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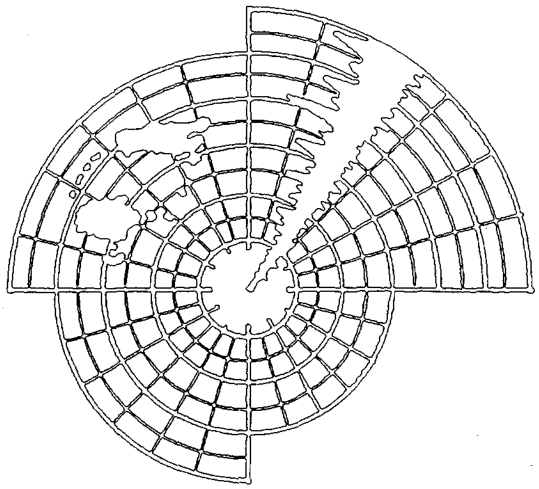

The A.B.C. of Cyclone Rehabilitation

A manual demonstrating the principles of Anchorage, Bracing and Continuity to provide structural integrity for rehabilitation of buildings damaged by cyclonic forces.

K. J. Macks, AM

**Under Contract No. 107.001.4 with the
Architecture for Education Unit, UNESCO Paris**

TERMS OF REFERENCE

The brief, given by the Architecture for Education Unit to the consultant, required to:

"Prepare a document containing technical guidelines for the repair and rehabilitation of existing educational buildings following cyclone damage, including guidelines for the reinforcement of the buildings to withstand cyclone forces. The guidelines shall be presented in a manner to be easily comprehended by people at community/local level with little technical knowledge. The document shall contain the following elements:

- a short description of the problem
- methodologies for the rehabilitation and reinforcement of various types of buildings/ construction systems
- typical examples from various countries illustrating the above problems and methodologies.

The document, tentatively entitled "ABC of Cyclone Rehabilitation" shall be amply illustrated: with drawings, photographs, sketches, etc."

SYNOPSIS

Part One: Collecting the Facts

Sections 1 – 6

Part One describes the problem and collects and collates the factual information needed before the solutions are initiated.

Section One introduces comments on the brief and objectives, UNESCO's contributions, the current state of knowledge, and recommends general areas where responsible actions can be taken to further existing education in this field. Section Two describes cyclones and their characteristics, lists extreme events and identifies the countries that are affected by the damaging forces of cyclones. Section Three describes the types of damages caused by cyclones and offers a case study. Section Four comments on the different methods of construction in different countries and offers typical examples in sketch form showing influences by region, climate and culture on building systems. Section Five introduces the reader to an understanding of wind loads, a commentary on wind force effects and common terminology, a procedure to determine wind loads, supported by tables determining wind loads from the British Wind Code for various parts of a building. It defines load areas and schedules the capacity of various fixings able to resist wind forces. Section Six contains evaluation methods and offers a sample maintenance inspection checklist system.

Part Two: Resolving the Problem

Sections 7 – 11

Part Two indicates the performance characteristics of common failures and lists which details to avoid and offers suggestions and typical details that can be used in the rehabilitation, together with conclusions and easy to read checklists.

Section Seven describes the principal factors that affect the performance of buildings under wind force conditions, offers practical comments and schedules examples of typical failures in construction systems. Section Eight models the loads on a simple three classroom building. Section Nine offers solutions to the problem of rehabilitation of existing damaged buildings and identifies key factors in "hold down" techniques for wall and roof systems, the importance of bracing and the value of good fixing to doors and windows. Section Ten contains case studies of five building projects which were rehabilitated and reinforced in 1972 and survive today. Section Eleven contains the conclusions and recommendations and identifies the responsibilities to be considered in the design of the buildings to resist cyclone forces. It contains useful checklists for designers and inspectors.

PREFACE

UNESCO has, over the last decade, paid considerable attention to the provision of information and guidelines for the mitigation of damages to educational buildings caused by cyclonic wind forces.

Cyclone, hurricane or typhoon forces (which all are the same physical phenomenon), cause maximum damages to the natural and built environment between latitudes 7° and 30° north and south of the equator and affect approximately 30% – 40% of the world's population.

UNESCO's aid to countries has been achieved by sending missions to countries affected by cyclones, followed up by the provision of sub-regional training courses headed by selected expert consultants.

They have encouraged personnel from affected countries to broaden their experience and to liaise with neighbouring countries with common concerns.

In addition, UNESCO has prepared technical documents and responded to requests for assistance by sending technical experts to attend and conduct National Training Courses and in funding of construction of model schools in selected areas.

Whilst the regions affected by cyclones have been identified and the effects of the cyclone damages recorded, the task of providing adequate technical information to mitigate the damages has not reached a stage where it is universally adopted and extended through the building society.

The need for further education is an on-going task as many of the teachers need teaching in order to pass on the upgraded technology to the new ever growing generations.

There is a need to record and evaluate the quantum of information presently available on the subject of wind forces and methods of construction that resist these forces and to endorse the best of this knowledge to member countries.

These methods, which may vary from country to country, will consist of many variations needed to cope with the different materials and construction techniques used in the different cyclone regions but they should all recognise the ABC of cyclone construction— Anchorage, Bracing and Continuity.

Whilst new schools should be built to new state of the art techniques, the stock of existing school buildings may not be fully resistant to wind forces.

This study will examine this question of existing buildings and their level of vulnerability, especially where wind damages have occurred.

It will offer advice on the evaluation of these buildings and their construction details and will suggest how to decide whether or not they can be recycled or demolished.

In offering design solutions, wind forces will be discussed in some detail to enable the reader to understand the sheer size of the forces involved which is often much greater than the uninitiated would estimate.

Examples will attempt to relate these forces to the human scale for easier acceptance.

The study, it is hoped, will encourage architects, engineers, government officials, builders, tradesmen and others into the preparation and study of similar manuals in different countries for the guidance of designers, Ministries of Education and community leaders.

These models, at village level, should also serve as examples of methods that others can use in their homes and other constructions.

About the Author

The author, architect K J Macks AM, LFRAIA, Hon.D.Eng, ASTC (Arch.) has extensive experience in design of buildings in cyclone regions. Mr. Macks is Principal of the architectural firm of Macks and Robinson Pty Ltd of Townsville, latitude 19°S, Australia, since 1963, whose buildings have yet to lose a roof. Since 1985 he has acted as an expert consultant from time to time for the UNESCO Principal Regional Office for Asia and the Pacific (Bangkok) and has been involved in many missions, national and sub-regional training courses, and has presented many papers and articles on the subject.

He has, for UNESCO, produced wind loading tables for Bangladesh and Vietnam (published to member countries), and has carried out advisory missions for UNESCO in China. He was co-author of an acclaimed Wind Code Design Manual for Sri Lanka in 1979.

He is Management Committee Chairman of the Cyclone Testing Station at James Cook University of North Queensland, Townsville, Australia, and is also Advisory Committee Chairman of the Australian Institute of Tropical Architecture, a UNESCO chair at James Cook University.

The opinions in this article are his and not necessarily those of UNESCO.

Acknowledgments

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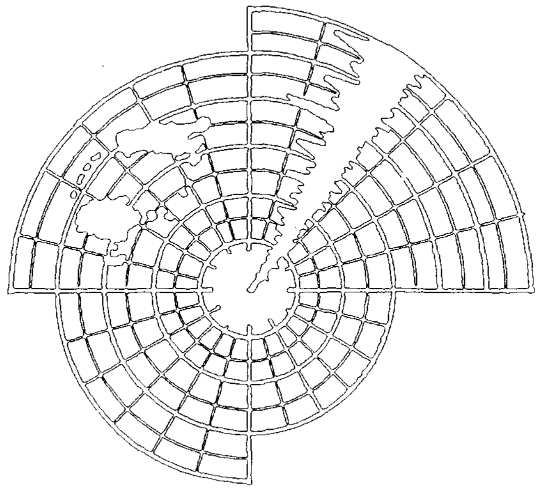
STRUCTURAL FLOWCHART OF CONTENTS



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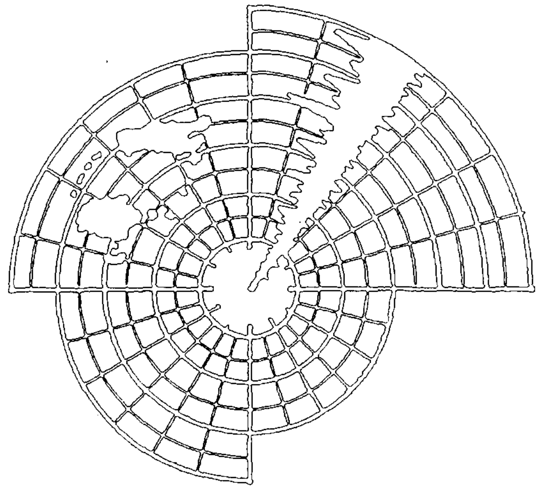
PART ONE: COLLECTING THE FACTS

Contents



PART ONE COLLECTING THE FACTS

1 INTRODUCTION

The objectives of this study are to prepare a document containing technical guidelines for the repair and rehabilitation of existing educational buildings to withstand cyclone forces.

This often complex subject will be presented as simply as possible and will attempt to describe the problem, offer methodologies for rehabilitation and reinforcement of various types of building construction systems and will offer typical examples from a selected range of countries.

The study will include a section on the theory of wind action on buildings and explanations and tables of wind forces and diagrams of load areas.

It is also important to have knowledge of the resistance capacities of various construction details so that designers can incorporate these details and their costings in the preliminary design and budgeted stages of building development and, of course, repair and rehabilitation.

This follows the UNESCO work over the past decade where training courses and workshops have been held throughout the cyclone regions.

Whilst these and other international efforts at co-operation and co-ordination are offered to help establish standards for local governments and research groups, it should be understood that it is the governments of individual countries that are primarily responsible for the mitigation against disaster events and the establishment of criteria and standards in their own countries.

Since 1970, and especially since 1985, there has been renewed interest in the mitigation of cyclone damages to buildings.

This has been caused by the increasing level of damages to buildings and communities by the effects of these high wind forces.

In the developed countries the economic costs of damages has escalated dramatically. In the poorer countries, and especially those with large populations at risk, the human cost and national disruption, despite significant improvements in countries like Bangladesh, continues to impact heavily on National and International agencies involved in dealing with post-disaster rehabilitation and recovery.

Skills have been developed in many areas to combat the problem and these skills are in a continual state of development and refinement.

The theory of how the winds blow, and their flow patterns around fixed objects and building shapes, is well known and readily understood.

The magnitude of the forces and the strength of the resistance mechanisms is less well known.

The practical knowledge of how many nails or screws to use in a typical construction detail, is not well known, nor is there an adequate understanding of the transfer of wind loads through the chain of construction links, from the roof and walls receiving the loads to the foundations where the loads are eventually dissipated.

Most countries now accept that the educational buildings, especially the town or village school are a focus in the community, known and recognised by the community and, since they are built by the government, they are expected to be safe from the effects of a disaster.

Failure of these buildings can kill or injure our children when they expect security therein.

This reinforces the responsibility of the government and its agencies to pay special care to the design of these buildings.

Retention of these buildings by better design initially, or by proper rehabilitation after damage, can enable these school buildings to serve a post disaster function, as shelter, meeting rooms and disaster co-ordination centres.

This is a further reason to treat school buildings as important structures.

The inspection and evaluation process in the post disaster situation is an important phase and should be carried out by experienced personnel and agreed by a third party from the educational ministry.

The following steps should be recorded:

1 Cost estimate to demolish damaged building and its foundations including removal from site.

2 Current replacement value of new type building similar to the damaged building, i.e. total cost and cost/m^2.

3 Cost estimate to repair and rehabilitate damaged building, including structural upgrading to resist wind loads.

Inspection teams evaluating damages and recommending plans of actions need to be careful in assessing the condition of damaged buildings.

It is easy in the midst of damaged townships, with debris in all directions, to take decisions to demolish and rebuild.

There should not be an automatic requirement to demolish walls and foundations, remove them from the site and then to bring in new materials and build new work to replace that which was satisfactory.

Proper evaluation should be carried out before these decisions are taken.

The author believes that where buildings have been erected with a reasonable amount of integrity and are damaged in a disaster event but not destroyed, then after an assessment of its condition the cost of bringing the building back to first class condition can be done for between 25% and 50% of its current replacement value.

This factor could save a great deal of expense, both of the home country and also of any donor countries or agencies where thousands of buildings are involved.

Experienced architects with good engineering advice can produce design solutions that can rehabilitate damaged buildings after this positive evaluation has been made.

The author has lived through a major cyclonic disaster and has been involved in inspections, assessment and reconstruction of a community and its buildings in the post disaster period.

There is little more forceful education than the actual personal experience of being with one's family throughout the disaster event, where the strength of the forces is brought home.

Where one has the technical knowledge, the messages are even more relevant as the sight of failed construction details imparts a telling comprehension of the power of the forces and the need for better quality design, detailing, and construction throughout those parts of the world that are subjected to damage by wind forces there is a need to know.

Research is an integral part of the learning process and is an essential item if we are to continue to improve the quality of our built environment. The results of research enable us to reduce the factors of safety used in design and lead to economic savings.

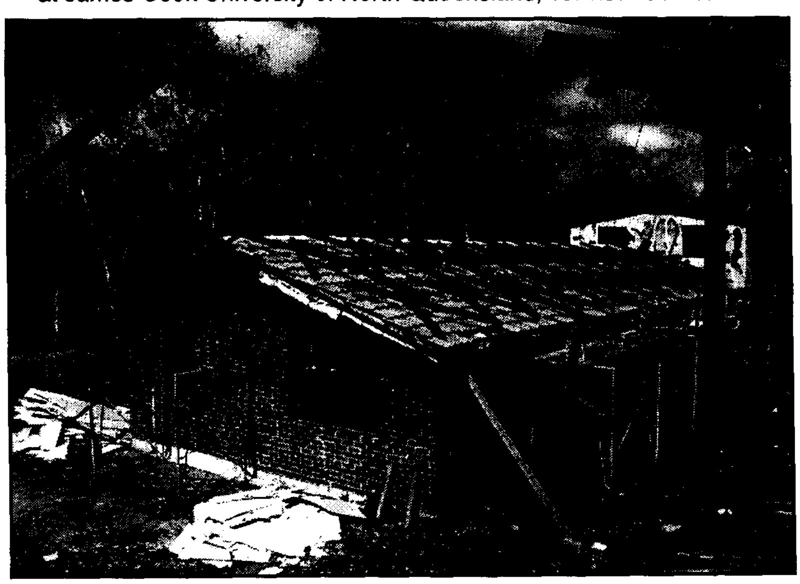
Support of independent research and evaluation by experienced teams should be sponsored by government agencies, academic institutions, private companies and commercial ventures.

Technical data banks should be maintained at selected epi-centres in the disaster regions so that expert advice can be readily obtained from people familiar with the region.

Testing stations should also be set up at selected research establishments in the region.

Full scale testings of buildings and/or building components, such as those currently being carried out by the Cyclone Testing Station at James Cook University in Townsville, Australia, are showing up the load-sharing capabilities of different building elements in resisting wind loads which offer cost savings.

The Cyclone Structural Testing Station
at James Cook University of North Queensland, Townsville Australia



A general overview should be determined so that overlap is avoided on major research projects.

Another prime need is for collation and dissemination of research done to date.

A great deal of research is lost once it is complete due to lack of publication and promotion.

The cost of reproducing research and technical data is a hurdle to be crossed. Perhaps support from product manufacturers or from the reinsurance industry and governments could assist in this regard, providing a suitable co-ordination body or council is set up to provide control.

A further major problem is to instil into the education courses for professional, technical and trade students the input needed to make these future leaders aware of the wind problem and its affect on construction details.

Unfortunately, too often schools do not upgrade their course material on a regular basis and the time lag in imparting new techniques is too slow.

With the growing demand for better buildings, the need to regularly update educational material is vital.

In any case, architects, engineers and their clients have a need to re-examine the security and integrity of constructions in regard to resistance to high wind damage areas.

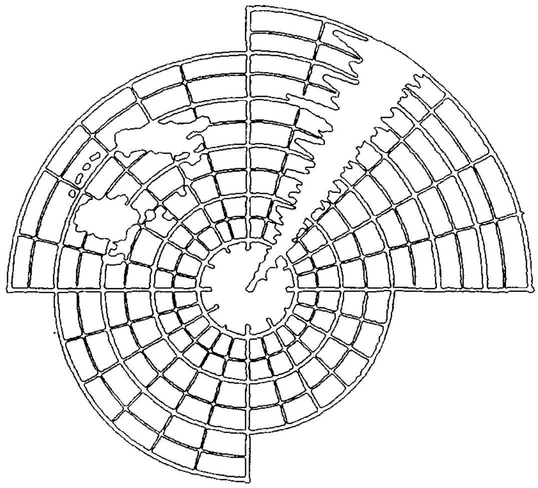
We must avoid letting theory alone dictate our responses in design and detailing to resist cyclonic wind forces.

There is a real need to understand the actual forces to be resisted by the actual construction details.

The architect must have a reasonable and practical knowledge of these forces as it is an integral element of the building design rather than leaving the whole problem to the engineer.

The rapid growth of population in many countries has identified the need to provide greater protection now that a large community is at risk.

The reliance on a limited number of experienced professionals and contractors is no longer satisfactory.



2 CYCLONES AND REGIONS AFFECTED

CONTENTS

2.1 WHAT IS A CYCLONE?

The education process in the understanding of cyclone resistant construction must include a knowledge of the basic nature of cyclones themselves, the scale of a cyclone, the area it can affect, the speed of cyclonic winds, rapid fluctuations in the wind speed, direction and pressures exerted on building structures and, not least, the time the cyclone event takes to arrive and depart.

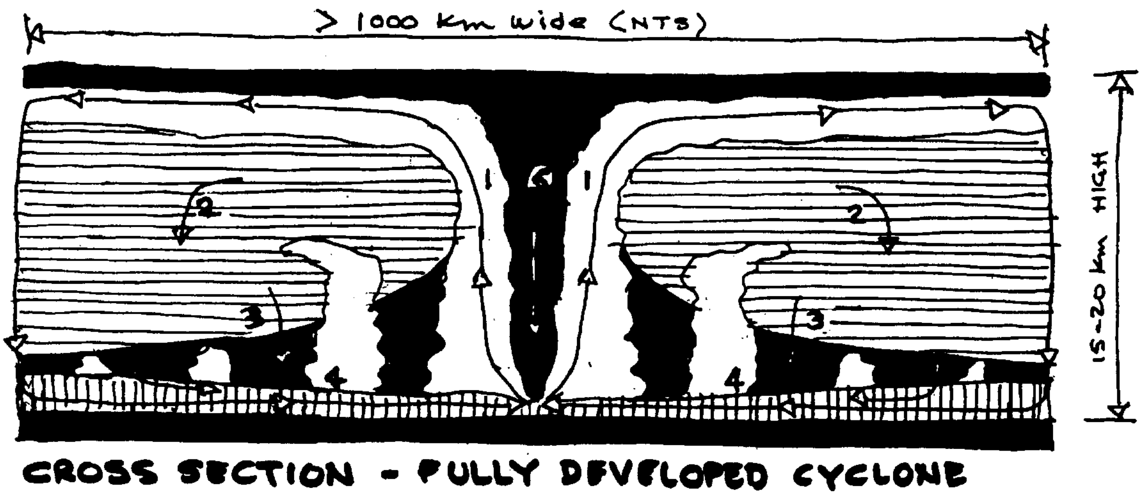
The principal Cyclone Season in the Southern Hemisphere is from November to April, and in the Northern Hemisphere from May to October, when warm tropical oceans and atmospheric conditions give rise to cyclonic events.

The area covered by an intense cyclone with winds in excess of 120 km/hr can have a diameter from 250 to 800 km and lesser wind affects to diameters of 1,200 km to 1,500 km.

A cyclone is a severe tropical storm of such magnitude that winds near the centre form a circular vortex or cyclonic whirl.

If these winds exceed 120 km/hr (35 m/s, 75 mph), the storm is called a typhoon, hurricane or cyclone. The rotation of the Cyclonic Vortex is clockwise south of the equator and anti-clockwise north of the equator.

Close to the centre of intense cyclones is an area of windless clear sky known as the 'eye'. Around this eye of 1 to 50 km diameter is a large mass of cloud from which heavy rain falls. The amount of rain that falls can be up to 350 mm and in extreme events over 1,000 mm.

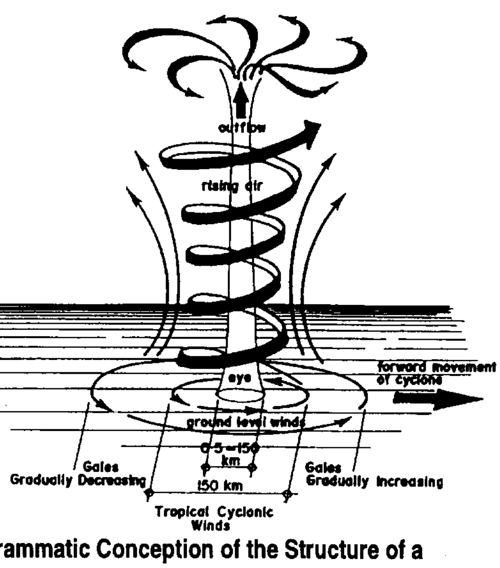


CROSS SECTION - FULLY DEVELOPED CYCLONE

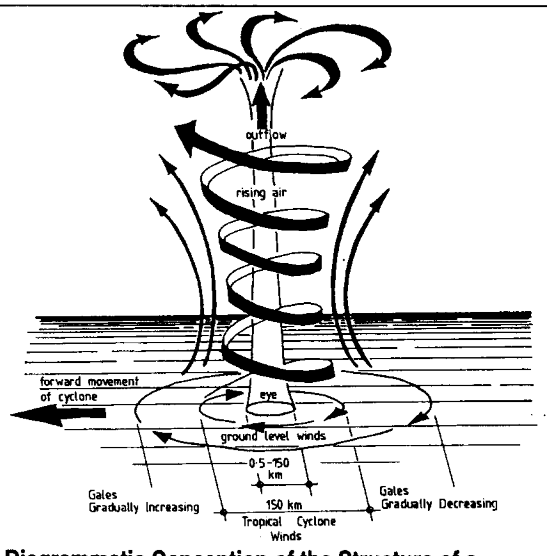
1.	CENTRAL CLOUD BANK	• Substantial rising air, violent precipitation.
2.	OUTSIDE CLOUD BANK	• Substantial rainfall.
3.	TRADE WIND CONVECTION LAYER	• Rising moisture by convection.
4.	WIND FLOW OVER SEA SURFACE	• Rising moisture from sea (fuel).
5.	EYE OF THE CYCLONE	• Calm, clear weather zone

The most important characteristic of a tropical cyclone in describing its intensity is the central pressure. The strong upwards flow of hot air generated by the release of latent heat lowers the pressure at the centre which sucks in the low level air and thus creates the strong low level winds. At the same time it acts like a giant straw sucking up the level of the sea above its normal level and creating a large mound of water which travels along with the cyclone and piles up against the coastline when the cyclone crosses the coast to form the storm surge. Consequently, in general the lower the central pressure the greater are the maximum winds and the higher is the storm surge.

