRACING

FIGURE 36. STRENGTH IN FRAMED TIMBER WALLS

Wall openings

The size and location of openings in walls are of great importance for extreme winds. The combination of a large inlet on the windward side with a small outlet on the leeward side will not affect the current of air in the building, but it will increase the wind velocity beyond the building. 1/ 2/ In ordinary weather, this means that it will not cool the interior (Figure 37a), whereas a small inlet and large outlet (Figure 37b) will have a different effect, giving higher velocities inside the building. While effects of this sort can be created in designing wall openings in relation to good or bad prevailing and predictable winds, they cannot be controlled precisely with a wind from an unpredictable direction, as would be the case in a cyclone.

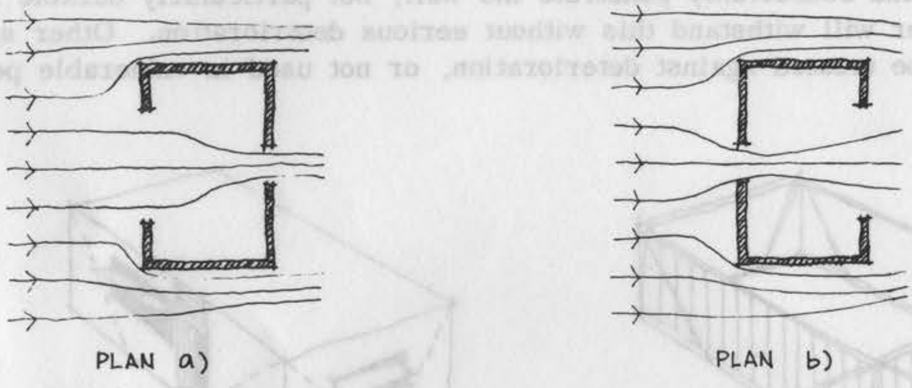


FIGURE 37. AIR FLOW THROUGH BUILDINGS

The direction of flow internally can be affected to some extent by an asymmetrical location of the openings, and the use of deflecting elements such as open casements, or internal partitions. Similarly, the flow in the height of internal spaces can be affected by the size and location of inlets, high or low in the wall. Smoke-tunnel and low-speed wind tunnel tests suggest that the location of the outlet has little or no effect on air movement within the space 3/ but the location of the inlet has importance (it should be low enough that the breeze is felt by the occupants).

The amount of flow inside the space can be increased by roof overhangs or window hoods, and its direction can be modified by pivoted windows or downward-directed louvres. 4/

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1. Olgyay, *Design with climate.*
2. Unesco, *Study of induced air movement,* EB Report 6, by Ishwar Chand.
3. Ibid.
4. Unesco, *Study of induced air movement,* EB Report 6, Ishwar Chand.

Again, these effects are useful if the designer knows which openings will act as outlets and inlets; that is to say, if he knows the direction of the wind.

Recent low-speed wind-tunnel tests have shown the influence of the dimensions and locations of window openings in models of simple buildings. Thus the width of a window opening will affect greatly the speed of air movement inside. Average wind speed inside the space will increase with width, up to about 1/2 of the total wall width (Figure 38a).

The height of the window affects indoor wind speeds up to about 1.1 m, where wind speed is maximum. With increased height, there may be more air movement at the top of the window but not in the occupancy zone (Figure 38b).

The sill height affects air motion at the working plane. The working plane will receive maximum air motion when the sill height is at 85% of the height of the plane (Figure 38c).

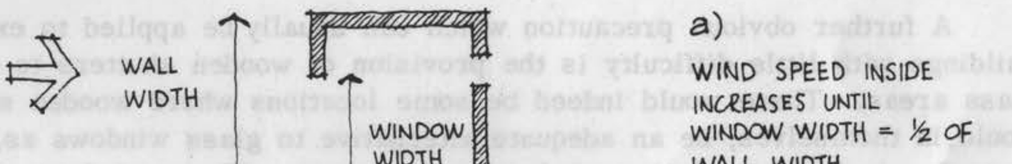


FIGURE 38. INCREASING AIR FLOW IN BUILDINGS

Protection of wall openings against damage

One of the most dangerous effects of strong winds, ranking perhaps equally with flying roof sheeting, is the amount of broken glass produced. Large sheets of glass in windows or doors commonly shatter because they are too thin and too large to withstand the local strength of the wind. Even more common is their breakage when struck by other wind-born debris.

Ways to combat this danger are to reduce large areas of glass or to break up necessarily large areas by glazing bars or mullions, and to use wired glass or increased glass thickness.

A further great advantage of avoiding breakage by reducing and strengthening large door and window areas is that this reduces the chances of sudden entry of violent wind, a major cause of the lift-off of roofs.

It should be said, however, that while small windows and solid buttressed masonry walls are better against strong winds, in tropical climates they tend also to reduce ventilation as well as promote glare and visual discomfort.

Wooden shutters

A further obvious precaution which can usually be applied to existing buildings with little difficulty is the provision of wooden shutters to protect glass areas. There would indeed be some locations where wooden shutters would, in themselves, be an adequate alternative to glass windows as, for example, in high-ventilating windows under eaves. These windows are almost permanently open.