(Above diagram adapted from Munich Reinsurance, 1990).
(Diagrams below adapted from Trollope, Prof. D H 1972).



Diagrammatic Conception of the Structure of a Tropical Cyclone (North of the Equator)



Diagrammatic Conception of the Structure of a Tropical Cyclone (South of the Equator)

In association with the cyclone occurs a strong reduction in barometric pressure. This can cause a rise in the water level called a 'storm surge'. Combined with wind driven sea water waves and astronomical tide, a rise of water level up to and often exceeding 10 metres can occur.

Consequently, damage to buildings during cyclones can consist of a combination of destructive high wind forces and widespread flooding.

"The most important characteristic of a tropical cyclone in describing its intensity is the central pressure. The strong upwards flow of hot air generated by the release of latent heat lowers the pressure at the centre which sucks in the low level air and thus creates the strong low level winds".

"At the same time it acts like a giant straw sucking up the level of the sea above its normal level and creating a large mound of water which travels along with the cyclone and piles up against the coastline when the cyclone crosses the coast to form the storm surge. Consequently, in general the lower the central pressure, the greater are the maximum winds and the higher is the storm surge" (Extracted from Munich Reinsurance, 1990).

Most people underestimate the effects and the power of a cyclone. It is therefore important to understand the magnitude of the forces and loads developed by severe events such as cyclones.

2.2 SEVERE CYCLONIC EVENTS

(a) PRESSURE AND FREQUENCY

Most cyclones have pressures between 950 mb and 985 mb with severe cyclones dropping to 920 mb or lower.

The lowest pressure recorded in a cyclone was 877 mb at sea level in Cyclone 'Nora' on 6 October 1973 over the Philippine sea by aircraft dropping a pressure recorder into the cyclone centre. The USA on Labour Day 1935 recorded 892 mb (Vickery D J, 1982:22).

The highest frequency of cyclones appears to be near the Philippines.

The areas where the greatest loss of life occurs are in the Bay of Bengal at the Bangladesh coast.

(b) WIND

Cyclone wind speeds normally vary between 30 m/s to above 60 m/s.

According to UNESCO records the strongest cyclone winds recorded were 320 km per hour or 90 m/s.

The areas with the strongest recorded winds caused by cyclone disturbances are in the Philippines in the western Pacific Ocean and around Mauritius in the Western Indian Ocean.

(c) STORM SURGE

Storm surges affect the Florida area of USA and the coastlines of the Gulf of Mexico, Bangladesh, and Vietnam most frequently and other countries in the cyclone regions from time to time.

A storm surge of 15 m in Cyclone "Mahina" (914 mb) (lat. 17°) in 1899 in Bathurst Bay, North Queensland, Australia, where a pearling fleet was destroyed has been well documented by the few survivors of that event.

The wave or storm surges that occur that cause such a loss of life in some areas are mostly 3 – 8 m above normal high tide level.

(e.g. Bangladesh: 1970 – 5.6 m with 400,000 lives lost; 1991 – 8.0 m with 140,000 lives lost).

(d) FLOODING

The worst flooding occurs in Bangladesh, with an area of 140,000 km^2, which has had 60% – 70% of the whole country flooded on a number of occasions.

China, made up of provinces, once had 85% of one province of 140,000 km^2 flooded in 1991.

2.3 REGIONS AFFECTED BY CYCLONES

Records taken over a 20 year period show that a global total of 2,000 cyclones have occurred in that period.

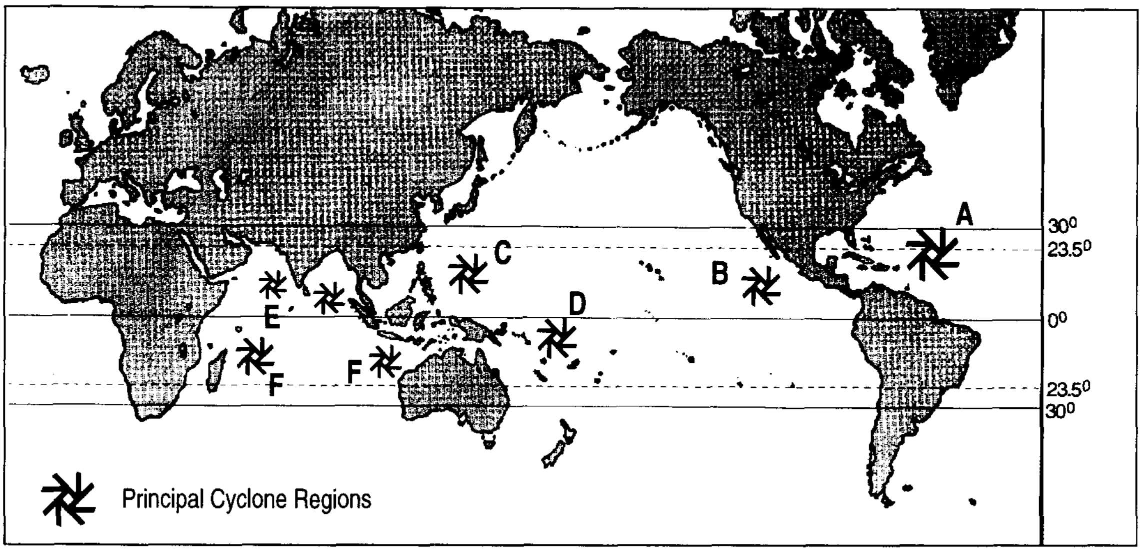
Distribution of cyclone events in the world's tropical regions is illustrated on the diagram.

Some 68% occur in the northern hemisphere and 32% in the southern hemisphere.

The regions affected with their cyclone season and the regions percentage of the total global events can be summarised as follows:

TABLE 1
CYCLONIC SEASONS AND TOTAL GLOBAL EVENTS

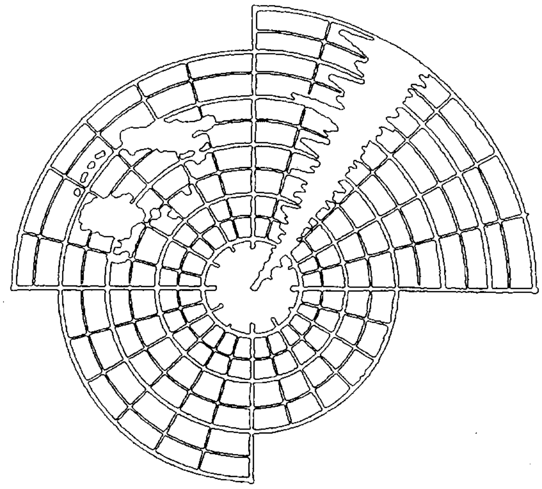
REGION	*SEASON*	*%*
North Atlantic – West	Aug – Oct	**12%**
East Pacific – North	June – Oct	**11%**
West Pacific – North	April – Dec	**30%**
West Pacific – South	Dec – April	**11%**
Indian Ocean – North	May – Dec	**15%**
Indian Ocean – South	Dec – April	**4%**



Distribution of Cyclone Events amongst the World's Tropical Regions

TABLE 2
CYCLONE AFFECTED COUNTRIES

REGION A North Atlantic - West			
Dominican Republic Bahamas Turks & Caicos Islands Dominica St Vincent Cuba Haiti Cayman Islands	Puerto Rico St Kitts & St Nevis Antigua Martinique Barbados Guyana Leeward Islands United States of America	Virgin Islands Anquilla Montserratt St Lucia Trinidad Tobago Colombia Venezuela	Jamaica St Martin Guadaloupe Grenada Netherlands Antilles Barbuda St Croix
REGION B East Pacific - North			
Mexico Belize	Nicaragua Guatemala	Honduras Costa Rica	Panama Hawaiian Islands
REGION C West Pacific - North			
Japan Hong Kong	China Philippines	Vietnam Guam	Thailand Micronesia & Caroline Islands
REGION D West Pacific - South			
American Samoa Tuvalu French Polynesia Papua New Guinea	Western Samoa Solomon Islands Cook Islands Australia - North East	Fiji Tonga New Caledonia	Kirabati Vanuatu
REGION E Indian Ocean - North			
Sri Lanka Pakistan	Maldives Myanmar	India	Bangladesh
REGION F Indian Ocean - South			
Mauritius Australia - North West	Madagascar	Reunion	Comoros Islands



3 DAMAGES CAUSED BY CYCLONES

CONTENTS

3.1 GENERAL DESCRIPTION

Damages caused by cyclones are increasing as the world's population grows, as the poorer countries develop to levels where their population is more able to purchase consumer goods and furnishings and live in better, more expensive accommodation.

In addition, the more developed nations see their population continuing to improve the value and quality of their possessions and insuring more.

Finally, more people are living in areas of risk, (e.g., valleys and coastal areas).

While economic losses in the decade 1980 – 1989 of $35 billion compared to $20 billion in the decade 1960 – 70 (a factor of 1.75), insured losses increased from $5.0 billion to $17 billion (a factor of 3.5) (Munich Reins. 1990:70).

Since 1990, the impact of disasters has continued to escalate greatly with cyclones in the Americas; the floods in China; the eruption at Mt Pinatubo in the Philippines; the earthquake in Kobe, Japan; and the 1995 floods in Europe among the major events.

The insurance companies are continually evaluating their position, reviewing the level and cost of insurance and identifying areas of high risk.

There are also sections of the affluent societies who rely on insurance and take less care in mitigating damages.

Some evacuate without adequate preparedness, thus increasing the risk and cost of damages.

Insurers will take steps to avoid these situations or place onerous conditions on these policies.

All governments are concerned with the mitigation of disaster events but their response is often mitigated itself by the nations ability to deal with the disaster events physically, technically, socially and financially.

For example, Bangladesh would have difficulty in fully responding to its 1991 flood, cyclone and storm surge disaster were it not for the donations and loans from the international community and national and international agencies technical assistance.

Other countries with internal conflict find priorities re-arranged with protective measures deleted for more political reasons.

The full effects of the Kobe earthquake will set new standards of risk recognition and appreciation of the need to place mitigation action at a higher priority level.

Cyclones and the storm surges and floods that accompany them have been responsible for the greatest loss of life of all disaster events.

Cyclones cause many affects on the environment and community:

- Development of severe forces.
- Wind conditions dangerous to human life.
- Wind conditions that damage or destroy buildings.
- Under certain conditions, storm surges can occur.
- Very heavy rainfall and flooding.
- Denuding of vegetation.
- Damage to crops.
- Disruption of transport.
- Damages to services, power, sewerage, water supply, stormwater.
- Disruption to business and social life.

The type of damages caused by cyclones to building structures can be summarised as listed hereunder. The list is a summary of broad areas which will be dealt with in greater detail later in this paper.

- Removal of roof cladding, (sheeting and tiles).
- Removal of the immediate supporting framework, (timber roofing battens).
- Removal of supporting roof framing structure, (timber and steel trusses and beams).
- Removal of wall top plates.
- Damage to walls, (brick, block, stone, timber), including demolition of same.
- Collapse of light framed and other building structures due to lack of bracing and stiffness.
- Serious damage to community infrastructure, (power poles, power lines, services).
- Serious damage to landscaping and environment by wind forces, violent rainfall, flood and landslides.
- Serious damages to communities by storm surge and wind damages.

The inability of the above structures to resist the wind forces emphasises the need for more education on techniques in building construction and design to enable all elements of building construction to resist these forces.

The examples of well designed structures which have survived should be better publicised and identification made of the reasons for their survival.

Broad policies should be adopted to provide:

- Better consideration by architects and engineers of disaster forces at professional level.
- Better knowledge by professionals of a range of design details that resist wind forces.
- Broader education of builders, inspectors and tradesmen at both technical colleges and at in-service training seminars.
- Better acceptance by manufacturers of their responsibilities to deliver better products and systems of passing on adequate fixing details.

- Education of key individuals or departments at National, State and regional level in governments and non-government agencies.
- Education in basic knowledge of wind forces and preventative measures and preparedness to the general public and to school children.

3.2 COMMONALITY WITH OTHER DISASTERS

As various disaster events are studied, experts produce reports explaining the effects, the damages and the forces created by the event and list their recommendations and guidelines to be followed in construction to mitigate further damages. A study of the recommendations for damage mitigation to building construction for bushfires, earthquakes and cyclones reveals that at least 60% of the measures needed are common.

It is recommended that further studies into the commonality of recommended responses to various disasters be made which may save a large amount of money if proven common responses can be developed.

3.3 CASE STUDY – BANGLADESH

In 1991 Bangladesh with a population of approx. 116,000,000 suffered 233 km cyclone winds, an 8.0 m high storm surge and major inland flooding of the Ganges, Brahmaputra and Megna Rivers from prior heavy monsoonal rainfall.

Whilst the loss of life was reported to be as high as 140,000, the event deserves closer examination in comparison with previous events.

The disastrous cyclone and storm surge of 5.6 m in 1970 caused 400,000 deaths when the population was approx. 58,000,000 to 60,000,000.

The enclosed diagram of statistics in 1970 and 1991 clearly show that the projection of loss of life from the 1970 event to 1991 in proportion to the doubling of the population from about 60 million to about 120 million would have caused about 800,000 deaths.

The actual loss of life at 140,000, painful to the nation as it was, showed a vast improvement below projections, indicating that 660,000 lives were saved.

Whilst this country is one of the poorest, it has shown remarkable progress in the two decades.

Their satellite warning systems are vastly improved so that faster better warnings were available and people were able to move earlier to safer locations.

Some of the mitigation works in provision of better buildings were in place and helped save lives.

The government and its assisting agencies, both locally and overseas, may take some credit for the magnitude of its improvement in preparedness.

Policies in place for the current decade 1990 - 2000 should show further significant improvements, especially if the "safe school" in each village programme is implemented.

The following diagrammatic sketches show one solution to overcome the wave surge problem adopted by government agencies.

The provision of secure classrooms, with accessible concrete roof areas of the size shown can, in emergencies, accommodate 1,000 people in the rooms and balcony and 1,000 people on the roof, albeit in crowded circumstances, but safe until floods recede.

The different designs shown are proposals for flood plains at different distances from the coastline, set at heights to be above the highest recorded storm surge heights at these locations.

Government departments have a number of school designs along these lines and implementation is proceeding.

The school could hold the normal village population of 2,000.

TABLE 3
FLOODS, CYCLONES, SEA SURGES IN BANGLADESH

ACTUAL 1970		*ESTIMATE 1990*	*ACTUAL 1991*
60,000,000	Population	120,000,000	116,000,000
400,000	Deaths	800,000	140,000
0.7%	Percentage of population killed	0.7%	0.12%
		SAVED	**660,000**
		EVACUATED	15,000,000

3.4 SAFE SCHOOL PLAN IN BANGLADESH

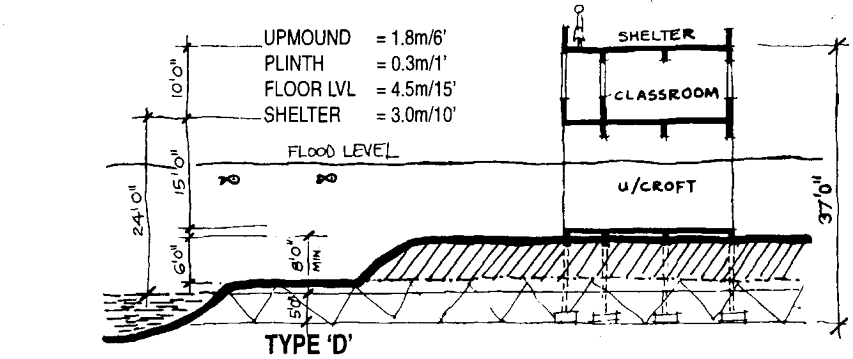
Current designs for schools aim to provide a secure school in each village of 2,000 people.

Depending on the proximity of the school to the coast and the risks of flooding by storm surges, the secure classroom block will be raised to safe nominated heights above the ground with open undercroft area at ground level of heights to allow design floods to pass under the classroom.

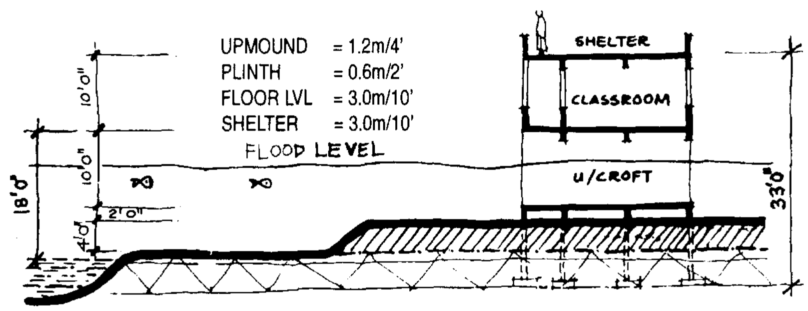
The classroom will provide access to a concrete roof with parapet.

In emergencies the village population could be given temporary accommodation in the school rooms and roof areas.

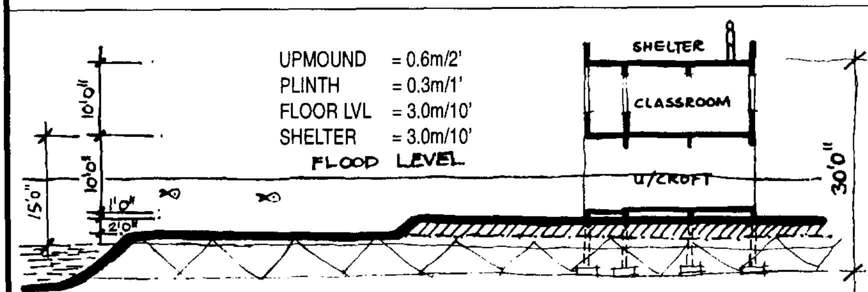
Coastal Schools – Recommended Height in Storm Surge Areas



TYPE 'D'
Within 15km/9 miles of coast

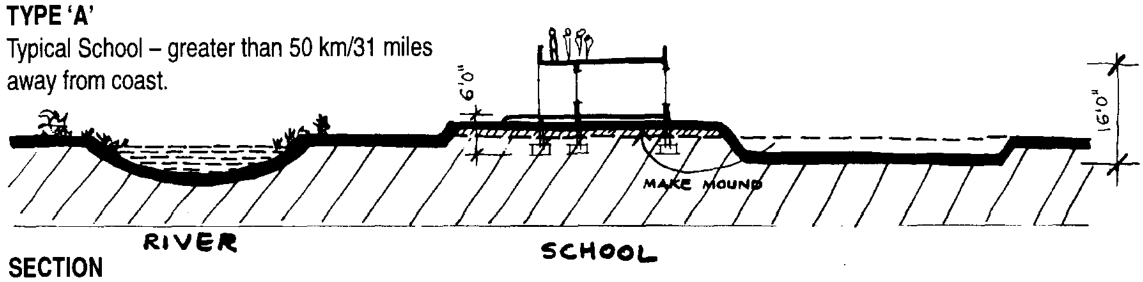


TYPE 'C'
Within 15–30 km/9–18 miles of coast

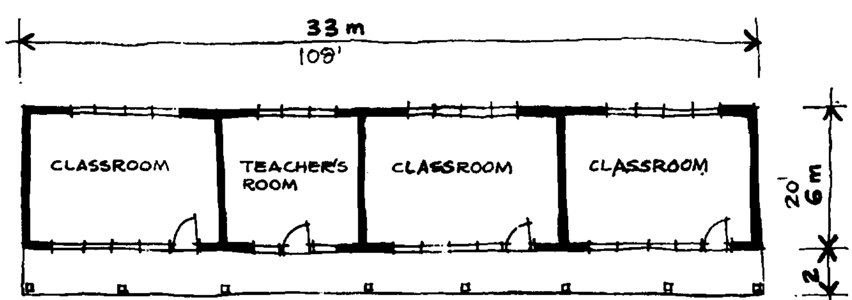


TYPE 'B'
Within 30–50 km/18–31 miles of coast

TYPE 'A'
Typical School – greater than 50 km/31 miles away from coast.

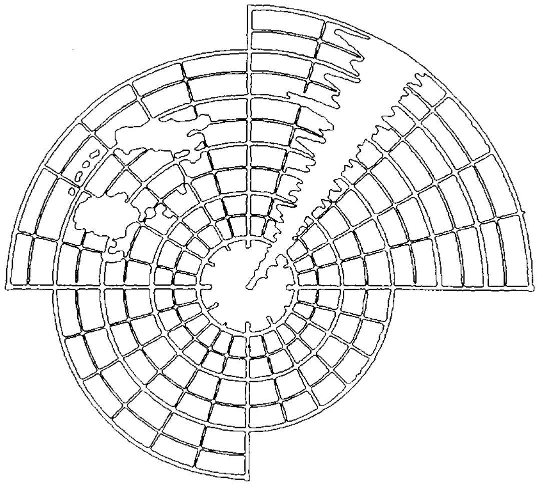


SECTION
Typical Bengali School



PLAN
Typical Bengali School for village of 2,000 population

Roof Area 270 m^2



4 SCHOOL TYPES IN CYCLONE AREAS

CONTENTS

4.1 VARIATIONS

There are over 70 countries located in regions affected by cyclones.

In the process of building construction and design of these school buildings it is noted that the methods of construction and materials used will vary a great deal, depending of a number of factors.

i.	Country to country.	Type of education system.
ii.	Different climate zone.	Tropics to temperate.
iii.	Different types of terrain.	Hills or plains.
iv.	Level of economy.	Poor to rich countries.
v.	Political management.	Autocratic to democratic.
vi.	Sophistication.	Natural ventilation or air conditioning.
vii.	Construction level.	Technical and trade skill levels.

4.2 WALLS, FLOORS AND ROOFS

Floors will range from natural ground to crushed rubble and render to timber, to concrete floors in isolated slabs or in homogenous in situ slabs with concrete finish, natural or polished or with ceramic tile, terrazzo, sheet vinyl, vinyl tile or carpet on the floor.

Walls will range from concrete to stone or brick with face work or rendered finish, or concrete masonry block, reinforced or loosely laid, or to framed wall structure with concrete steel or timber portal frames and infill walls of brick or stud frame where walls are sheeted with sheet materials of fibre cement, metal cladding, plywood plasterboard or boarding.

Windows could be casement type, vertically sliding box frame, horizontally sliding box frame, horizontally sliding aluminium and glass, timber, metal or wooden louvre windows to awning type or pivot hung. Other windows are sheeted with galvanised iron casements and wrought iron grilles or still others are left open where climate demands prevail.

Roof cladding and framing is sheet or tile on battens supported on rafters, or sheet roofing supported on purlins. Rafters are supported by beams or purlins which in turn are supported by trusses, beams or wall frames.

Prefab light weight trusses at close centres are also used to support batten and sheet or tile roofs. Still other have concrete roof structures with various methods of finish or waterproofing systems.

4.3 TRADITIONAL CONSTRUCTION SYSTEMS

Traditional systems of building have developed in each of the countries depending on the economy, materials and skills available.

For example a design for imported prefabricated steel truss frames in the hills of Papua New Guinea or Bhutan would soon be discarded when the cost of transport over long distances for days on poor narrow hilly roads is considered. Substitutions would be made with local materials such as log beams or locally made systems.

The above example of failed technology transfer points to the failure of the designer to properly consider the location of the building and the availability of materials, technology or of the local economy.

4.4 PRE-FABRICATION SYSTEMS

Similar problems with simple solutions to provide aid to developing countries such as delivery of sophisticated prefabricated schools of frames, panels and bolted connections may occur when the design, often made in a different climate zone, is delivered.

Local personnel will mostly accept the school as a gift but often with one eye closed. When bolts rust, they are not replaced (none are locally available in that gauge or type), when panels are damaged they deteriorate without repair and the locals do not have the same feelings of responsibility to looking after the building than they would to one that they built themselves. The result is that the building can easily lose its structural integrity and fail in the next disaster.

4.5 DESIGN – UNESCO PRINCIPLES

The UNESCO general principles of educational building for classrooms in tropical areas are shown on the following diagram "Design Principles for Tropical Areas" which sets out certain recommended criteria for structure, orientation, ventilation, acoustics and seating arrangements for primary and secondary schools.

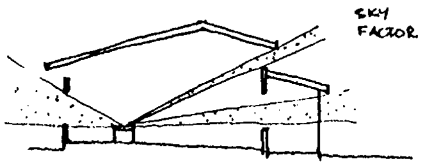
Desirable acoustics call for no student to be more than 6.0 m from the teacher and day lighting levels should illuminate the interiors to 100 to 300 lux.

Classrooms will vary in length from 7.0 m to 9.0 m and in width from 4.2 m to 7.0 m.

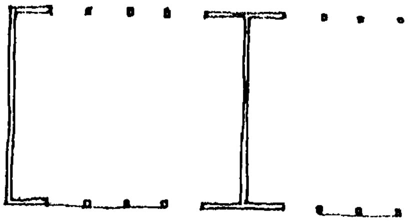
Most classroom buildings will be of single room width with a passage or open balcony along one side to allow maximum cross-ventilation.

DESIGN PRINCIPLES FOR TROPICAL AREAS

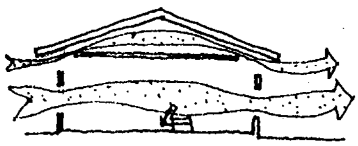
Source: Beynon, John (1986): "General Principals of Good School Building Design which have relevance to schools in cyclone affected areas".



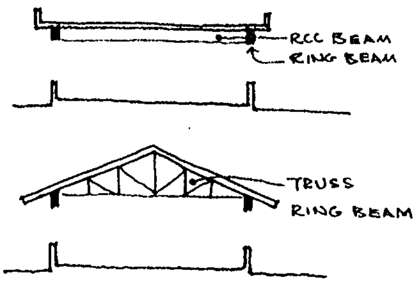
A. DAYLIGHT ILLUMINATION



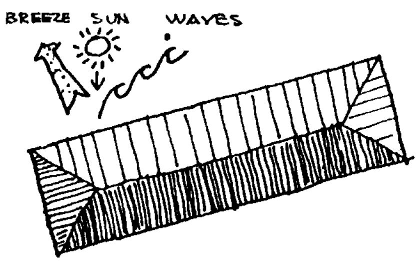
B. MAXIMUM OPENINGS



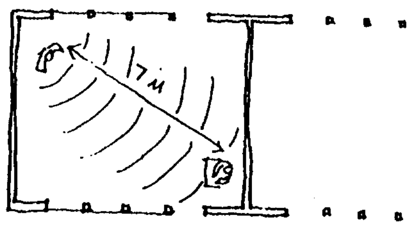
C. NATURAL VENTILATION



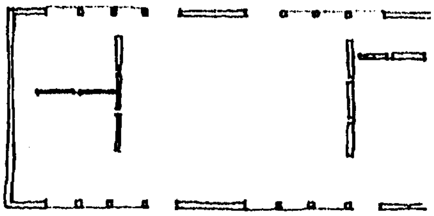
D. STRUCTURE



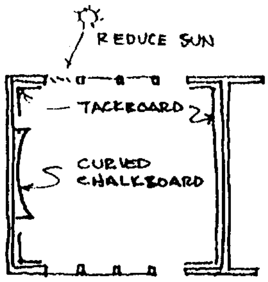
E. ORIENTATION



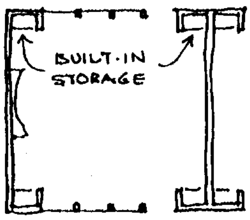
F. ACOUSTICS



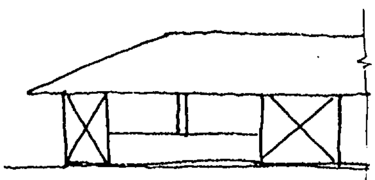
G. FLEXIBLE SPACE



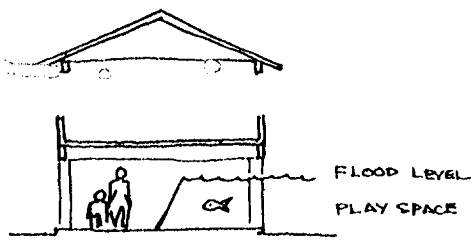
H. CHALKBOARDS/TACKBOARDS



I. STORAGE AS BRACING



J. BRACING



K. BUILDING ON STILTS

J.B. 8.4.86

4.6 SCHEDULE OF TYPICAL CONSTRUCTION TYPES

Attached hereafter is a schedule of typical types of construction for the countries listed.

i. Sri Lanka.
ii. The Philippines.
iii. Vietnam.
iv. China.
v. Bangladesh.
vi. Caribbean.
vii. Australia.
viii. Tonga.
ix. Mauritius.

It is recognised that, in each of the countries above, there are a number of construction types not shown. The list is indicative of selected current or traditional methods.

4.7 SKETCHES OF TYPICAL SCHOOL DESIGNS

Sketches of selected traditional or current designs of schools from the countries listed in 4.6. above are attached hereafter, together with notes of the construction materials used.

Later chapters offer comments on methods and ideas that may be applied to the existing constructions to mitigate damage.

This visual portfolio shows the variety of building types responding to different cultural and climatic environments.

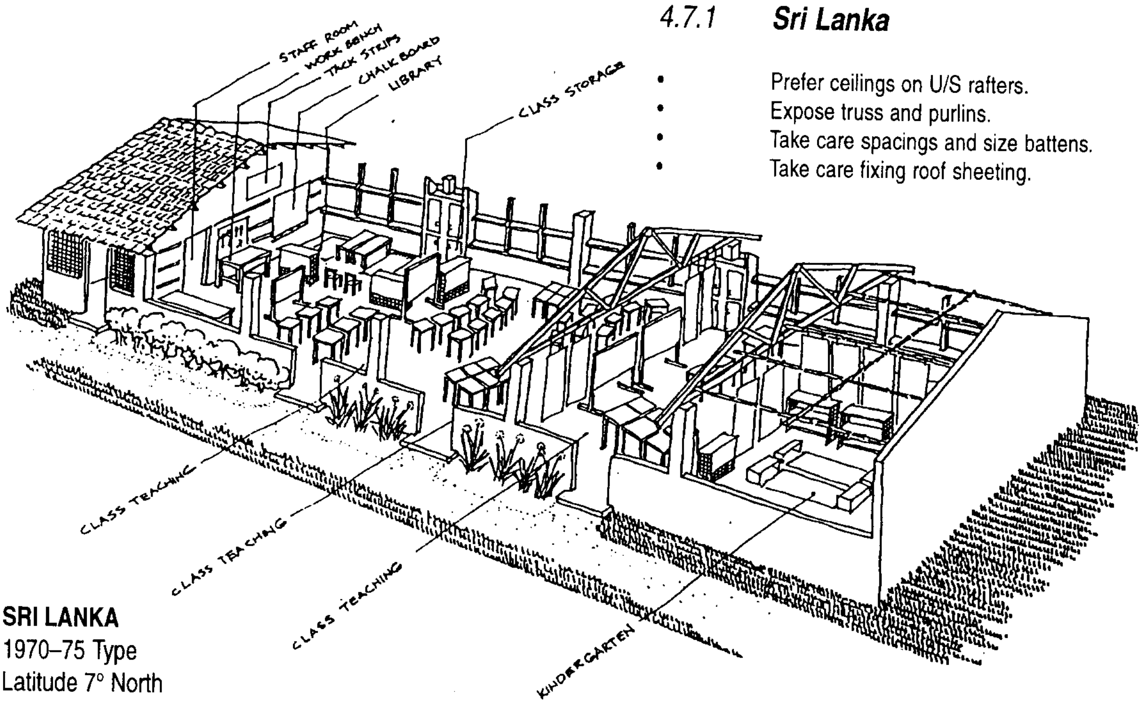
TABLE 4
SCHEDULE OF TYPICAL CONSTRUCTION TYPES

COUNTRY	*FLOORS*	*WALLS*	*ROOF FRAME*	*ROOFING*
i. Philippines	R C Slab	a. 230 brick, or, b. Concrete masonry block reinforced. c. Portal frame.	a/b. Purlins on beams, or, a/b. Rafters on beams, or, trusses, beams. c. Purlins.	CGI fixed to purlins or, CGI on battens.
ii. Vietnam	a. R C Slab b. Render on brick or aggregate	Load bearing. 230 thick solid brick rendered.	a. Steel truss. Purlins. Rafters. b. Concrete slab.	a. CGI on battens. Tiles on battens. b. Brick piers supporting slate tiles.
iii. China	R C Slab	Concrete frame. 230 solid brick infill. Cement render both sides infill.	a. Concrete slab. b. Timber truss, timber purlins. c. Timber truss, timber purlins.	a. Membrane & render. b. Tiles or battens. c. CGI on battens.
iv. Caribbean (various styles)	R C Slab	230 brick load bearing.	Trusses, rafters and purlins.	CGI on battens.
v. Sri Lanka	R C Slab or render on crushed aggregate or brick.	230 solid brick walls to 1.0 m height (open over), thence brick piers to support trusses	Timber roof, trusses, purlins and rafters.	Tiles and battens. CFC or CGI roofing.
vi. Bangladesh	R C Slab	130-230 brick with piers.	a. Concrete & tiles. b. Truss, purlin, rafter.	a. Tiles or concrete. b. CGI on battens.
vii. Mauritius	R C Slab	230 solid brick.	R C slab or trusses & purlins & rafters.	Tiles on concrete or CGI on battens.
viii. Tonga	R C Slab or timber on bearers and joists on stumps.	Prefabricated timber panels.	Prefabricated roof trusses.	CGI on battens.
ix. Australia	R C Slab	Timber frame & cladding.	Steel portal, plus purlins.	CGI or pan type steel roof.

LEGEND:
CGI = Corrugated galvanised iron,
CFC = Corrugated fibre cement,
RC = Reinforced concrete.

4.7.1 *Sri Lanka*

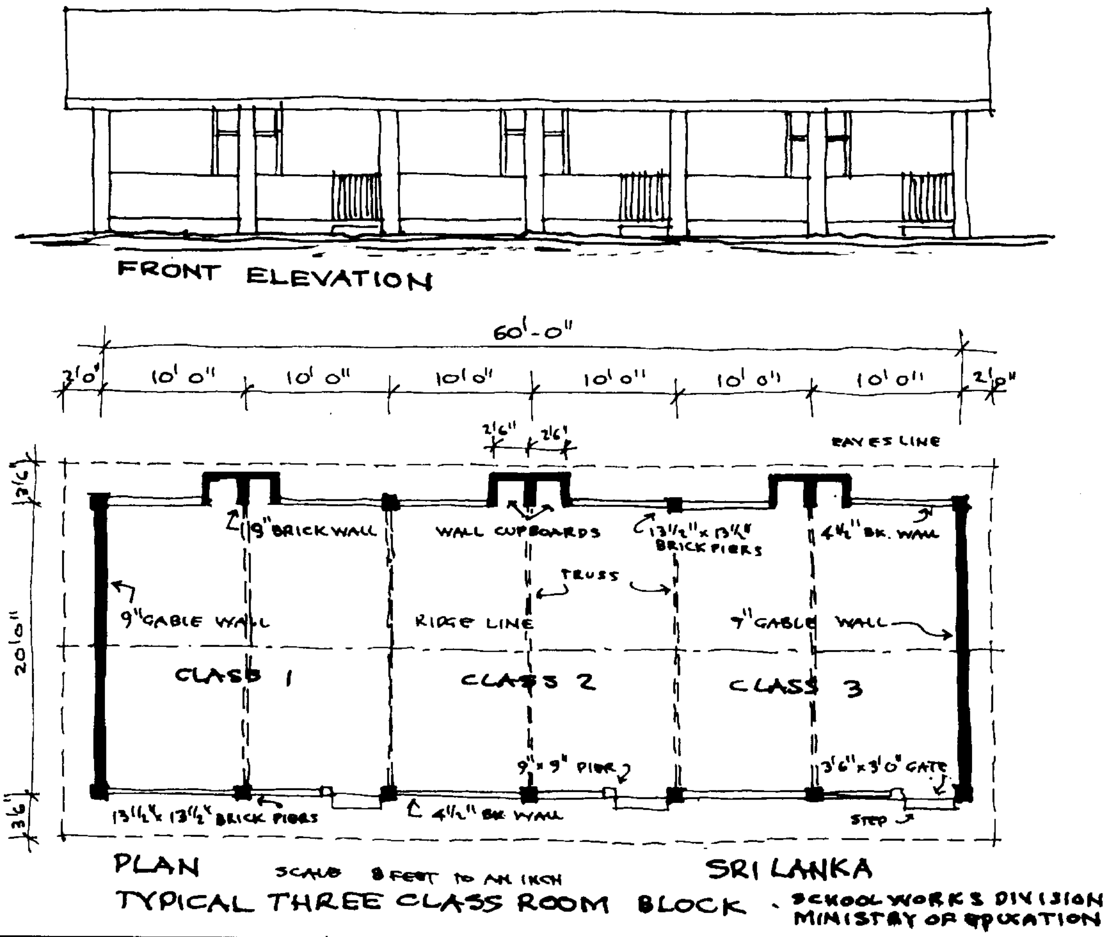
- Prefer ceilings on U/S rafters.
- Expose truss and purlins.
- Take care spacings and size battens.
- Take care fixing roof sheeting.



SRI LANKA
1970–75 Type
Latitude 7° North

- Columns need to be reinforced concrete in lieu of brick
- Roof needs to be braced in roof plane
- Bracing needed in wall planes
- Note building sides are open so wind loads are lower than in a fully enclosed building.
- Good quality timber trusses
- Good brickwork and rendering
- Prefer extra truss at gable walls
- Roof normally tiles on battens on purlins on rafters supported by roof trusses
- Prefer sheet cladding to roof

(Diagram Source: UNESCO 1982: Educational Buildings: Occasional Paper No.1)



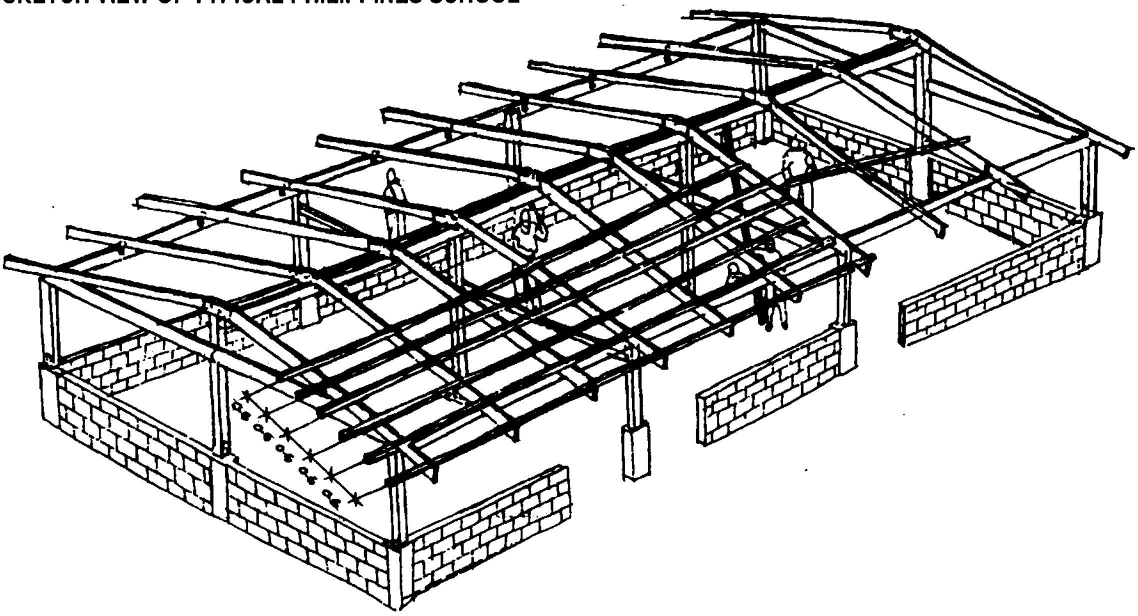
4.7.2 Philippines

- Portal frames of posts and beams.
- Tie beams at ridge and external wall.
- Purlins fixed to rafters via timber cleats.
- CGI roof sheeting.
- Masonry block spandrel walls.
- Window and door infill.
- Bracing to underside of purlins.
- Design, documentation and details by government are generally high quality (good example to others).
- Roof and window fixings shown on drawings.

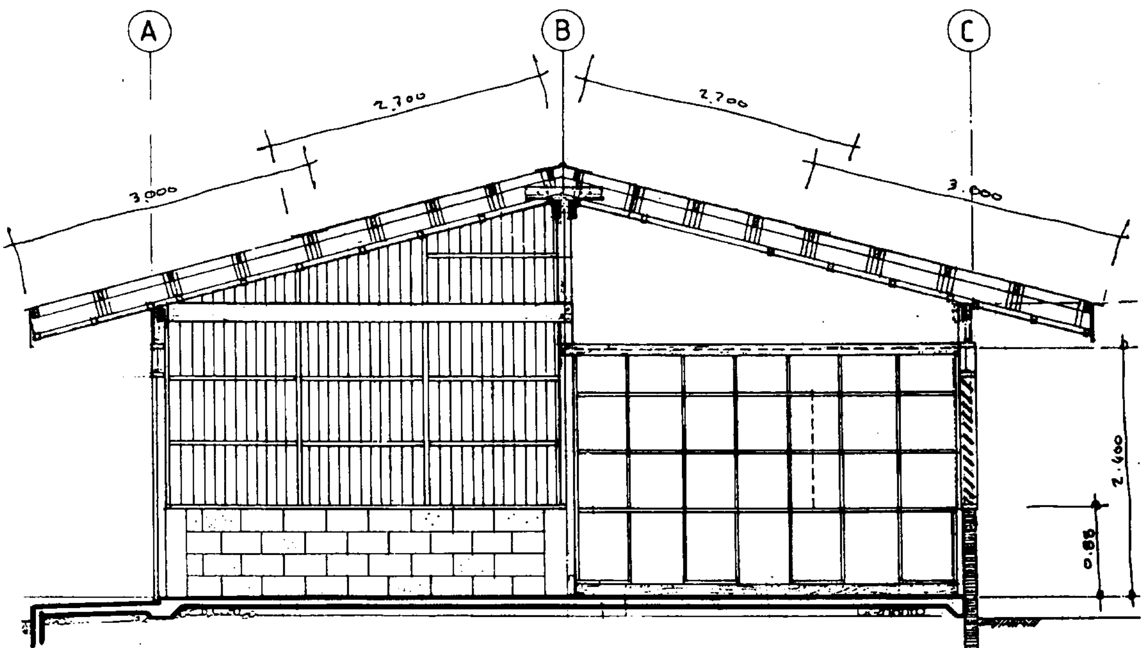
Comments

- Check alternate roof materials.
- Check diaphragm action of ceiling and their fixings.
- Check variety of purlin fixing details.
- Control reinforced masonry construction.
- Check bracing of walls, roofs.