Shutters are sometimes louvred, more commonly solid. They themselves sometimes fail through deterioration caused by their design, weathering and intermittent use.

If they rely on a hinged connection to the wall or window frame (Figures 39a, 39b) there is a tendency for them to shake, and therefore loosen, when not in use. If supported along one vertical edge (as in Figure 39b) there is a long-term tendency for them to sag, particularly if the component timber shrinks, causing a poor fit when (rarely) brought into use.

The simple sliding type (Figure 39c) can be fixed on the outside walls of new and existing buildings. The fixings and framing need detailing against deterioration from exposure. The simplest and most fool-proof type would be moved by sliding across manually when needed. It is preferable if these are accessible from the outside, because they would be difficult to move from the inside under damp conditions. When not in use they form no obstruction or annoyance, and the lack of fastenings and moving parts reduces the likelihood of their falling apart.

A good alternative is the louvred shutter which, together with the honeycombed brick wall mentioned in the section on walls, allows the wind to stream freely through the building - thus avoiding pressure build-up and collapse of walls or failure of shutters (Figure 39d).

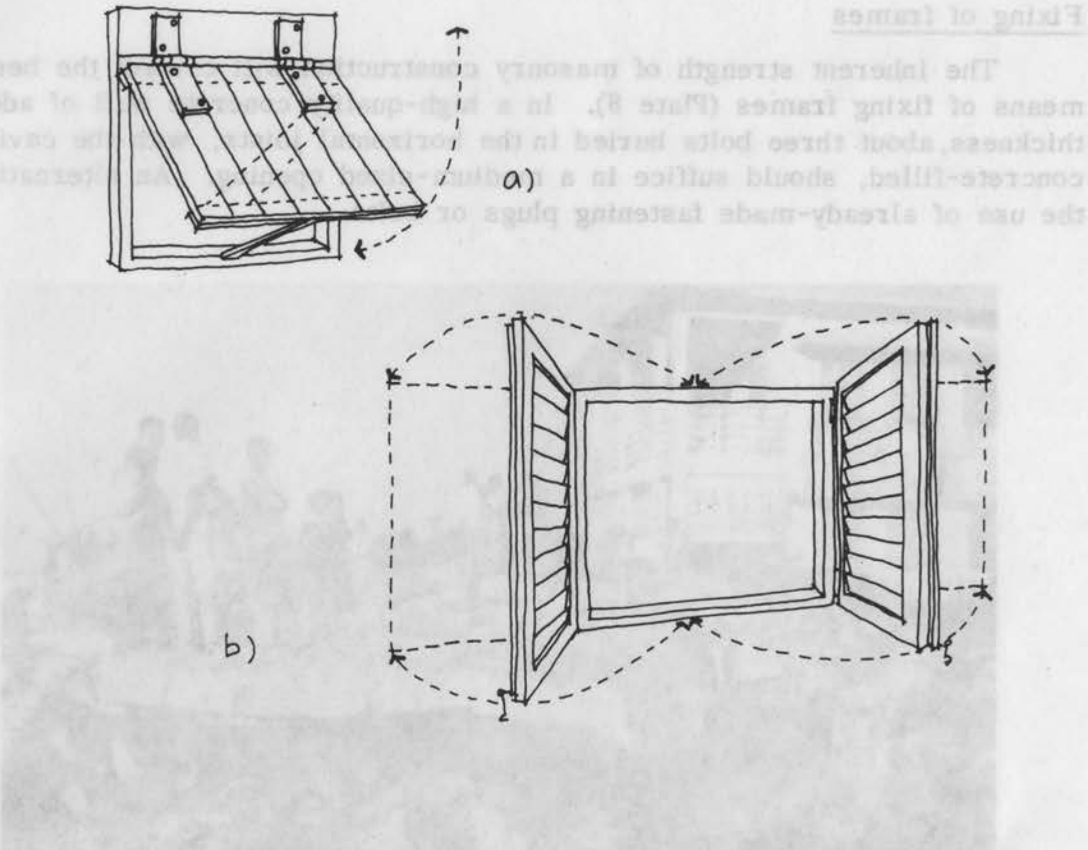


FIGURE 39. WINDOW TYPES

Fixing of frames

The inherent strength of masonry construction will control the best means of fixing frames (Plate 8). In a high-quality concrete wall of adequate thickness, about three bolts buried in the horizontal joints, with the cavities concrete-filled, should suffice in a medium-sized opening. An alternative is the use of already-made fastening plugs or bolts.

Plate 8. Shutters and frames in the two-storey building have successfully withstood the cyclone that has just destroyed the school building in the foreground.

Where the masonry construction is of lower strength, as for example with stabilized earth blocks or medium-to-low-quality brickwork (Plate 9), it will be necessary to spread the possible point loads over a larger area to resist wind or water bearing on the window. These walls should be reinforced in the horizontal joints and by vertical rods. The frame fixings might take the form of hoop-iron straps with ragged ends, fixed to the frame and set in horizontal joints (Figure 40). Their shape and placing should be such that they form a good bond with the mortar of the joint without destroying the primary function of the joint - which is to bond the masonry units together. The length and number of strap fixings should be appropriate to the size and strength of the masonry units. Protection by galvanizing or other means is recommended. (A simple protection might be to dip the straps in hot bitumen and then drop them into sand, to provide a bonding to the mortar joint).