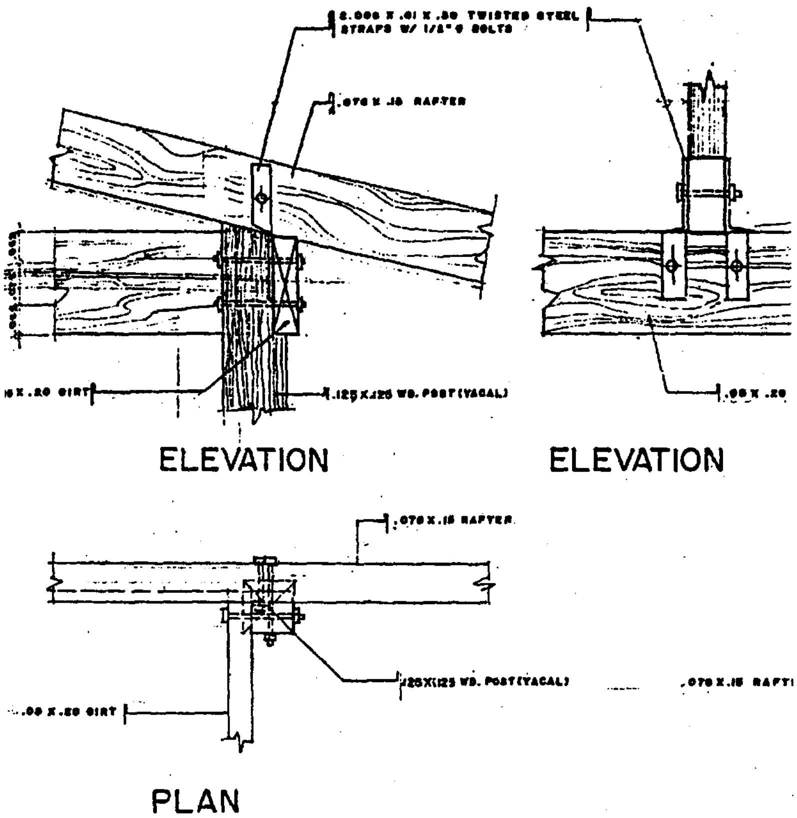
SKETCH VIEW OF TYPICAL PHILIPPINES SCHOOL



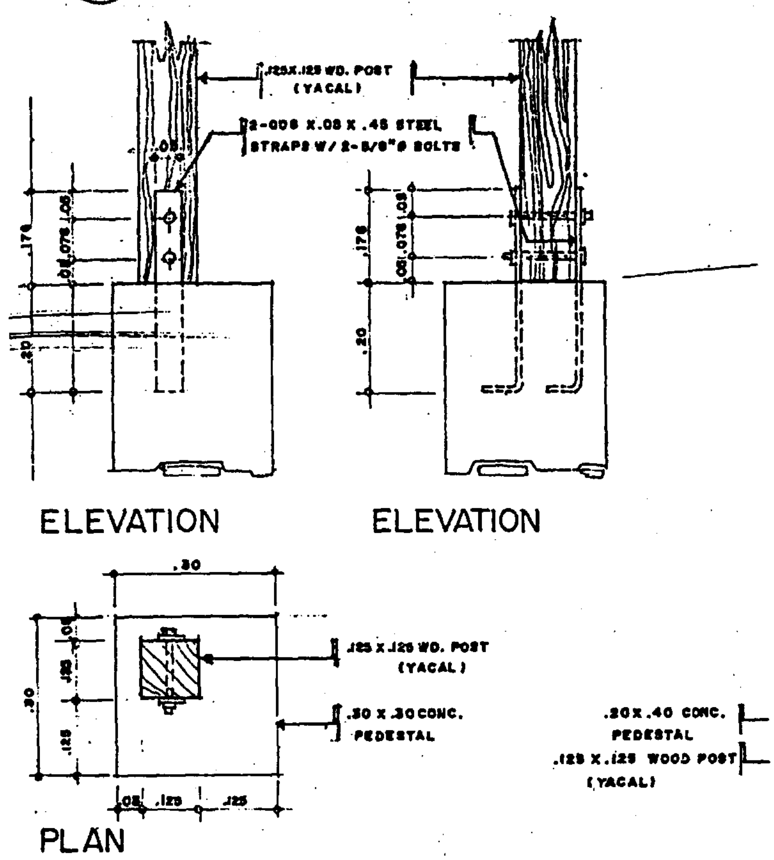
DETAIL CROSS-SECTION



TYPICAL STRUCTURAL DETAILS – TYPICAL PHILIPPINES SCHOOL



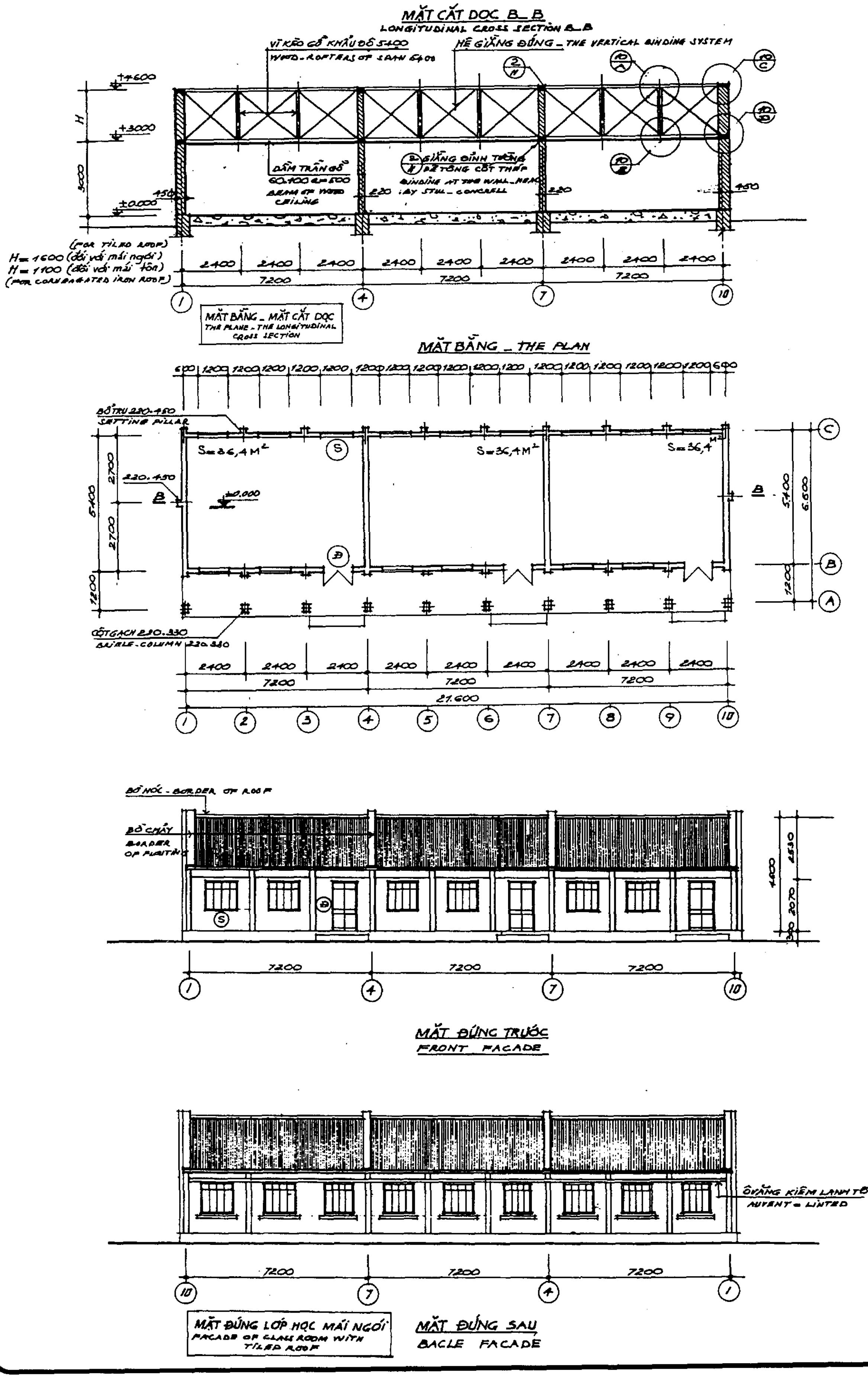
1/S-8 DET. OF RAFTER CONNECTION
SCALE: 1:10 MTS.



1/S-5 DET. OF POST SUPPORT @ CORNERS
SCALE: 1:10 MTS.

4.7.3 Vietnam

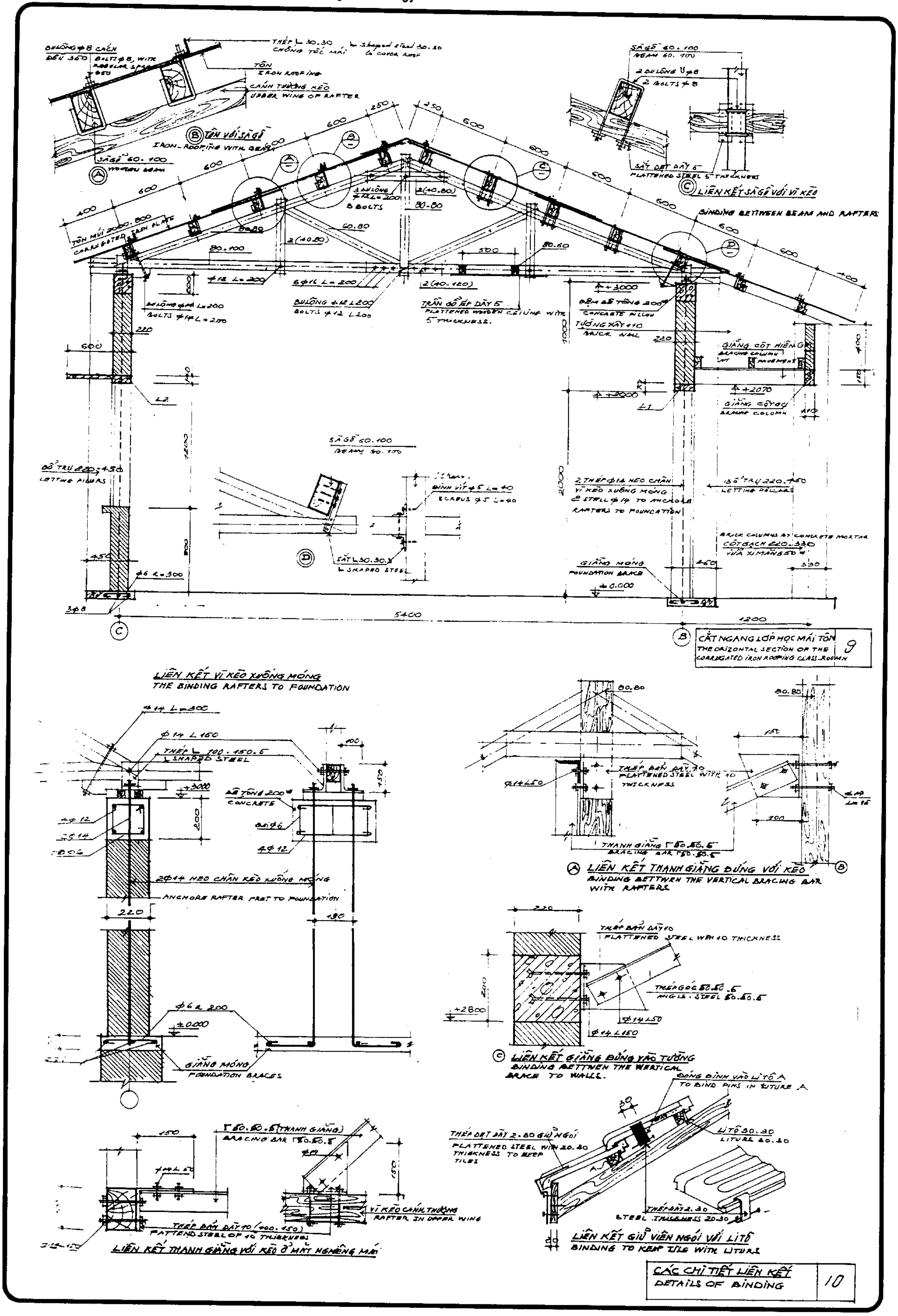
PLANS, SECTIONS AND ELEVATIONS OF TYPICAL SCHOOL BUILDING – VIETNAM



TYPICAL CROSS-SECTION AND STRUCTURAL DETAILS - VIETNAM

Comment

- Need to review design and construction details to add variety and options to existing technology.

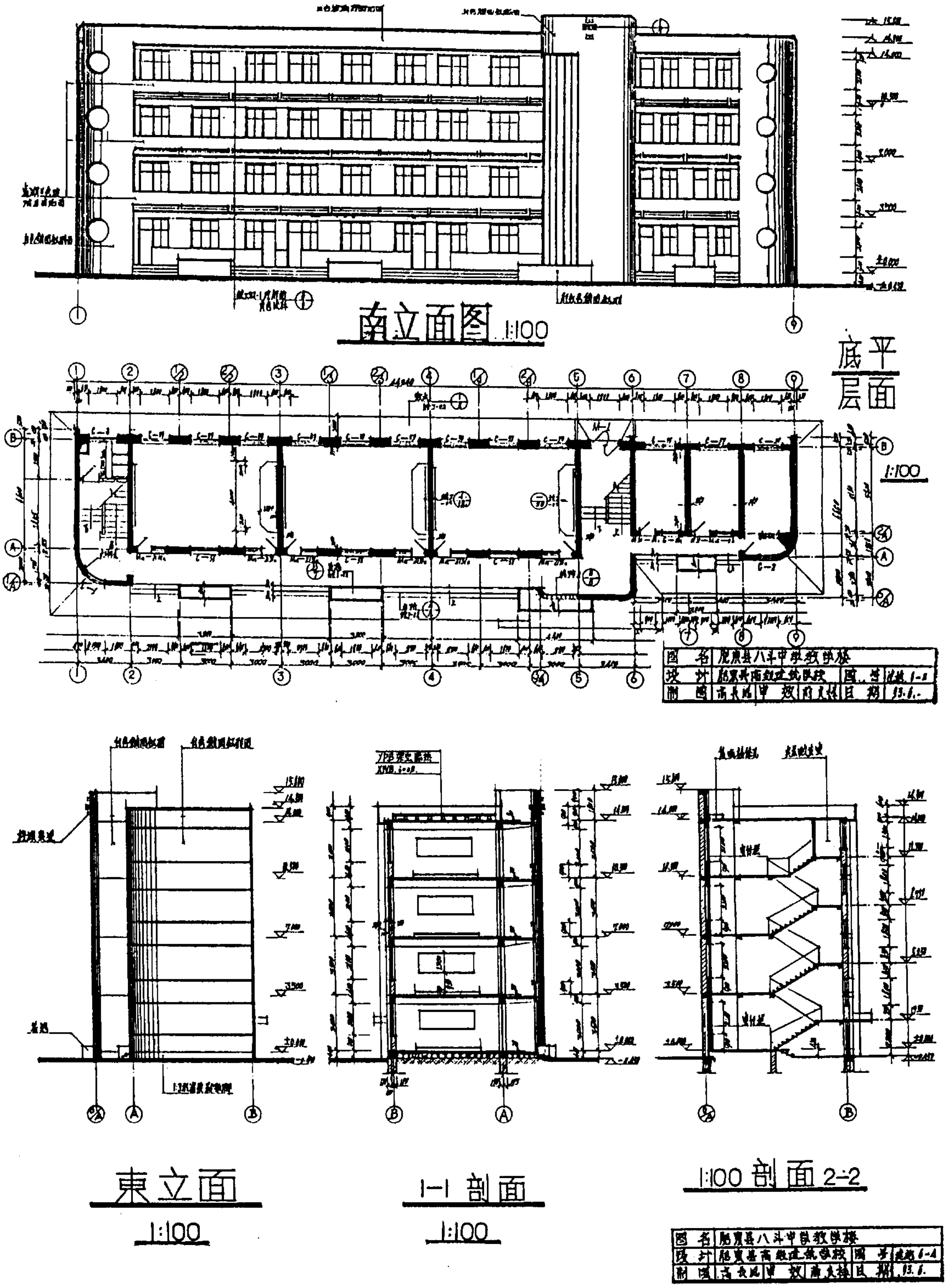


4.7.4 *China*

Comments:

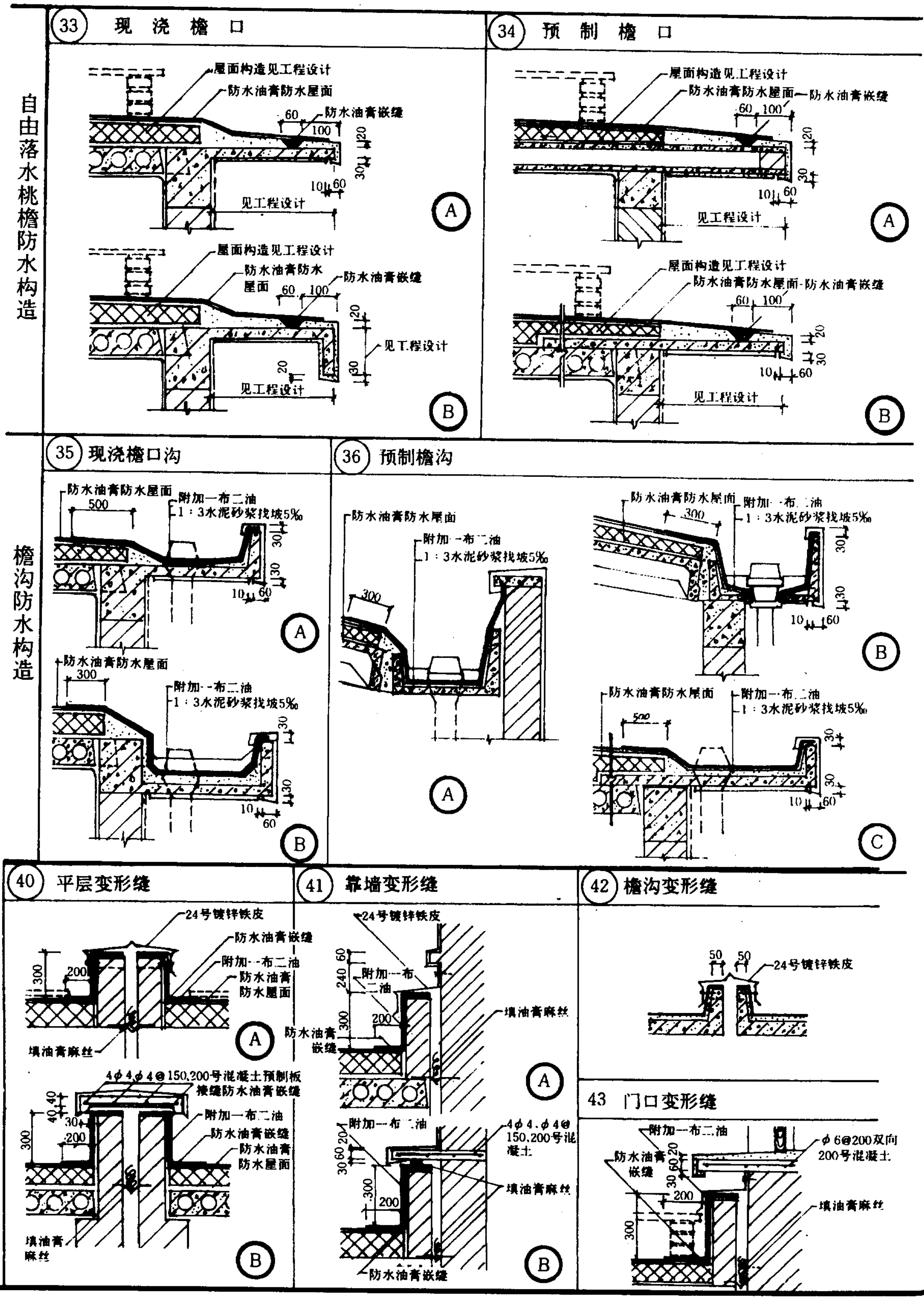
- Generally good construction techniques and details.
- Need to review waterproofing techniques at roofs and walls are installed as detailed.
- Maintain quality construction superintendance.

FLOOR PLAN, ELEVATIONS AND SECTIONS OF A TYPICAL CHINESE SCHOOL BUILDING



Typical roof details: The following details are extracts from the publications of the China Building Technology and Development Centre (CBTDC), Beijing.

TYPICAL CONSTRUCTION DETAILS FOR CHINESE SCHOOLS



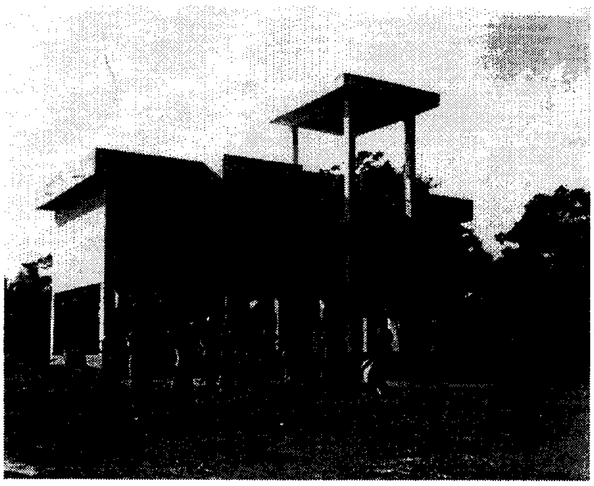
4.7.5 Bangladesh

(a) Pucca Construction

- Concrete frame.
- Brick infill.
- Concrete roof slabs or pre-cast.
- Concrete roof tiles, (or quarry tiles). (Prefer insulated blocks).

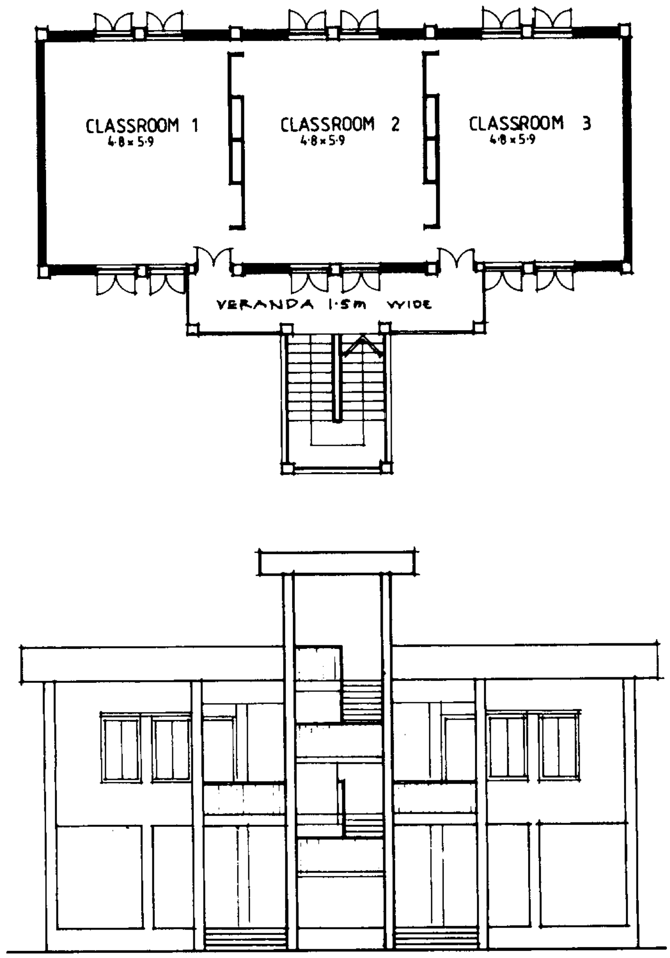
Notes:

- Lack of insulation in roof structure.
- Transfer of radiant heat to interior.
- Cost.
- Watch that adequate cross ventilation is provided.



TYPICAL BANGLADESH 'PUCCA' SCHOOL BUILDING

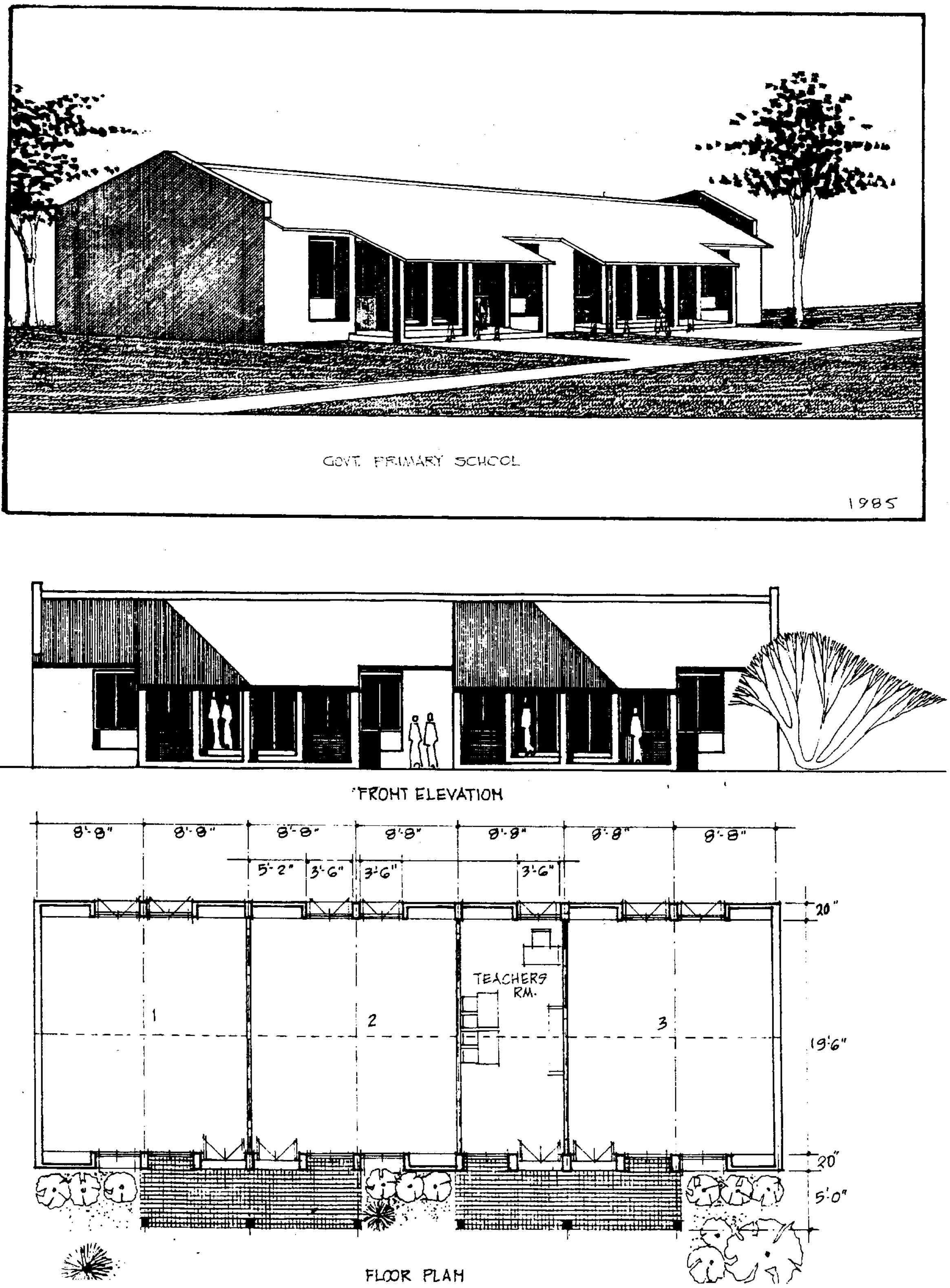
FLOOR PLAN AND CROSS-SECTION THROUGH TYPICAL BANGLADESH 'PUCCA' SCHOOL BUILDING



(b) *Semi-Pucca Construction*

- Need for extra truss at end brick walls.
- Brace roof framing in roof plane.
- Provide lateral support between trusses.
- Check spacing of purlins: Reduce if possible.

SKETCH VIEW, ELEVATION AND FLOOR PLAN OF TYPICAL BANGLADESH "SEMI-PUCCA" SCHOOL BUILDING

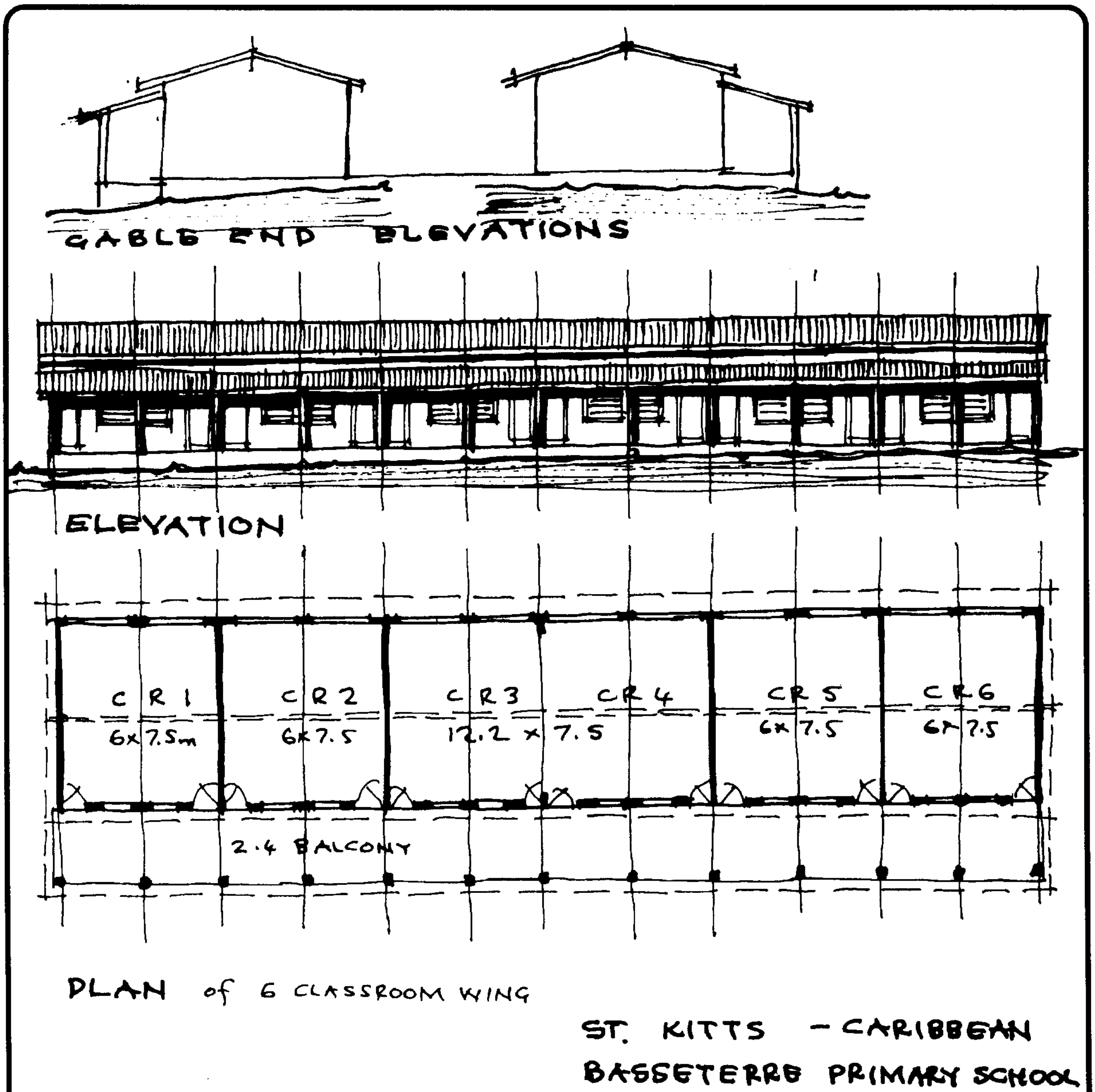


4.7.6 Caribbean

- Load bearing.
- Brick walls.
- Timber roof trusses.
- Purlin beams.
- Rafters and tiles on battens or sheet roofing on purlins.

Decide:

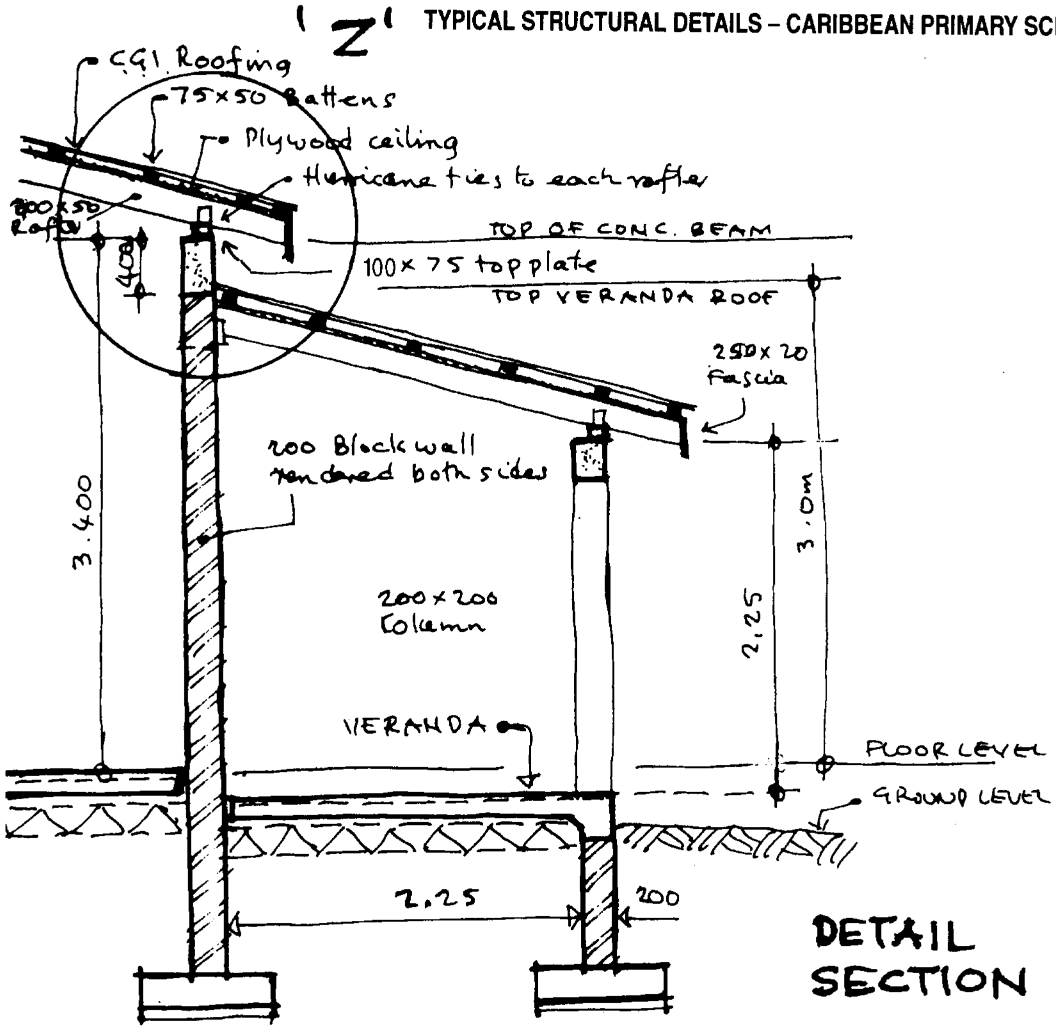
- Prefer ceilings on underside of rafters.
- Expose truss and purlins.
- Take care spacings and size of battens.
- Take care fixing roof sheeting.



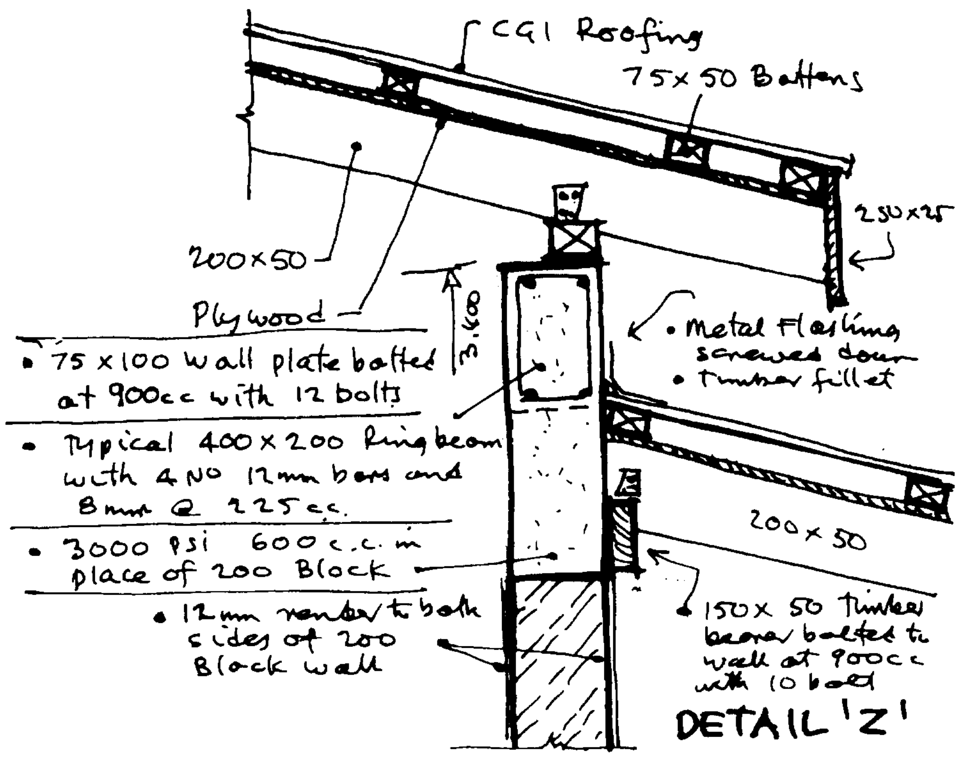
TYPICAL CARIBBEAN PRIMARY SCHOOL – PLAN AND ELEVATIONS

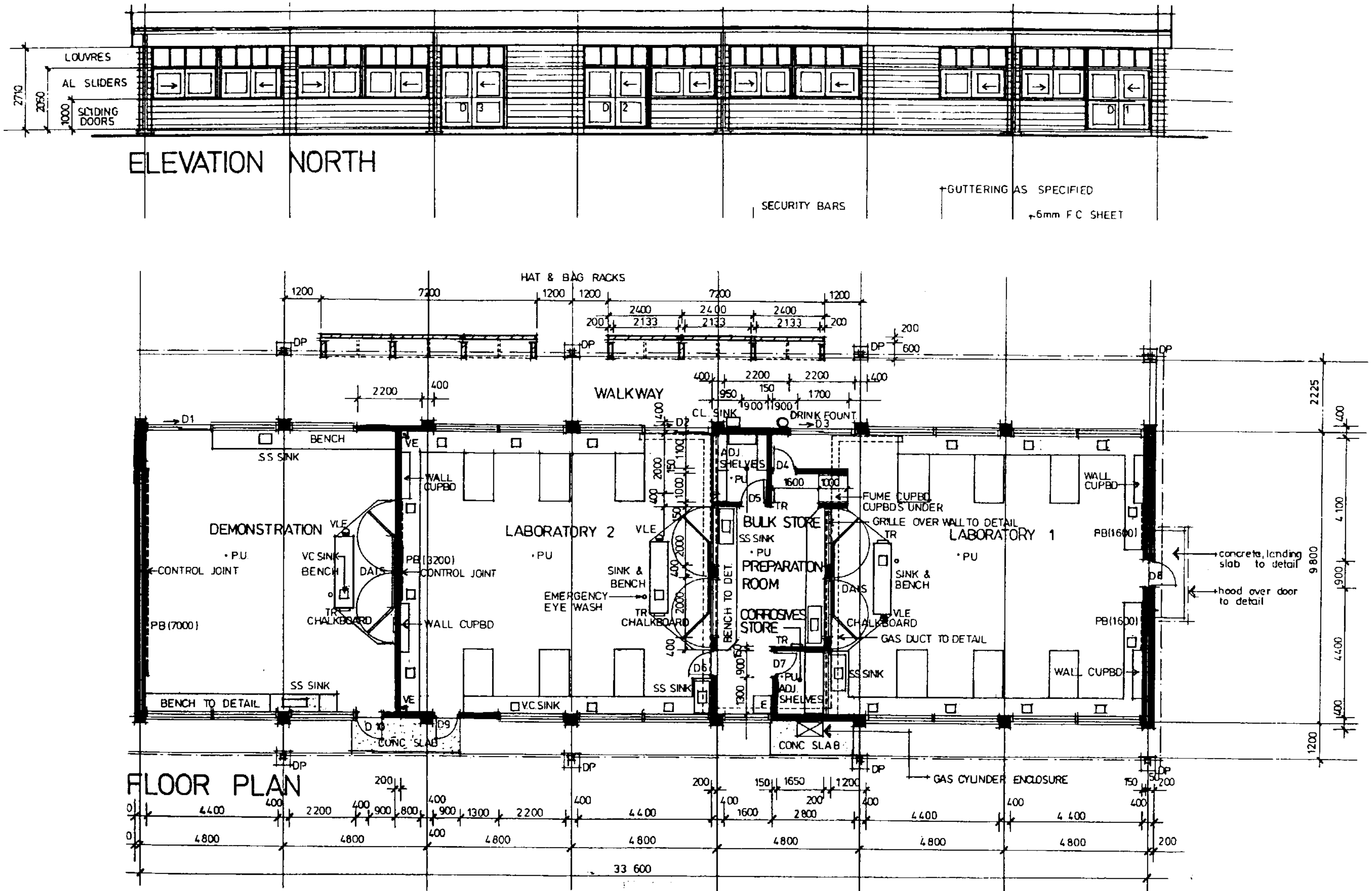
Plan adapted from UNESCO Mission Report on Caribbean Sub-Region on Program Request 5168 November 1991 by James Lewis.

'Z' TYPICAL STRUCTURAL DETAILS – CARIBBEAN PRIMARY SCHOOL



ST. KITTS – CARIBBEAN
BASSETERRE PRIMARY SCHOOL



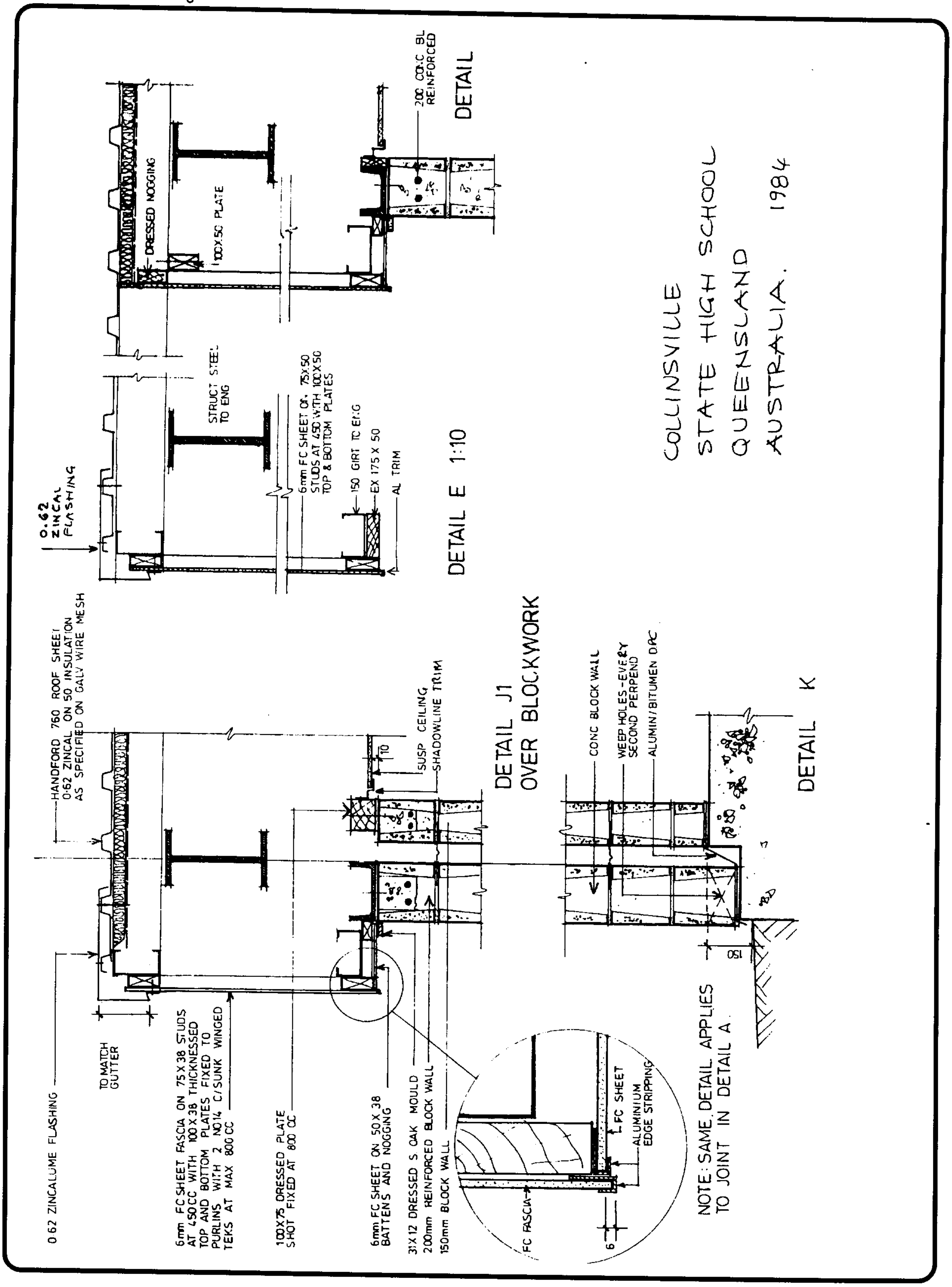

LOUVRES
AL SLIDERS
SLIDING DOORS
ELEVATION NORTH
SECURITY BARS
GUTTERING AS SPECIFIED
6mm F.C. SHEET
HAT & BAG RACKS
WALKWAY
DEMONSTRATION
LABORATORY 2
BULK STORE
PREPARATION ROOM
CORROSIVES STORE
LABORATORY 1
BENCH
SS SINK
WALL CUPBD
CONTROL JOINT
CHALKBOARD
EMERGENCY EYE WASH
SINK & BENCH
BENCH TO DETAIL
FUME CUPBD
CUPBDS UNDER
GRILLE OVER WALL TO DETAIL
GAS DUCT TO DETAIL
DRINK FOUNT
CL. SINK
ADJ. SHELVES
concrete landing slab to detail
hood over door to detail
CONC SLAB
GAS CYLINDER ENCLOSURE
FLOOR PLAN
33 600

School buildings are built in different styles.

- Roof pitch 5° to 15°.
- Concrete foundations.
- Concrete floor slab.
- Steel portal frames at 30 c.c. on pad foundations.
- Timber roof purlins, 150 x 50 @ 600 c.c. 170.
- Corrugated or pan type galv. steel roof sheeting.

Notes

- Foundation sizes to be adequate.
- Brace roof framing in plane of purlins.
- Fix steel ties between portals.
- Purlins (steel or timber).
- Bracing to portals in each plane.
- Purlin spacing too great.
- Fixing of roof sheet to purlin.



4.7.8 *Tonga*

TONGA TYPICAL SCHOOL BUILDING

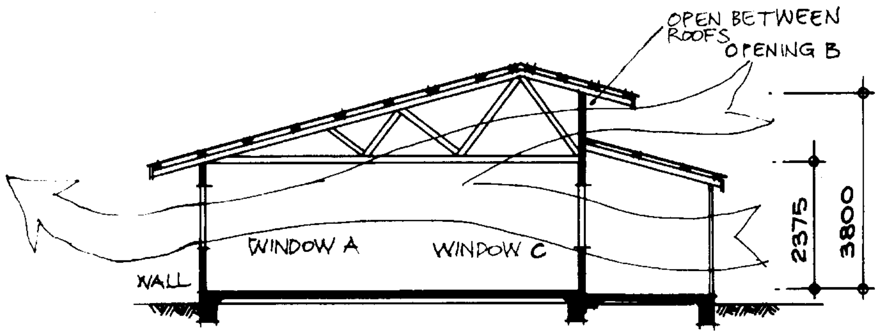
- Concrete floor slab
- Prefab wall frames with plywood wall cladding
- Prefab roof trusses
- Purlin Battens
- CGI roof sheet

- Wall panels 2.4 x 1.2 prefabricated and bolted.
- Roof trusses prefabricated and bolted.
- Factory Produced Components
- Note good cross ventilation.