Fixing frames in timber-framed construction is normally much simpler, taking the form of bolting or spiking of the units together. Sometimes the door and window frames are an inherent part of the structural framework of the building.

Plate 9. Failure to spread the load over the brickwork by adequate anchorage has resulted in the loss of three of these four window frames and shutters.

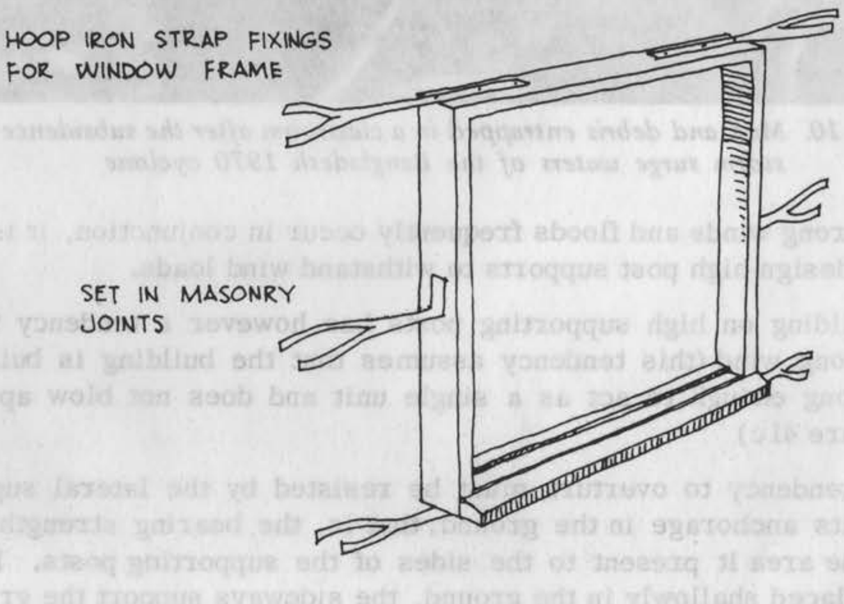


FIGURE 40. ANCHORING DOOR AND WINDOW FRAMES TO MASONRY WALLS

Foundations

There are some conflicts in the design requirements of the parts of the building below floor level to withstand, respectively, strong wind and flooding.

Design against strong wind suggests that the floor should be supported on low, continuous walls, which keep out wind and hence defeat the tendency for upward pressures on the floor (Figure 41a).

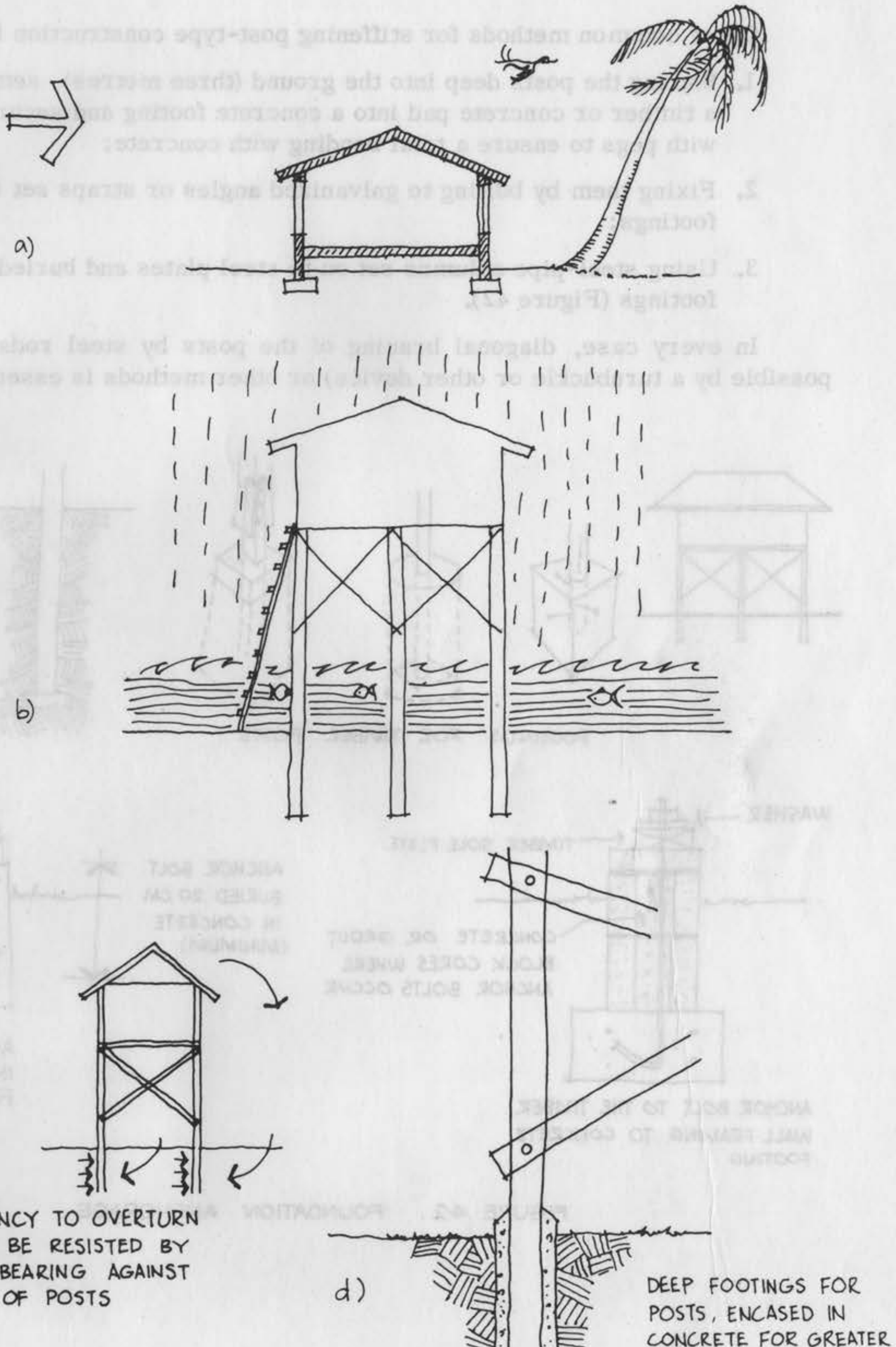
Design against floods implies the use of posts to raise the floor as high as possible (Figure 41b) reducing the scouring effects of large obstructions to water currents, the possible collapse of foundation walls under dynamic loading, and the entrapment of mud and decaying matter afterwards (Plate 10).