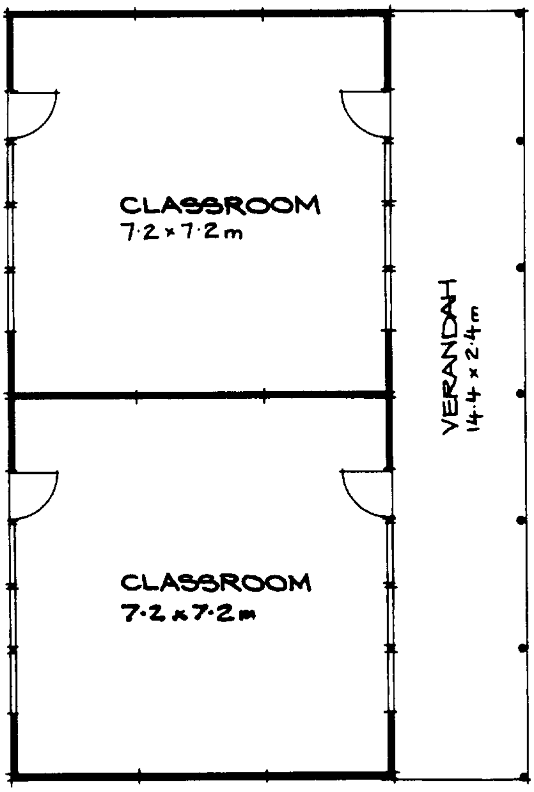
If opening at 'B' is open then internal pressure is sharply reduced.

If opening closed by windows then internal pressure adds to suction force.

- Check size/spacing or roof battens
- Check fixing of roof sheeting
- Check bracing in wall plane
- Check bracing in roof plane

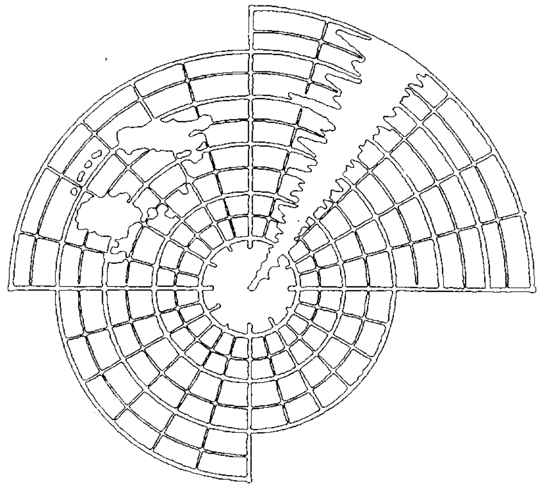


SECTION



PLAN - 2 CLASSROOMS

PREFABRICATED PANEL CONSTRUCTION.
TONGA - MINISTRY OF EDUCATION



5 INTRODUCTION TO WIND LOADS

CONTENTS

5.1 GENERAL COMMENTS

Before looking at details of buildings and how they should be designed and built or rehabilitated in order to withstand cyclonic winds, there must be some understanding of what forces a cyclone is going to apply to buildings as a whole, or to a component of the building, roof, wall, window or even just a barge flashing.

Unless designers have a quantitative estimate of the force on each part of the building it is impossible to even guess the number of screws or nails needed to fix a roof down, what size glass is needed in a window, or to be confident that the building being designed will survive a cyclone.

Cyclonic wind forces on a building act predominantly upwards and horizontal. A building must have a structural system, which will remain intact under these loads and transmit the wind forces to the ground through its structural members, connections and cladding without failure of these elements.

To provide structural adequacy and integrity during cyclonic winds the following properties must be designed and built-in throughout the structure.

These properties can be thought of as "The ABC of Cyclone-Resistant Construction".

A **Anchorage**

Every part of the structure MUST be anchored back to some secure point which is capable of resisting the applied forces. This is generally the foundations.

B **Bracing**

Every part of the structure MUST be held rigid so it cannot tilt, slide or rack.

C **Continuity**

Every part of the structure MUST be properly connected in a continuous line from roof cladding to the foundations.

If one takes the analogy that a building is a chain with a load applied at one end, then if a single link is missing or of inadequate strength, the chain will not support the load. This chain must extend from the point of application of the wind pressure down to the foundations.

It is important to remember this ABC of wind resistance, i.e., ANCHORAGE, BRACING and CONTINUITY. The roof framing should be anchored together, it should also be anchored to the supporting walls. The roofs should be braced to prevent lateral twisting, walls should be braced and stiff enough to resist loads, and continuity of fixings should be maintained from the roof cladding down to the foundation level. This will enable all of the building elements to carry out a "load sharing" role in resisting forces.

5.2 WIND LOADS

The selection of design figures for loads due to wind is a fairly involved process, particularly if an accurate figure for the wind load at any instant is required.

It is made complex by the following factors:

i. The gustiness of the real wind particularly under storm conditions.

Variations in gust speed during the peak 10 minutes of a cyclone can show dramatic changes in direction each few seconds, combined with rapid fluctuations in wind speed from say 20 kph to 200 kph from minute to minute or from second to second.

These dynamic effects place great dynamic stresses on the structural cladding especially at the edges and corners of roofs and walls.

ii. The load on any building is greatly affected by the shape of the land and the number and shape of any projections from the land, (i.e., trees, ridges, escarpments, other buildings, etc.) on the windward side of the building under consideration and to a far lesser extent the land shape etc. on the leeward side.

iii. The load on a particular building or part of that building can vary widely with fairly small variations in the shape of the building.

iv. The wind direction that can be expected during a cyclone cannot be predicted with any certainty, the factors will obviously be different on any one building for a different wind direction.

Therefore the problem of accurately predicting the exact maximum likely wind force on any building is extremely difficult and leaves the designer to follow code provisions for these loads and forces.

Codes are formed from the results of research both in the field and in various laboratories.

One can be fairly certain that if a building is designed to withstand the maximum forces laid down by the Code it will not suffer serious damage in a cyclone or other wind storm that could reasonably be expected to occur.

Further detailed information on wind forces, pressures and overall wind loads are set out later in this study where tables of likely loads are provided.

5.3 BRIEF COMMENTARY ON WIND FORCE EFFECTS

5.3.1 Wind Speed

The wind moves over the ground at a certain speed normally referred to in metres per second (m/sec), kilometres per hour (km/hr), or miles per hour (miles/hr). In a cyclone or typhoon as in all wind environments the wind fluctuates and changes speed rapidly so that in a period of one hour, the forward wind speed is less than the maximum wind speeds which are achieved over periods of a few seconds only. The fastest design wind speed, which is the wind speed used in cyclone wind design, is that which occurs in a three second wind gust. This is referred to as the design wind velocity speed (v). Design wind speeds are normally those which occur at a height of 30'0" (10.0 m) above the ground on an open, inland terrain (site terrain category 2), such as at an airport, and are based on a 50 year return of the wind event. This is the international datum for wind speed and wind force calculation.

5.3.2 Height

The wind speed and wind gust varies with height, being slower near ground level where the wind is slowed down by the roughness of the ground, and faster at high altitudes where there is less interference to the wind's forward speed. This effect can be measured at altitude intervals of 30'0" (10.0 m) and thus taller buildings are subjected to higher wind speeds than are low buildings. A design factor for different building heights has been established.

5.3.3 Wind Zones

Due to various geographical features, cyclonic storms occur with predictable frequency in different locations. Cyclones are at their strongest over landfall and once they have travelled up to 30 miles inland lose a substantial part of their force. By reviewing meteorological data of a country subjected to cyclones it is possible to define the zones which receive the strongest winds, strong winds and less strong winds.

5.3.4 Site Terrain Category

The smoother the ground surface the less friction there is for the wind and therefore faster wind speeds result at smoother ground levels. Ground roughness characteristics known as terrain categories have been defined. In general these can be ranked as follows, from fastest wind speeds to slowest: flat sea coast areas; exposed hills; level open ground; built-up suburban regions; forested areas and densely built-up city areas. A design factor for terrain categories has been developed and is shown on the diagrams.

5.3.5 Wind Pressure

The wind speed can be converted into the pressures exerted on a plane surface normal to the wind. Tables cover all commonly used units of measure for both wind speed and free stream dynamic pressure. This table may be used for conversion of wind speed into pressures.

5.3.6 Structural Wind Loads

Winds create both positive and negative pressures on buildings. The windward forces which are tending to push toward the surface of the building are considered to be *positive* external pressures. Those pressures which are caused by the aerofoil effects of wind blowing around the walls or over the roofs create a partial vacuum or a net *negative* (suction) external pressure tending to pull away from the surface of the building.

As well as these external effects, a building can be pressurised with internal pressure (or partial vacuum) if openings occur in the building envelope.

An opening can occur when a window breaks resulting in the immediate addition of the internal pressure to the external suction. If the building is not designed for both of these pressures, the building could "explode" when the window breakage develops the internal pressure.

It is the resultant sum of the positive and negative pressures which determines the total force on any plane of a building's exterior.

These outward bearing forces are particularly strong on roofs where positive and negative forces combine and under some circumstances create a force stronger than the wind force itself. The tables give the pressures for buildings open on both sides or on one side.

As the wind passes over or around objects such as tress, ridges, fences, buildings, cliffs and valleys, the wind becomes turbulent and causes local increases in air speed and wind pressure. The effect of these air pressures on the edges and perimeters of these obstructions can become much more severe than the normal wind pressure. These effects are catered for by allowing a local pressure co-efficient for critical areas of buildings. Figures show the affected local areas of a building and gives these factors. These loads are applied only in calculation of the forces on the cladding. See also notes in paragraph 5.3.11. hereafter.

5.3.7 Other Effects on Wind Speed

The wind speed is also affected by atmospheric pressure, the ambient temperature and air density. However, for this paper, these effects are not taken into account and the factor used is 1.0.

5.3.8 *Return Periods*

Selective increases can be made to the design wind forces to cater for the expected life of a building or to give a building a greater factor of safety.

If a building is to remain intact for a once in 100 year event, it should be expected to resist the worst wind speed that could occur or be exceeded in a 100 year period. This wind speed would be higher than the worst wind speed expected in a period of 50 years. Therefore, the 50 year wind and 100 year wind can be referred to as specific events. Since this wind could arrive at any time, it would damage all buildings designed for a lesser event.

A 500 year or 1,000 year event would be described as catastrophic and, since meaningful records are not known for these periods, assumptions of their forces can only be assessed.

5.3.9 *Post Disaster Functions*

Important buildings, such as hospitals, police stations, post and telecommunications buildings, electricity generation and control buildings and refuge shelters (such as schools) should be expected to survive severe events such as cyclones so that they are able to serve their "post disaster function" during the recovery period.

Whilst most buildings should be designed for a 50 year event, post disaster buildings should be designed for 100 year event. The increase in design loads for the 100 year event is approximately 20%.

5.3.10 *Cyclonic Overload on Materials*

In considering the ability of building materials and their fixings that resist the cyclone wind loads, it is important to remember that the materials have to resist the maximum design forces only for very short periods of approximately 3-5 seconds. These short term loads may occur many times over the duration of a storm.

Some materials are able to accept short term overload situations with enough flexibility to recover to their normal strength. As timber will flex and recover, an overload allowance of 100% is allowed in the design of timber members for 3-5 second wind gusts. Steel members are permitted on overload factor 33%. Brickwork, on the other hand, will not recover after cracking.

5.3.11 *Special Notes on Cladding Loads*

The building structure has to resist the overall structural wind load applied to the total building and in this situation there is some load sharing by the total structure as the worst wind loads do not envelope the whole building at one time.

However the wind loads, fluctuating in speed and direction every 3-5 seconds create a dynamic cyclical pressure on the cladding on the buildings' walls and roofs.

These loads are referred to as cladding loads. Dealing with the resistance of wind forces on claddings in low rise buildings is often left to the contractors and tradesmen.

It is only in recent decades that closer attention has been paid to these loads by professional Engineers, Architects, Researchers and Manufacturers.

The wind forces on claddings are most severe at edges and corners such as eaves, barges and ridges, often where inadequate fixings and protection expose weaknesses in cladding fixings.

Cladding loads in these areas can be 50% larger than the overall structural loads applied to the building as a whole.

It is important to design both claddings and their small fixings to resist these wind loads. This involves study and understanding the real cladding loads, the nature and strength of the cladding material, the resistance of individual small fixings (such as nails and screws and bolts) and the batten or rafter spacings which affect the load area and consequent uplift forces.

The tables hereafter offer advice in resolving these wind loads.

5.4 PROCEDURE TO DETERMINE WIND LOADS

The following procedure may be followed to design a building which will be resistant to damages in high winds.

1. *Collect the Facts*

a) Identify national wind zone.
b) Identify wind speed.
c) Identify height of building and coefficient.
d) Identify terrain category and coefficient.
e) Identify topographical effects (hills, escarpments, valleys).
f) Determine design pressure.

2. *Determine the Wind Forces*

a) Identify building dimensions, length, height, width, shape and slope of roof.
b) Determine wind pressure co-efficients for wall and roof loads, both structural loads and cladding loads, and slope of roof.
c) Calculate structural loads
   - on walls.
   - on roof.
   - on windows.
d) Calculate cladding loads on walls and on roof.

3. Determine Wind Loads

a) Work out actual loads.
b) Determine structural lines of forces.
c) Decide on lines of resistance –
- in wall plane.
- in roof plane.
- in floor plane.
- in roof framing.

4. Design Construction Details & Connections

a) Decide on details.
b) Design resistance members.
c) Design fixing details.
d) Decide on materials to be used.
e) Specify workmanship required.
f) Check load areas and overturning moments.

5. Checklist of Key Points

Some of the important points to be kept in mind as one works their way through this procedure are spelled out below:

a) The design wind applies to the wind speed at a height of 10 m on a terrain category 2 site (e.g. at 30'0" (10 m) on an airfield) and is based on a 50 year wind return.

b) If the site is more exposed (beside the sea) the design wind is higher. If the site is more protected (in city areas) the design wind is less.

c) If the building is higher than 30'0" (10 m) the design wind is higher. If the site is more protected (in city areas) the design wind is less.

d) The design wind is to be converted to free stream dynamic pressure (e.g. kgf/m^2, or pounds force per sq.ft. or kilopascals). This pressure becomes the design pressure.

e) This design pressure is increased or decreased by coefficients which provide the actual pressure applied to various parts of the building's walls and roof areas and depends on the wind direction, the disposition of openings in the building and the roof slope.

f) This pressure or suction force resulting from the design wind and the building shape is to be added to the internal pressure generated inside the building which tends to push the walls and roof outwards. The resulting total pressure is the force to be resisted by the structure of the building and is referred to as the "Structural Load".

g) In addition, the cladding materials (roof sheeting and wall materials) are subjected to local pressures tending to pull off the cladding. These forces effect the cladding only and do not affect the structure.

h) The cladding of the central wall and roof areas carry the same loads as the structural loads. However, perimeters of walls and roof areas carry a greater suction (50% greater). While the corners of the roof and sharp ridges and projections carry an even greater suction (100% greater). These forces are pressures affecting the fixing of the claddings to their immediate supporting members and are referred to as "Cladding Load".

The accompanying table gives a listing of the force of aerofoil effect at different wind speeds.

5.5 AEROFOIL EFFECT

TABLE 5
AEROFOIL EFFECT — "WHEN ROOFS FLY"
MACKS WIND MOVEMENT CHART

VELOCITY	*TYPICAL MOVEMENT*	*VELOCITY (miles/hr)*
0.00 m/sec	Dead calm - birds fly	
0.23 m/sec	Leaf moves	0.50 mph
0.50 m/sec	Leaf flies	1.15 mph
0.75 m/sec	Paper flies	1.80 mph
0 – 5 m/sec		0 – 11 mph
5 – 10 m/sec	Loose aluminium sheets fly	11 – 22 mph
10 – 15 m/sec	Loose galvanised iron sheets fly	22 – 33 mph
15 – 20 m/sec	Loose fibre cement sheets fly	33 – 45 mph
20 – 25 m/sec		45 – 56 mph
25 – 30 m/sec	Loose concrete and clay tiles fly	56 – 67 mph
30 – 35 m/sec	Roof sheets fixed to battens fly	67 – 78 mph
35 – 40 m/sec	DC3 aircraft take off speed	78 – 90 mph
40 – 45 m/sec	Roof tiles nailed to battens fly	90 – 100 mph
45 – 50 m/sec	Garden walls blow over	100 – 112 mph
50 – 55 m/sec	Unreinforced brick walls fail	112 – 123 mph
55 – 60 m/sec	Major damage from flying debris	123 – 134 mph
60 – 65 m/sec		134 – 145 mph
65 – 70 m/sec	100 mm thick concrete slabs move	145 – 156 mph
70 – 75 m/sec		156 – 168 mph
75 – 80 m/sec	150 mm thick concrete slabs move	168 – 179 mph
80 – 85 m/sec		179 – 190 mph
85 – 90 m/sec		190 – 201 mph
90 – 95 m/sec		201 – 212 mph
95 – 100 m/sec	200 mm thick concrete slabs move	212 – 224 mph

5.6 WIND SPEED CONVERSION

TABLE 6
CONVERSION OF WIND SPEED TO FREE STREAM DYNAMIC PRESSURE

SPEED				*FREE STREAM DYNAMIC PRESSURE*			
m/sec	*knots*	*miles/hr*	*km/hr*	*lbf/ft²*	*kgf/m²*	*N/m²*	*kPa*
0.278	0.540	0.6212	1.000	0.001	0.005	0.047	0.00005
0.447	0.868	1.000	1.609	0.003	0.012	0.122	0.0001
0.514	1.000	1.150	1.850	0.003	0.016	0.162	0.0002
1.000	1.942	2.237	3.600	0.013	0.063	0.613	0.0006
1.277	2.480	2.856	4.597	0.021	0.102	1.000	0.001
4.000	7.770	8.947	14.40	0.205	1.000	9.808	0.010
8.835	17.162	19.762	31.81	1.000	4.883	47.85	0.048
10.000	19.425	22.368	36.00	1.282	6.255	61.30	0.061
20.0	38.85	44.74	72.02	5.124	25.02	245.2	0.245
30.0	58.28	67.10	108.0	11.53	56.29	551.7	0.552
35.0	67.98	78.29	128.0	15.69	76.63	750.9	0.751
40.0	77.70	89.47	144.0	20.50	100.0	980.8	0.981
40.3	78.28	90.14	145.1	20.81	102.1	1000.0	1.000
45.0	87.41	100.66	162.0	25.94	126.7	1241.0	1.241
50.0	97.12	111.84	180.0	32.03	156.4	1532.0	1.532
55.0	106.84	123.02	198.0	38.75	189.2	1854.0	1.854
60.0	116.55	134.21	216.0	46.12	225.2	2207.0	2.207
65.0	126.26	145.39	234.0	54.13	264.3	2589.0	2.589
70.0	135.98	156.57	252.0	62.73	306.5	3004.0	3.004
75.0	145.69	167.76	270.0	72.06	351.8	3448.0	3.448
80.0	155.40	178.94	288.0	81.99	400.3	3923.0	3.923
85.0	165.11	190.13	306.0	92.55	451.9	4429.0	4.429
90.0	174.83	201.31	324.0	103.80	506.7	4965.0	4.965
95.0	184.54	212.50	342.0	115.60	564.4	5532.0	5.532
100.0	194.55	223.68	360.0	128.10	625.5	6130.0	6.130

FORMULAE

$P = 0.613\ V^2$ N/m² (Pa) (for V in m/sec)
$P = 0.0625\ V^2$ kgf/m² (for V in m/sec)
$P = 0.00256\ V^2$ lbf/ft² (for V in miles/hr)

where: P = Free Stream Dynamic Pressure
V = Basic Wind Speed

STANDARD UNITS

m/sec = metres per second
miles/hr (or mph) = miles per hour
km/hr = kilometres per hour
lbf/ft² = pounds force per square foot
kgf/m² = kilograms force per square metre
N/m² = Newtons per square metre
kPa = kiloPascals per square metre

5.7 WIND LOADS

Although damage to buildings during cyclones is often caused by a combination of wind and flood water, it is the effect of destructive high winds that concerns cyclone resistant design most.

Before proceeding to discuss the calculation of Design Wind loads on a building, it is of value to briefly discuss how the wind acts on a structure.

When the wind is slowed down or changed in direction as it passes a structure, pressures are developed which act on the surfaces of the structure. These pressures may be positive or negative (suctions).

5.7.1 *Types of Force*

There are four main types of force induced in a structure by air moving past.

(i) Dynamic free-stream reference pressure
(ii) Surface wind pressure distribution
(iii) Aerodynamic lift force
(iv) Aerodynamic drag force

(i) Dynamic Free-Stream Reference Pressure

Dynamic pressure is the free-stream pressure energy in the approaching wind.

(ii) Surface Wind Pressure Distribution

a) *Attached Flow* over windward surfaces can create both positive and negative pressures.

b) *Separated Air Flow* in the wake of a building always creates a negative pressure.

(iii) Aerodynamic Lift Force

Aerodynamic lift force is the force acting on a building normal to the direction of the approaching air flow. The aerodynamic lift force is responsible for large uplift forces on roofs and cross-wind forces on tall buildings.

(iv) Aerodynamic Drag Force

Aerodynamic drag force is the force acting on a building in the direction of the approaching wind.

5.7.2 *Roofs*

Wind pressures on low pitch roofs experience negative pressures (or suctions) and will act upwards at right angles to the roof. Pressures will generally be highest near the windward edge of an area of roof.

TABLE 7
VERTICAL AND HORIZONTAL FORCES % OF INCLINED FORCES

ROOF SLOPE DEGREES	*VERTICAL COMPONENT*	*HORIZONTAL COMPONENT*
5°	100%	9%
10°	99%	17%
15°	97%	26%
20°	94%	34%
30°	87%	50%
40°	77%	64%

On a gable roof, barges, verges, eaves and corners experience strong negative pressures, whilst on a hip roof, the ridge and ridge hips carry the strong negative pressures (suction).

The inducement of suction, particularly on the front edge of the roof does not require any opening in the building to generate it. Consequently, it is possible for a roof to be sucked off without any openings in the building at all.

The slope of the roof significantly effects the proportion of vertical uplift forces to horizontal forces acting on a roof. Low pitched roofs of 0° to 10° experience almost 100% suction, whilst in roofs of 30° pitch or more, the roof experiences a significant percentage of dynamic pressure tending to hold the roof on, but the turbulent area moves from the eaves to the leeward side of the ridges.

5.7.3 *Walls*

Pressures on walls vary with wind direction and may range from positive (pressure) to negative (suction).

By introducing openings into the front of a building, an internal pressure is produced. This compounds the suction forces on the roof.

5.8 DIAGRAMS OF THE EFFECTS OF WINDS

The following diagrams illustrate the effects of the wind on a building and shows how the wind affects the various walls and roof slopes.

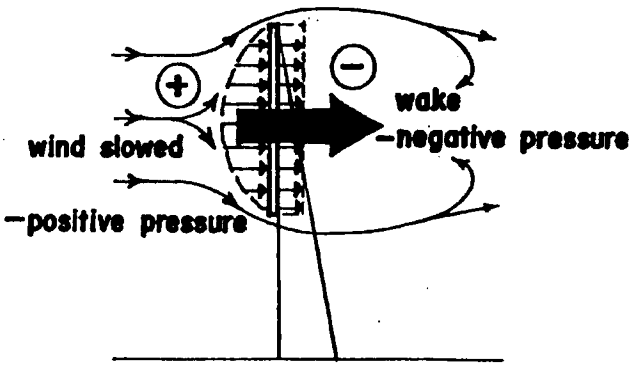
The wind forces create pressure loads on some walls and roof slopes and suction loads on others.

In addition, internal pressure is acting on the walls and ceilings internally. If a door or window is open or broken then these internal forces change from pressure to suction in some cases.

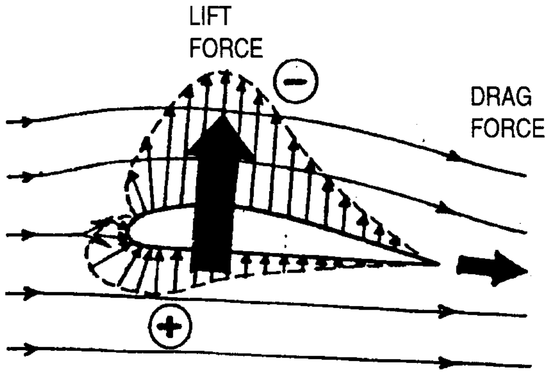
All of the above forces are acting on the building simultaneously and in addition, the size of the forces fluctuate rapidly depending on the size, speed, direction and pressure of the cyclone itself.

The final few diagrams show the resistance mechanisms required to resist the wind forces actions on the building elements. More detail discussion on these connections will be provided in later sections in this paper.

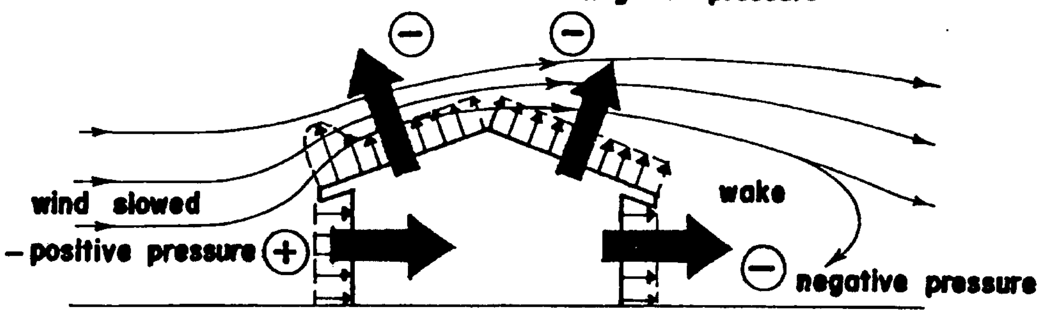
WIND ACTION ON BUILDINGS AND ROOF STRUCTURE



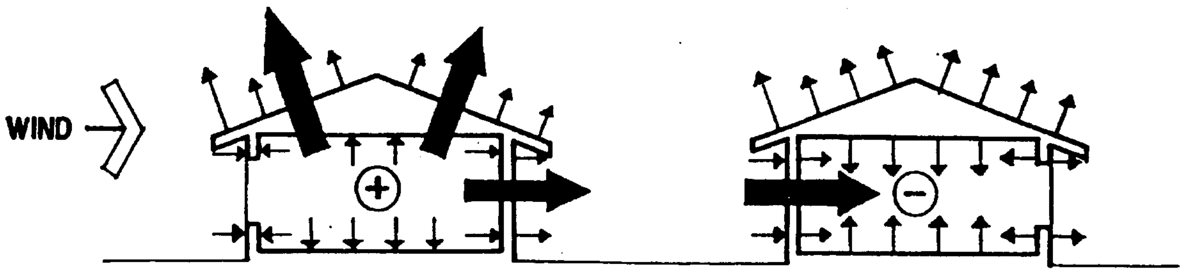
HOARDING – experiences drag force and overturning



AEROPLANE WING – experiences lift force and little drag force

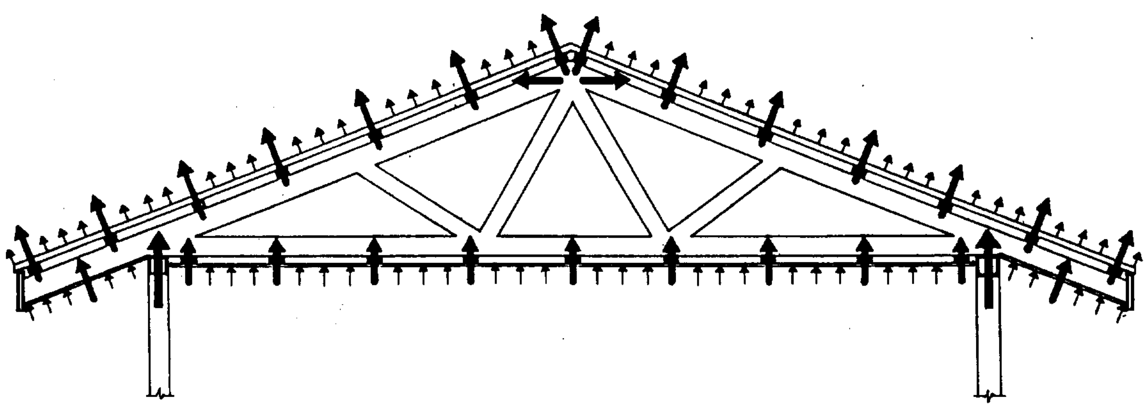


HOUSE – lift forces, drag forces, overturning forces

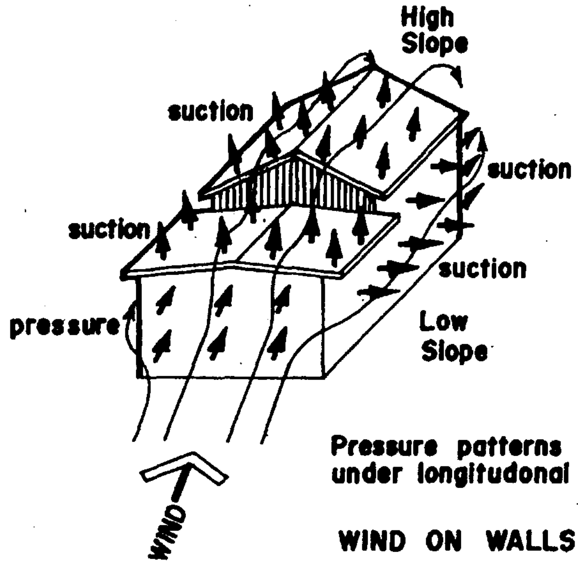


opening in windward wall
– positive internal pressure

opening in leeward or side wall
–negative internal pressure

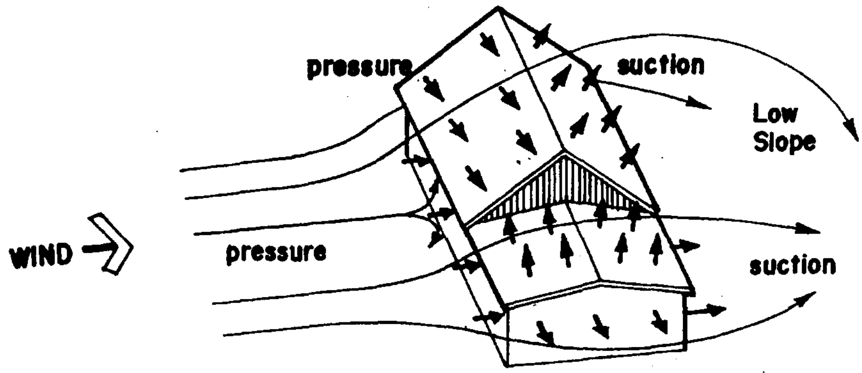


WIND ACTION ON BUILDINGS



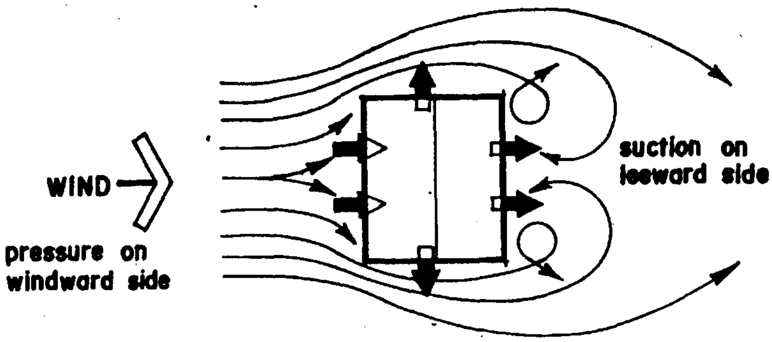
Pressure patterns on a building under longitudonal wind.

WIND ON WALLS

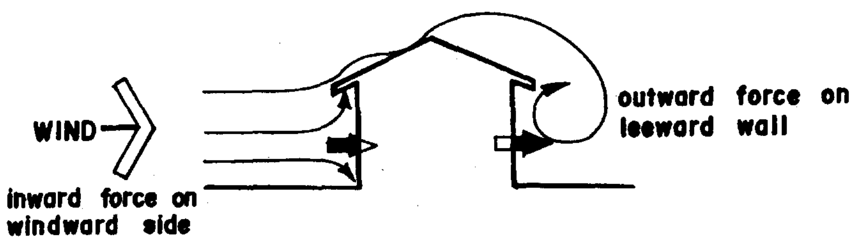


Pressure patterns on a building under lateral wind.

WIND ON WALLS

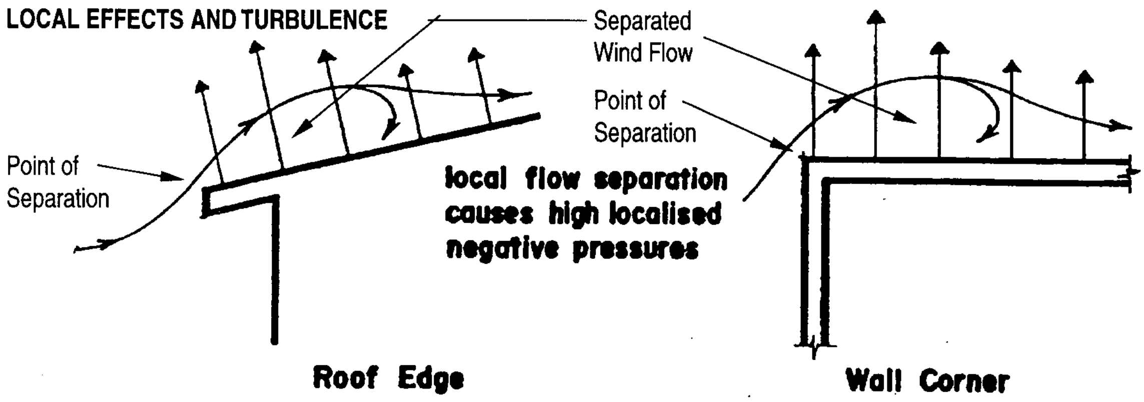


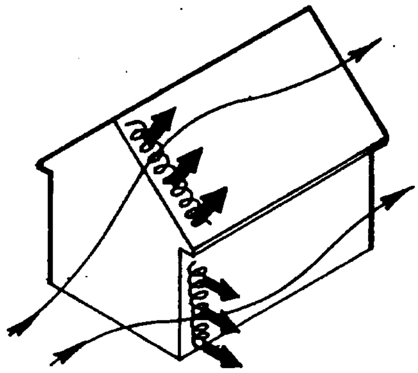
Plan of air flow around a building.



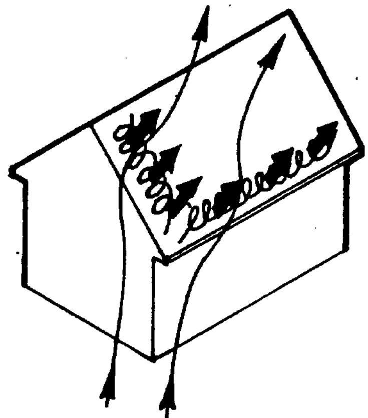
Elevation of air flow over a building.

LOCAL EFFECTS AND TURBULENCE

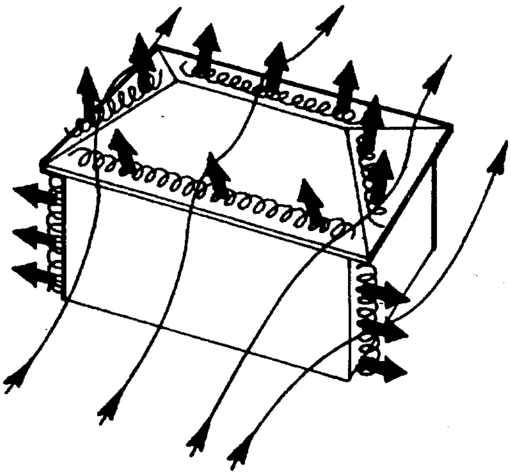




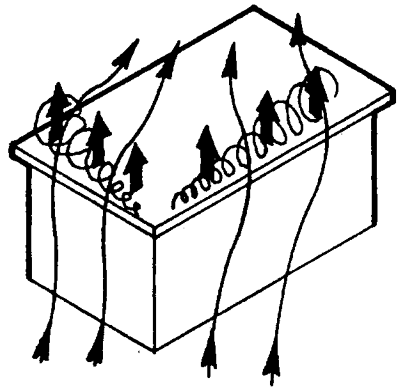
wind flow end on – gables and corners experience locally stronger uplift forces



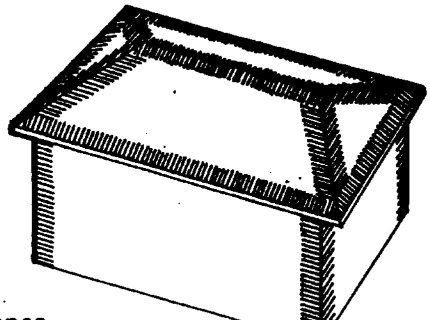
wind flow onto corner – gables and eaves experience locally stronger uplift forces



wind flow onto side – eaves ridge and hips experience locally stronger uplift forces



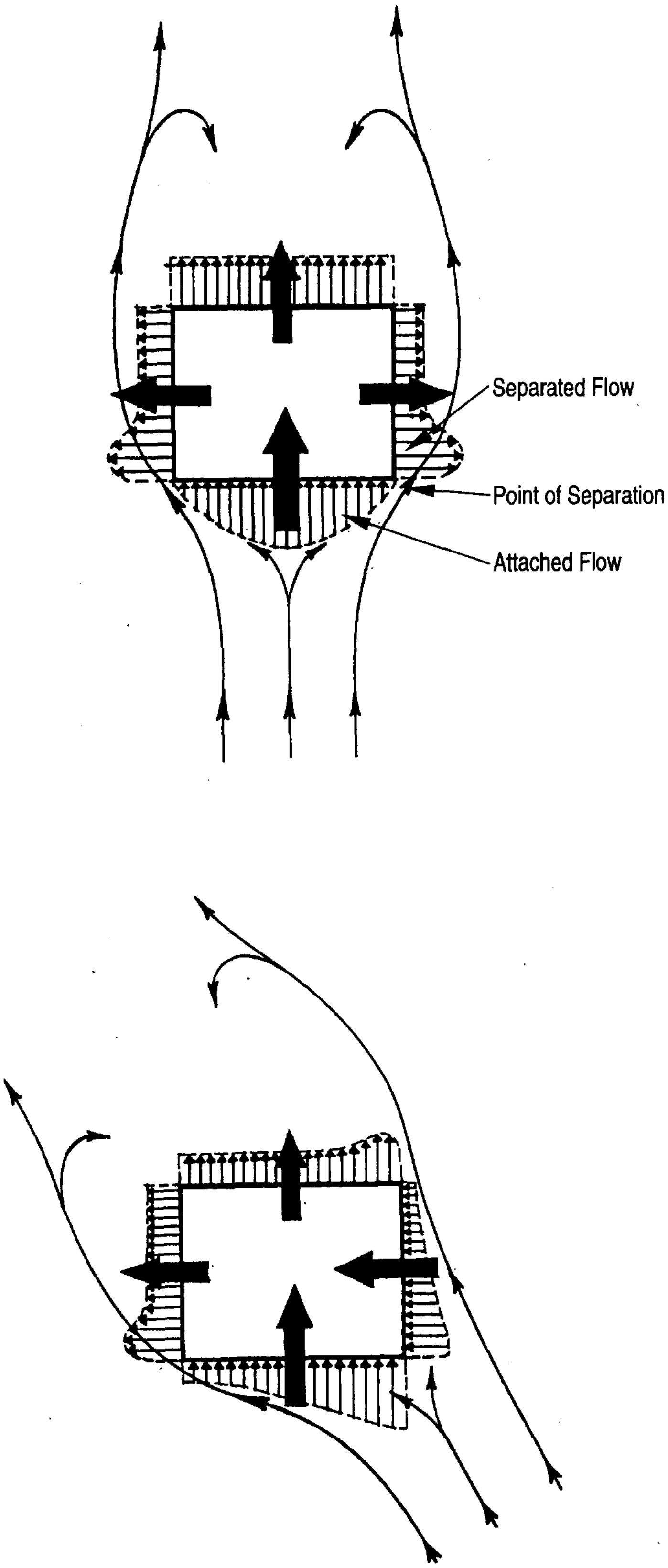
wind flow onto corner of flat roof – eaves and barges experience locally stronger uplift forces

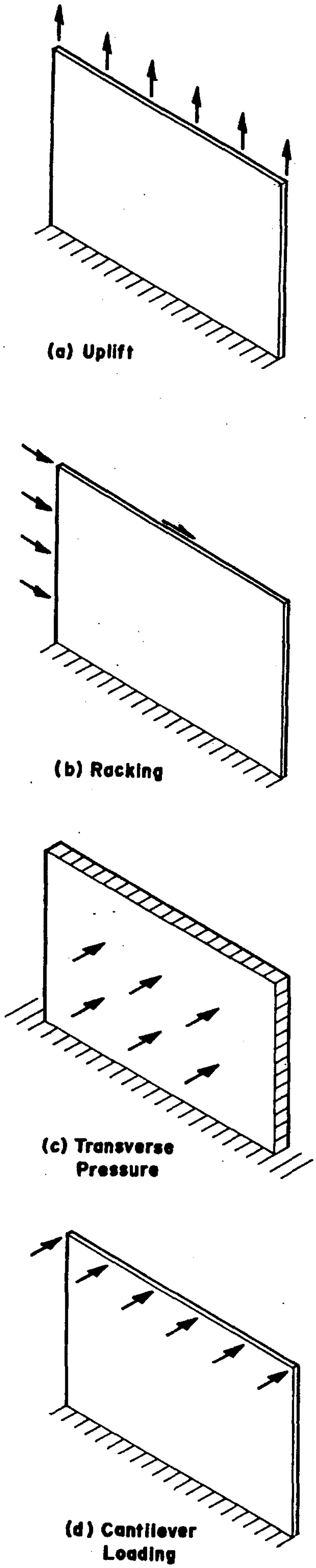


regions of roof and walls that experience higher local uplift forces

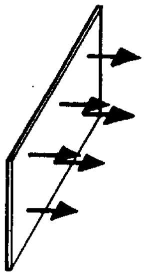
EFFECTS OF TURBULENCE AT EDGES AND CHANGES IN ROOF SLOPE

WIND ACTION ON WALLS

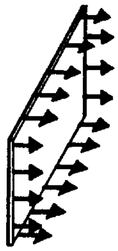




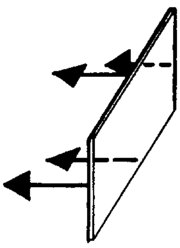
SUCTION PRESSURE ON WALLS



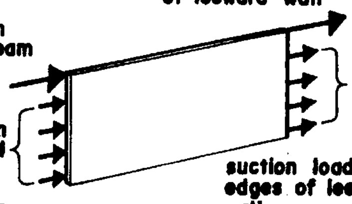
Suction on side and leeward walls sucking cladding off and wall out.



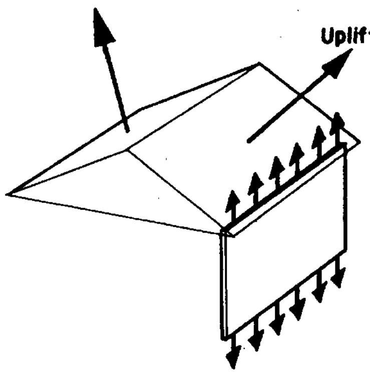
Suction loads transferred to wall edges : eaves, floor, intersecting walls.



Leeward and side walls require holding back at ceiling line, floor line, crosswalls.

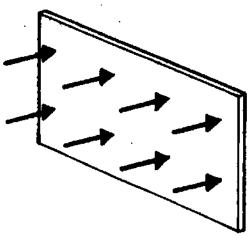


RACKING FORCES ON CROSSWALLS

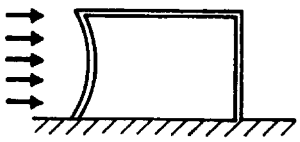


UPLIFT FROM ROOF TRANSFERRED THROUGH WALLS
(Through connection in walls if no tie rods direct from rafters to footing.)

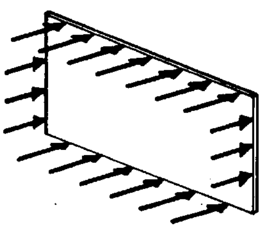
PRESSURE ON WALLS



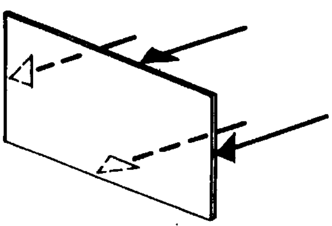
Pressure on windward walls blowing cladding and wall in.



Windward wall bends under wind load : held at edges.

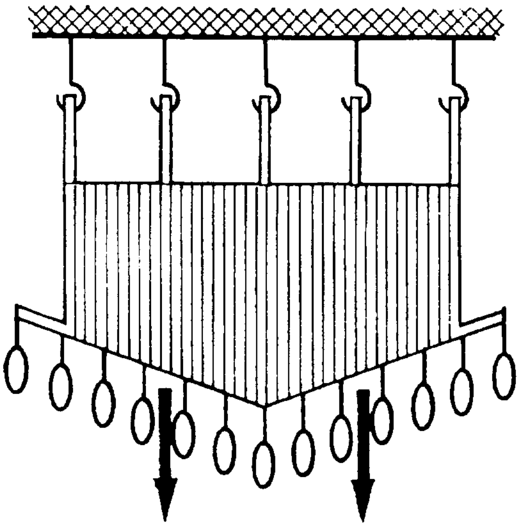


Windward wall load transferred to wall edges : eaves line, floor line, intersecting walls.