Plate 10. Mud and debris entrapped in a classroom after the subsidence of the storm surge waters of the Bangladesh 1970 cyclone

As strong winds and floods frequently occur in conjunction, it is necessary at least to design high post supports to withstand wind loads.

A building on high supporting posts has however a tendency to overturn in strong wind (this tendency assumes that the building is built intrinsically strong enough to act as a single unit and does not blow apart in wind) (Figure 41c)

The tendency to overturn must be resisted by the lateral support offered by its anchorage in the ground; that is, the bearing strength of the soil over the area it present to the sides of the supporting posts. If the posts are placed shallowly in the ground, the sideways support the ground offers against overturning is very little. Therefore it is necessary to sink supporting posts as deeply as possible into the ground. It is also best to increase the area supported by the soil by (for example) encasting the posts in concrete (Figure 41d)



c) TENDENCY TO OVERTURN MUST BE RESISTED BY SOIL BEARING AGAINST SIDE OF POSTS

d) DEEP FOOTINGS FOR POSTS, ENCASED IN CONCRETE FOR GREATER LATERAL RESISTANCE

FIGURE 41. FOUNDATIONS

Other common methods for stiffening post-type construction include :

1. Sinking the posts deep into the ground (three metres), setting them on a timber or concrete pad into a concrete footing and securing them with pegs to ensure a total bonding with concrete;
2. Fixing them by bolting to galvanized angles or straps set into concrete footings;
3. Using steel-pipe columns set on to steel plates and buried into concrete footings (Figure 42).

In every case, diagonal bracing of the posts by steel rods (tightened if possible by a turnbuckle or other device) or other methods is essential.

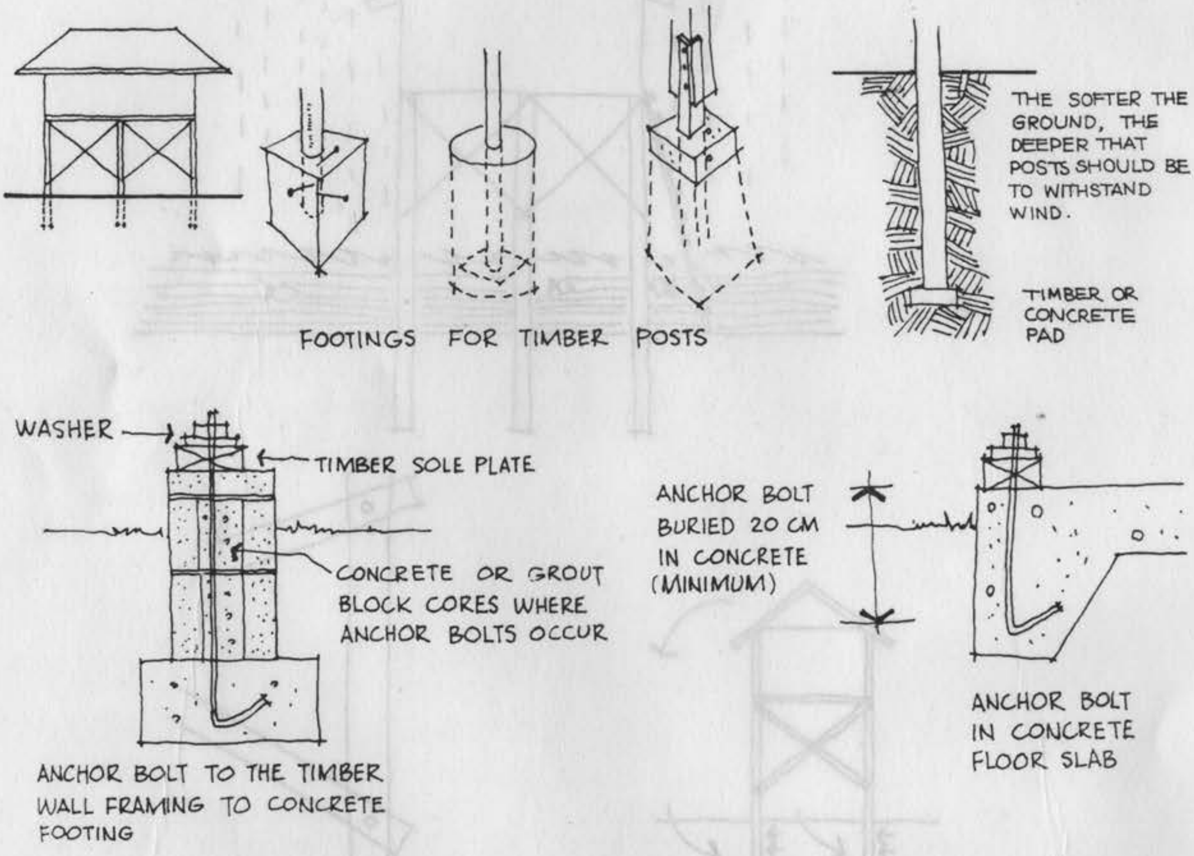


FIGURE 42. FOUNDATION ANCHORAGE

CHAPTER SIX

DETERIORATION OF MATERIALS AND FIXINGS

The most common deterioration giving rise to building failures in strong winds is the shrinkage of timbers and concrete, and the corrosion of metals.

Shrinkage of timbers

Timber inevitably shrinks in width as it loses its moisture; shrinkage in length is almost nil. The use of well-seasoned timber will reduce the amount of shrinkage. Poorly-seasoned timber of some species will commonly shrink as much as 10% after installation.

Some of the effects of timber shrinkage are obvious. One instance is the opening up of cracks in boarding which let in light and weather. Shrinkage also causes joints to loosen and nails and other fixings to work loose. In design against strong wind, the probability of shrinkage should be allowed for and the joint either made capable of being subsequently tightened, or made independent of shrinkage.

Other contributing influences to unsatisfactory performance include twisting, which may be inherent in the growth pattern of a particular tree; imperfections derived from milling an inferior log, or the central part of a log (heartwood) or the inferior outer edge (sapwood); or the differential shrinkage of opposite sides of a timber member caused by poor milling practice.

Most wood is particularly susceptible to decay if it is subjected to alternating damp and dry conditions. Some species decay very rapidly while some are almost permanent. Common precautions against deterioration include painting, or treatment with various wood-preserving oils (sump oil can be a cheap local treatment in the absence of creosote or more specifically designed preparations). It is important that timber likely to become damp be primed in future inaccessible parts before assembly. The best precaution is to ensure that detailed design prevents water from lodging or being trapped in places where it can promote timber decay. Common locations of this kind are post connections to the ground, door and window details, exposed walls and wall bracing, verandah construction - particularly of the inner wall to floor joint - and wherever an object is fastened to timber in an exposed position (Plate 11).

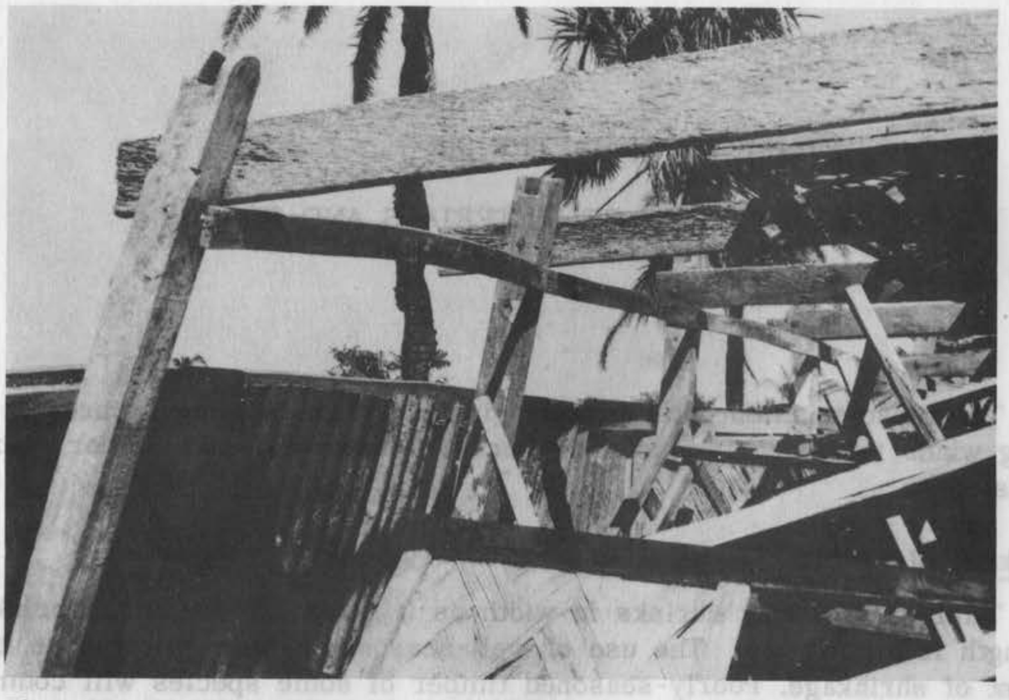


Plate 11. Decaying timber clearly contributed to the failure of this coconut palm frame.

Shrinkage of timber and the general loosening of fixings over time frequently result in the loss of door and window frames in quite soundly constructed buildings. Not usually an essential factor in the stability of the structural frame, their fastenings are sometimes overlooked in the early stages of assembly. Sometimes only weatherproofing-stops hold them in place; when these shrink or decay, there is a strong possibility of damage or loss.

Deterioration of concrete

Cement will continue to shrink indefinitely after setting. When used in concrete, the shrinkage will cause cracks throughout the concrete mass, unless the concrete mix is well designed and made. The cracks may be minute or highly visible.

A good concrete mix is one in which the continued shrinkage of the cement is prevented by the presence of closely packed aggregate; that is there should be the minimum amount of water, and just enough cement in the mix to adhere to the grains of aggregate without separating them. Obviously, the aggregate must also be graded to permit the dense packing of the grains, without air spaces or an excess of cement.

The reinforcing of concrete (normally with steel but occasionally with other materials such as bamboo) must be located within the thickness of the concrete. Any steel which, from bad placement, is exposed - for example on the bottom of a slab - or which is set on a metal spacer itself exposed, will be a probable cause of corrosion (particularly in hot, humid regions) (Plate 12). The corrosion by rusting will cause expansion and hence cracking and further deterioration of the concrete (Plate 13).

Plate 12. Exposed reinforcement in the underside of the concrete roof of this school is a factor contributing to failure of the slab.

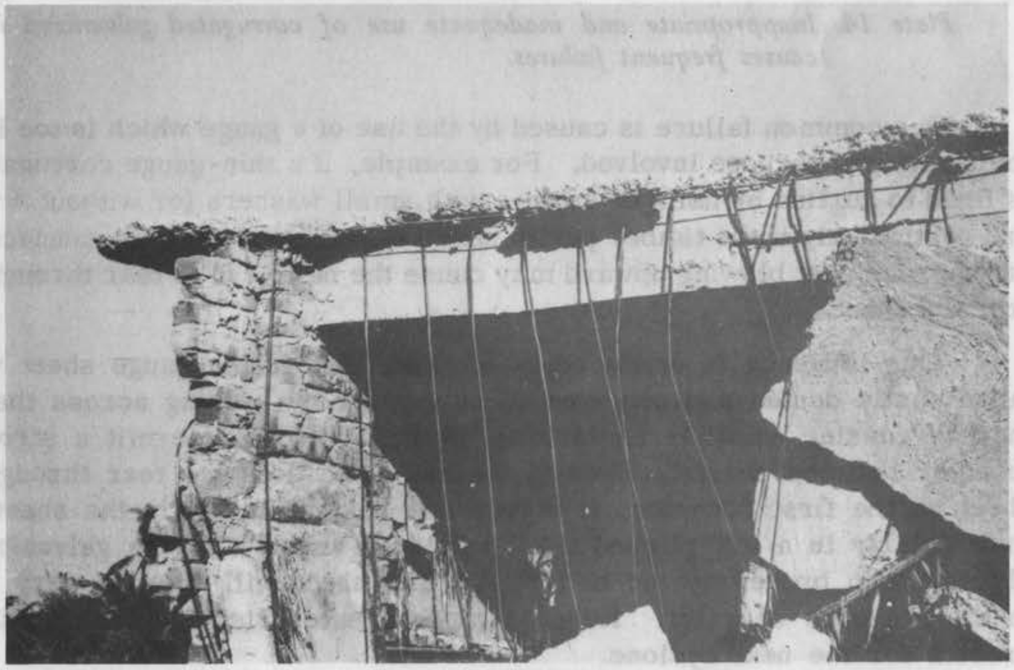


Plate 13. Corrosion, expansion, cracking and final failure under extreme loading of cyclonic wind forces

Corrosion of metal

Galvanizing is the most common method for the protection of steel sheet against rust. One of the ubiquitous building materials in developing countries is galvanized corrugated ('g. i. ') steel sheet which is a practical material, strong and light, if used correctly. However, a number of inappropriate and inadequate uses have caused frequent failures (Plate 14).

Plate 14. Inappropriate and inadequate use of corrugated galvanized iron causes frequent failures.

One common failure is caused by the use of a gauge which is too light for the structural purpose involved. For example, if a thin-gauge corrugated sheet is fixed to purlins by nails or screws with small washers (or without washers) and particularly if the timber purlin shrinks, thus loosening the connection, a strong wind gust blowing upward may cause the nail head to tear through and free the sheet.

This tendency is enhanced by the fact that a thin-gauge sheet will be more easily dented and damaged in laying, or by walking across the roof, thereby causing small irregularities of fit, which will permit a strong wind to enter between sheets. Even if the nail head does not tear through the sheet on the first occasion, it may cause an indentation in the sheet which (particularly in a low pitched roof) will hold water. As the galvanizing has already been broken by the nail fixing, the sheet will corrode very rapidly in the presence of water. Hence a much greater risk of failure will be present for the next cyclone.

Aluminium is used more rarely than galvanized iron. It is usually more expensive and less strong, but it has superior thermal qualities and does not corrode in normal situations if properly fixed. It is susceptible, however, to bi-metallic corrosion if fixings are not also of aluminium; for example, if steel nails are used for fixing, in the absence of special aluminium nails.

Detachable elements

The use of detachable building elements which can be taken down or adjusted to meet severe weather conditions is not recommended in general. The reasons for this are the following:

1. Unless there is a clearly established practice for emergencies, and clear authority demarcations, nobody is likely to be available, or prepared, or knowledgeable enough to ensure that the precautions are undertaken at the correct time, and that readjustments are made afterwards. This is particularly the case if the emergency develops out of normal working hours or days;
2. Deterioration of materials in exposed positions frequently makes them inoperative on the rare occasion of emergency. If an element (e.g. detachable overhang) is partly disengaged and then the attempt abandoned, it is likely to increase rather than diminish the risk of damage. Stored ropes or nets for anchoring down vulnerable elements may also deteriorate. Maintenance of these items should be part of the practical education programme in the school. Organized 'drill' programmes of this kind make possible many precautions otherwise ruled out on practical grounds;
3. Storage of items rarely used usually makes them impossible to locate quickly. They are often bulky, and storage space is expensive;
4. The use of removable or detachable items usually involves more expense than that of fixed items.

A variation of a suggestion made by Finney[1] might be feasible in school design. This is to make 'removable' roof canopies serve also as storm shutters (Figure 43). Although this proposal suffers from many of the disadvantages listed above, it serves two functions instead of one, and may therefore be an economical devise in some cases.

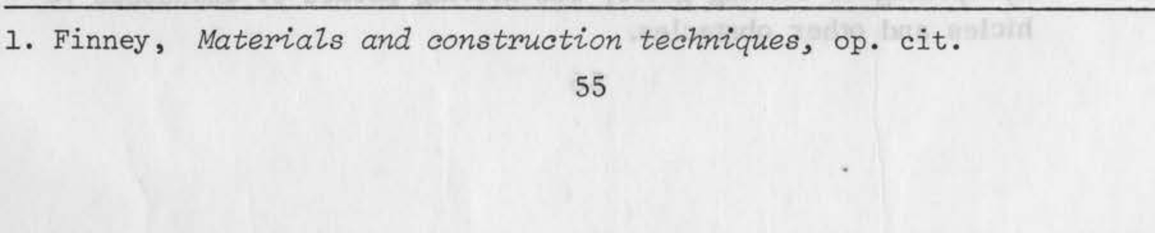


FIGURE 43. CANOPIES AS WIND SHUTTERS

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[1] Finney, *Materials and construction techniques*, op. cit.

CHAPTER SEVEN

EMERGENCY MEASURES TO PROTECT BUILDINGS

Protection against strong wind

1. Remove all loose objects - store, or cover with coconut rope netting (Figure 44a)
2. Weak or doubtful roofs - cover with nets firmly anchored or (if flat or low pitched) place heavy rocks or sandbags along edge and ridge (Figure 44b)
3. Weak-framed structure : tie down with guy ropes at about 45° to ground and anchor to hooks and rocks (Figure 44c).
4. Large areas of glass : - tape in a small square pattern with medical adhesive tape or insulating tape, or nail solid sheets or boards across openings (inside and out) to reduce the movement of broken glass or prevent admission of flying debris (Figure 44c). Buttress any openings likely to fail with heavy furniture or lumber.
5. Retire to the strongest area with a supply of fresh water and clothing.

Protection against water

1. Store objects (particularly glass) which are likely to sustain or cause damage. Discard perishable items.
2. If stacking objects on tables and shelves inside the building, make sure of even loading (otherwise buoyancy in the rising water will tip the stacked material).
3. Block drainage and W.C. pipes with removable stoppers to prevent prevent sewage backflow and silting up of pipes. Disconnect electric power.
4. Check walls, ceilings and roofs for ventilation openings at highest points. (Otherwise trapped air may cause explosive pressures). If necessary make escape openings by removing material at critical locations (Figure 45a).
5. Investigate the possibility of directing erosion away from footings by opening or closing gates, and moving parked or abandoned vehicles and other obstacles.

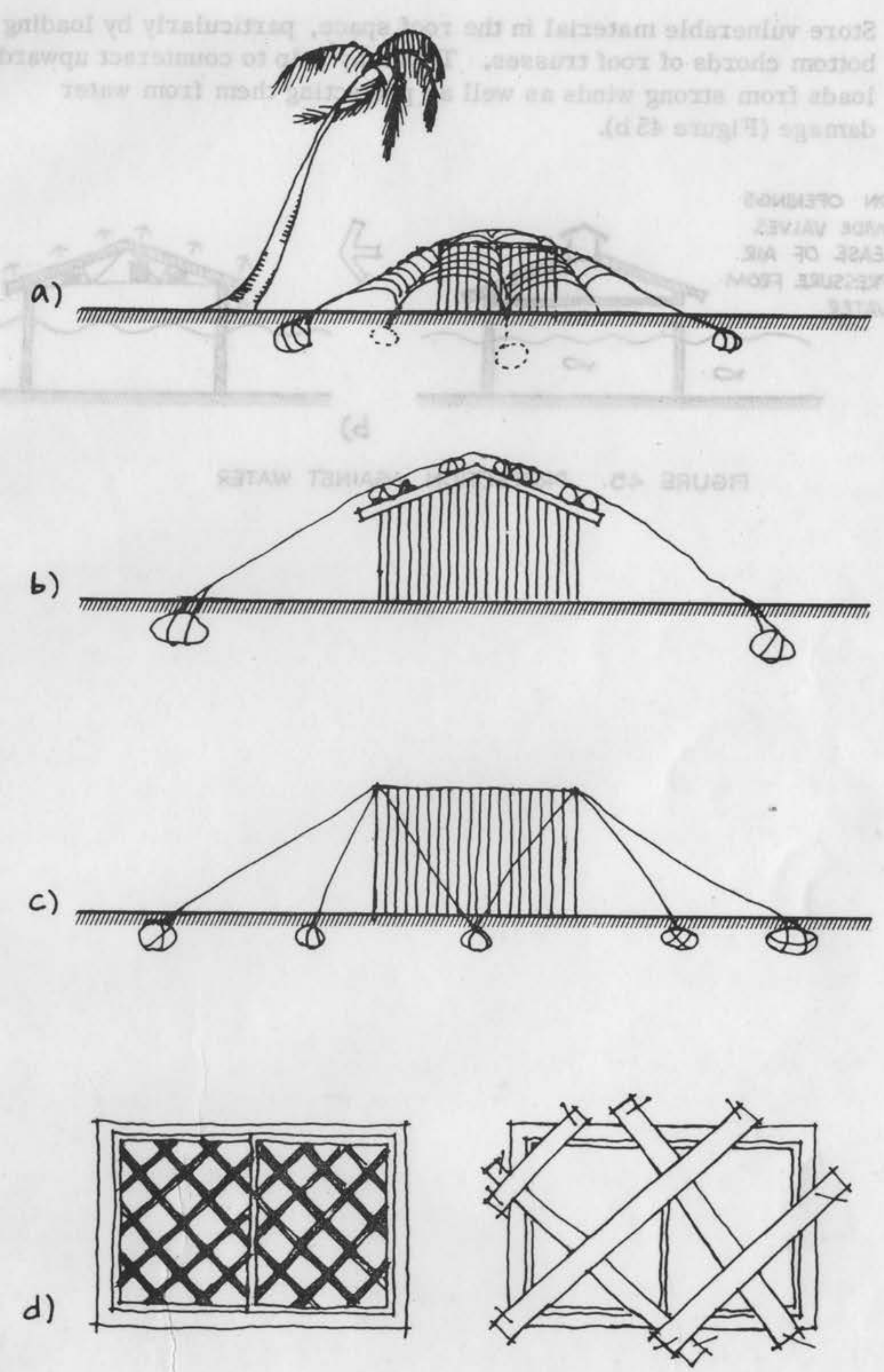

FIGURE 44. PROTECTION AGAINST STRONG WIND

6. Store vulnerable material in the roof space, particularly by loading bottom chords of roof trusses. This may help to counteract upward loads from strong winds as well as protecting them from water damage (Figure 45 b).

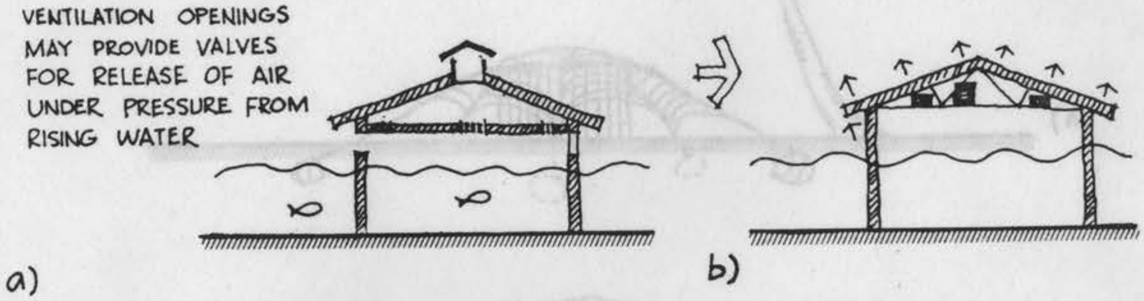

FIGURE 45. PROTECTION AGAINST WATER

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