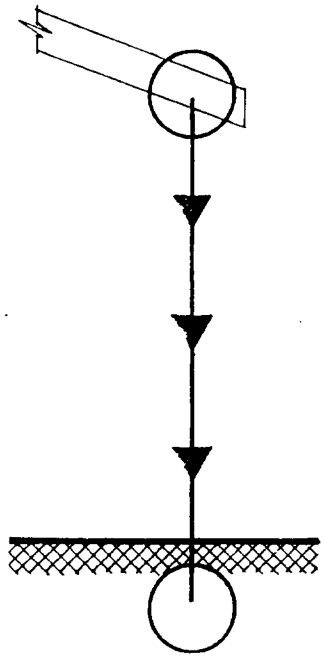


Windward wall requires support from ceiling line, floor line, crosswalls.

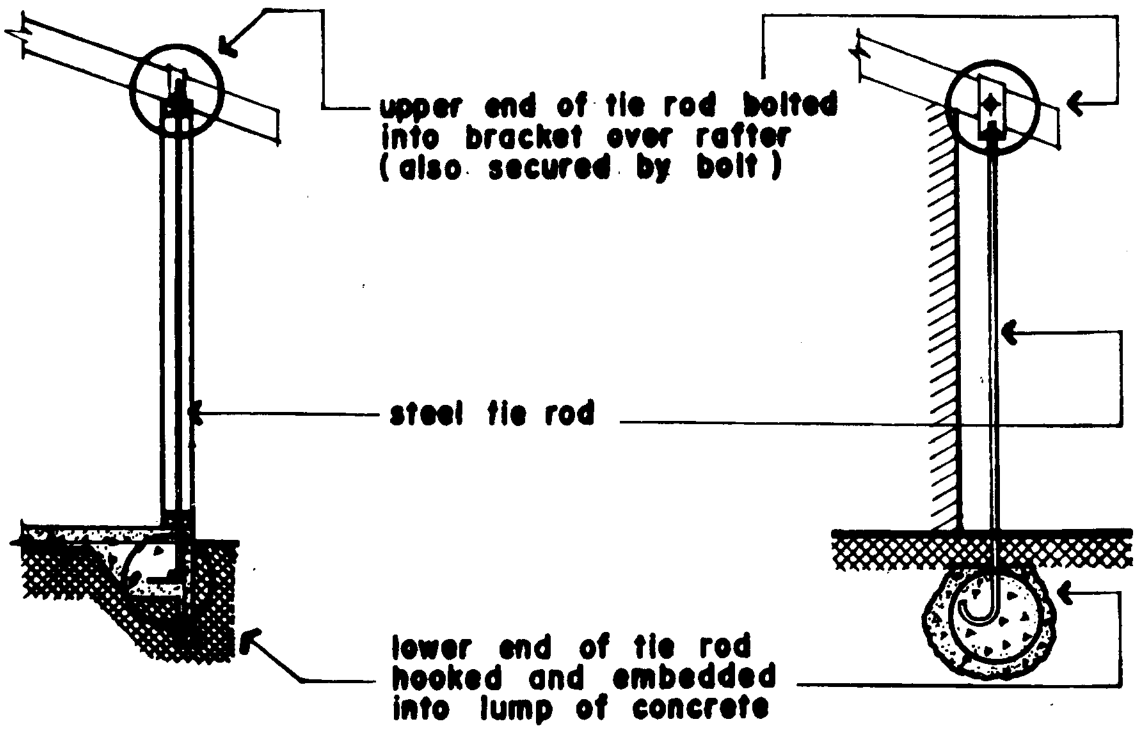
SIMPLE ROOF HOLD-DOWN SOLUTIONS



Uplift forces on a roof are equivalent to hanging bags of cement at close centres from the roof battens, with the house inverted and suspended from its footings.



The roof rafters must therefore be strongly anchored to the ground.

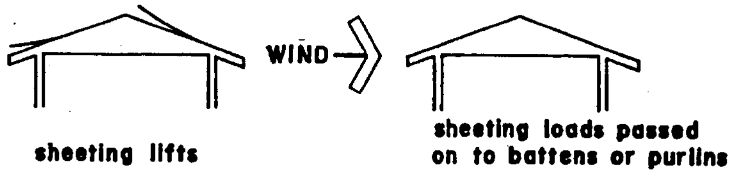


Steel rod bolted over rafter and embedded into concrete footings.

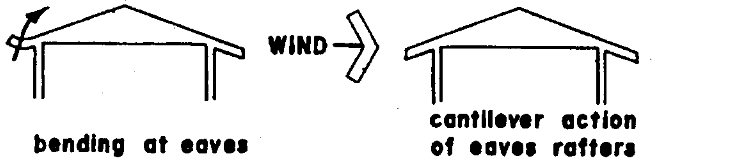
CONCRETE WEIGHT EQUALS NETT UPLIFT LOADS

WIND ACTION | **RESISTANCE MECHANISM**

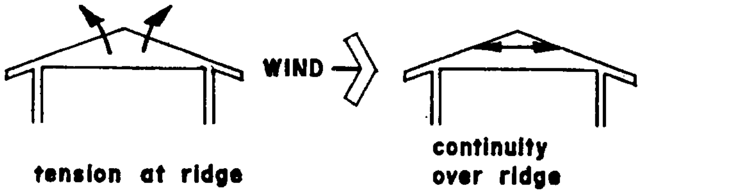
ROOFS



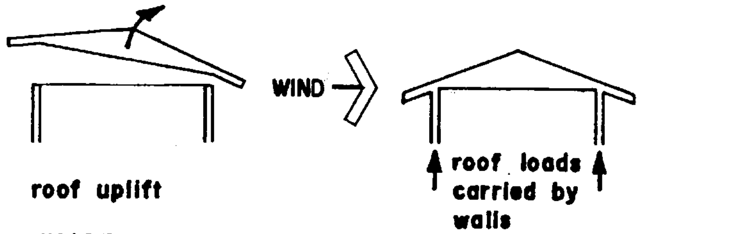
BETTER FIXING NEEDED FOR ROOF SHEETING TO SUPPORTS



SIZE OF RAFTER AND FIXING TO BE ADEQUATE

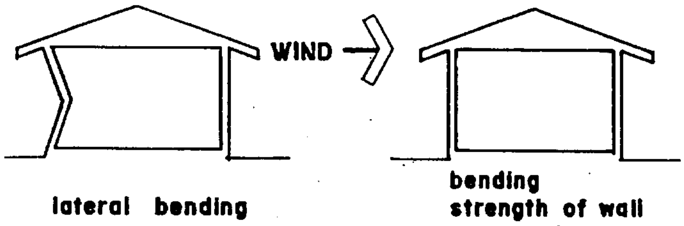


IMPROVE FIXING AT RIDGE BY BETTER FIXING BETWEEN RAFTERS AND ADEQUATE ROOF FRAMING

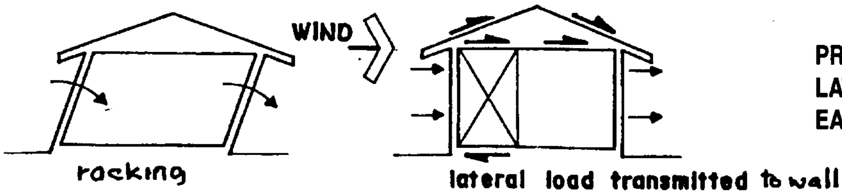


FIX ROOF FRAMING DOWN THROUGH WALLS

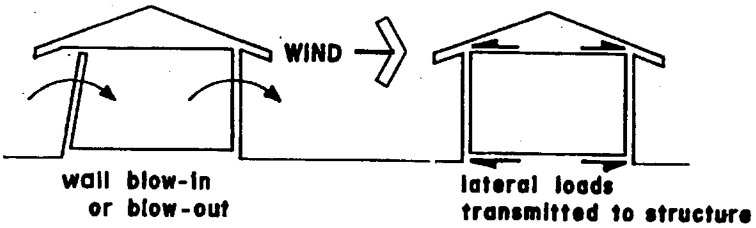
WALLS



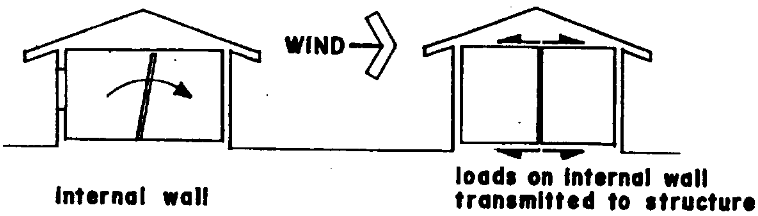
WALL STRUCTURE TO BE STIFF FOR FULL HEIGHT. TAKE CARE AT WINDOW SILLS AND WINDOW HEADS



PROVIDE ADEQUATE LATERAL BRACING ON EACH AXIS



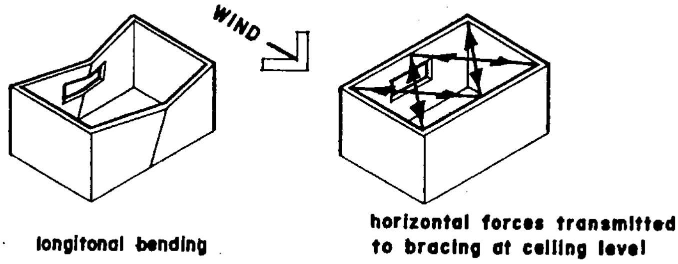
PROVIDE ADEQUATE DIAPHRAGM ACTION



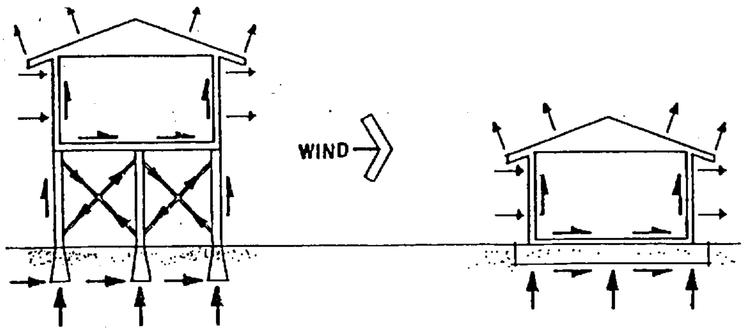
FIX INTERNAL WALLS TO CEILING TO AVOID VERTICAL CANTILEVERS

WIND ACTION

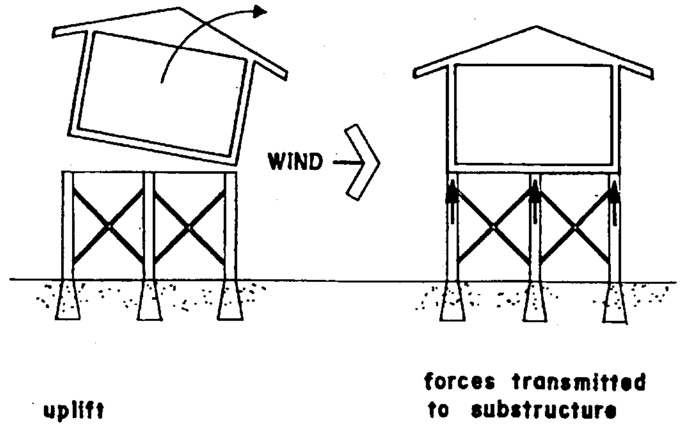
DIAPHRAGM NEEDED AT CEILING OR BEAM SUPPORT TO WINDWARD WALL



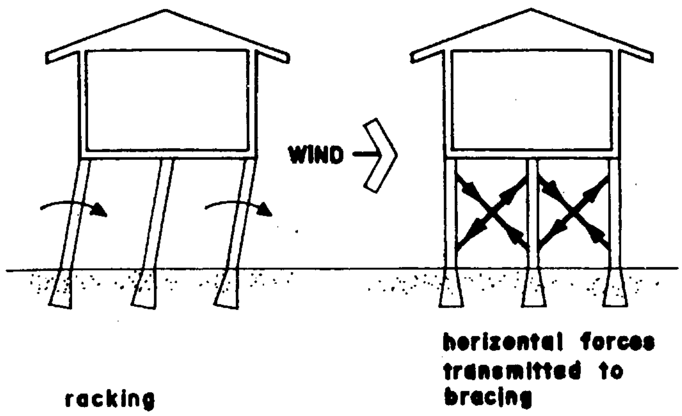
LINES OF TRANSMISSION OF WIND FORCES FOR BOTH DOUBLE AND SINGLE STORY BUILDINGS



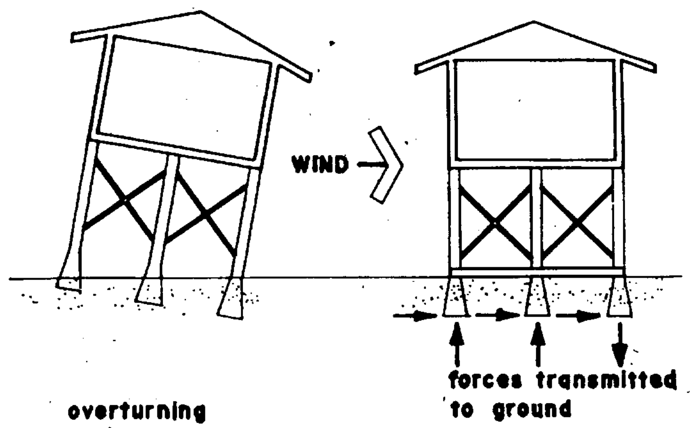
PROVIDE ADEQUATE FIXING OF UPPER STOREY TO SUB-SUPPORTS



BRACE SUB-FRAME



DESIGN ADEQUATE FOUNDATIONS AND CONSIDER FLOOR SLAB TO UNDERCROFT



5.9 SITE EXPOSURE - TERRAIN CATEGORY OR GROUND ROUGHNESS

Dispersal of Tropical Cyclones over tropical oceans is rare. Most are absorbed in to the middle or upper atmosphere or alternatively, gradually weaken over land mass.

Cyclonic winds normally lose intensity once the cyclone has passed over the coastline. The degree of this loss of intensity depends on many factors not the least of which are:

a. The degree of exposure, and;

b. Surface 'roughness',
(Cyclonic winds lose intensity much faster over terrains littered with many permanent obstructions than over flat open plains.)

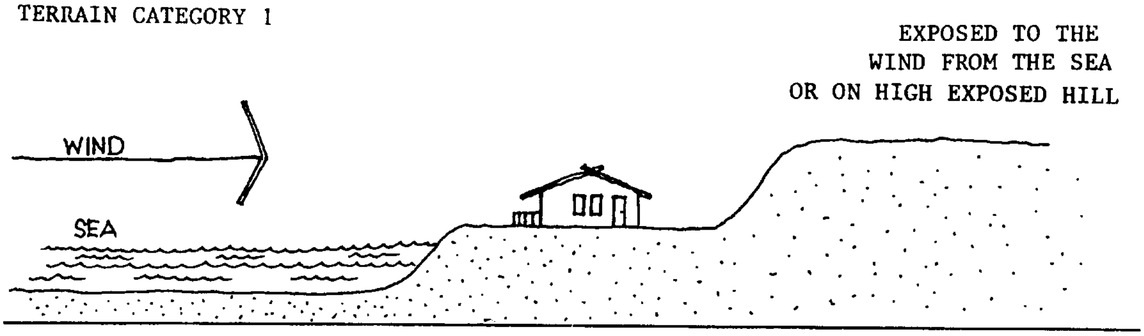
So as to facilitate design, different types of terrain and collections of buildings are categorized in what are termed 'terrain categories'.

Terrain Category One

'Exposed open terrain with few or no scattered obstructions and in which surrounding objects are less than 1.5 metres high'. (Open sea coast, flat treeless plains.)

TERRAIN CATEGORIES - ROUGHNESS OF SITE

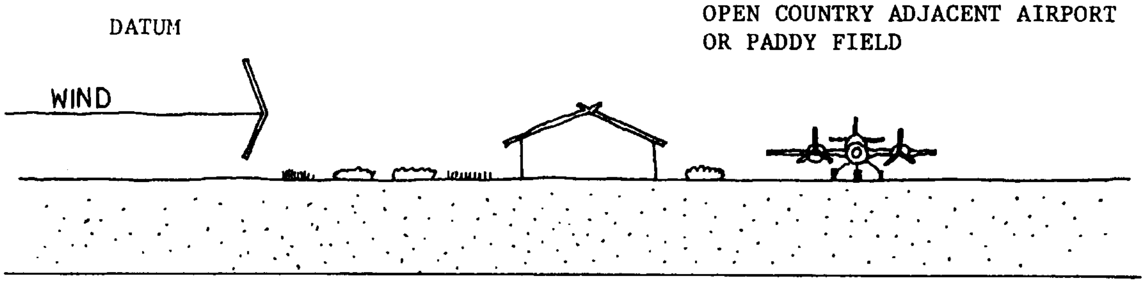
TERRAIN CATEGORY 1



Terrain Category Two

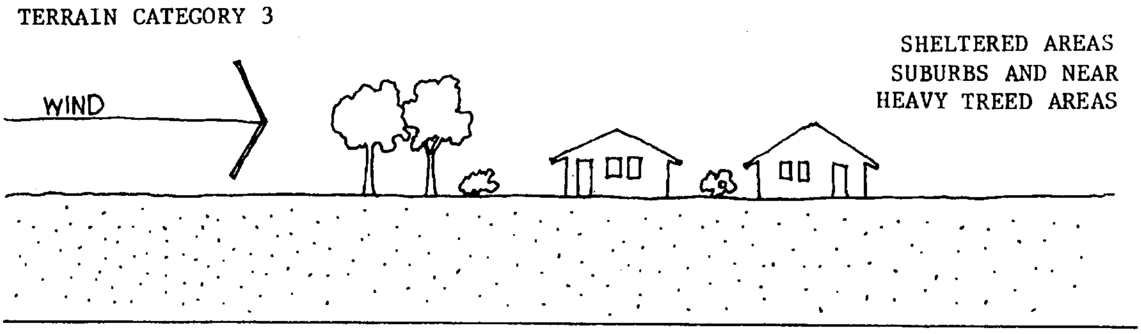
'Open terrain with well scattered obstructions having heights generally 1.5 to 10 metres'. (Airfields, open park land, sparsely built up outskirts of town.)

TERRAIN CATEGORY 2



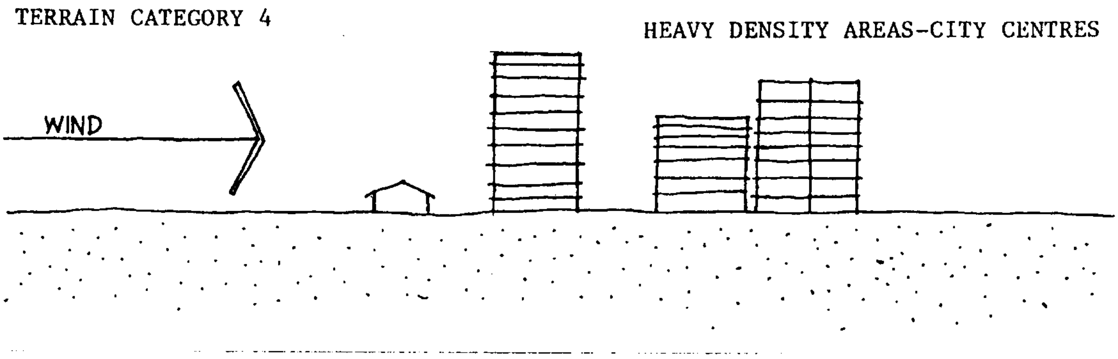
Terrain Category Three

'Terrains of numerous closely spaced obstructions being the size of domestic houses'. (Well wooded areas, suburbs and towns.)



Terrain Category Four

'Terrains of numerous large, high closely spaced obstructions'. (Such as those found in dense city centres.)



The purpose of this categorisation is to obtain a multiplying factor (itself relative to building height) for each terrain category (available in tabulated form ... "British Wind Code CP3" Section 5.10) by which the basic wind velocity is multiplied to obtain the Design Wind Velocity.

5.10 DESIGN LOADS

There are three types of specific loads that affect a structure:

(i) Dead loads;
(ii) Live loads, and;
(iii) Loads applied to a structure during the course of a natural disaster (such as strong wind, flood and earthquake). For the sake of this paper we shall confine our comments to wind loads.

5.10.1 Dead Loads

The load due to the weight of the structure is called the dead load.

Dead load = cladding + battens + rafters + stud walls + flooring + bearers + posts + footing (and so on).

Examples of typical dead loads for some structural materials are set out in the accompanying Table 8.

(The following table was originally prepared by Engineer David. H. Lloyd)

TABLE 8
TABLE 'A' - DEAD LOADS

ELEMENT	*UNIT OF FORCE PER SQM (KN/sq.m))*	*TOTAL OF CONTRIBUTING UNITS OF FORCE PER SQM (KN/sq.m)*	*TOTAL OF CONTRIBUTING ELEMENTS IN POUNDS PER SQUARE FEET*
FLOORS			
TIMBER 20 mm T&G hardwood boards on 100 x 50 mm joists at 450 mm cc on 100 x 75 mm bearers Average Load. T&G Boards. Joists. Bearers.	 0.259 kN/sq.m 0.115 kN/sq.m 0.014 kN/sq.m	0.388 kN/sq.m	(8.2 psf)
CONCRETE 100 mm RC slab. 150 mm RC slab.	 2.40 kN/sq.m 3.60 kN/sq.m		 (50 psf) (75 psf)
ROOFS			
0.80 mm (22 g) GI sheet on 100 x 50 mm rafters at 450 mm cc - GI sheet including Joint Laps. Rafters.	0.096 kN/sq.m 0.115 kN/sq.m	0.211 kN/sq.m	(4.4 psf)
0.80 mm Aluminium sheet on 100 x 50 mm rafters at 450 mm cc. Aluminium sheets. Rafters.	 0.029 kN/sq.m 0.115 kN/sq.m	0.144 kN/sq.m	(3.0 psf)
Corrugated AC on 100 x 50 mm rafters at 450 mm cc. AC. Rafters.	 0.134 kN/sq.m 0.115 kN/sq.m	0.249 kN/sq.m	(5.2 psf)
Terra Cotta Tiles on 100 x 50 mm rafters at 450 mm cc with 50 x 25 mm tile battens. Tiles. Rafters. Battens.	 0.575 kN/sq.m 0.115 kN/sq.m 0.024 kN/sq.m	0.714 kN/sq.m	(15 psf)
Concrete Tiles on 100 x 50 mm rafters at 450 mm cc with 50 x 25 mm battens at 300 mm cc. Tiles. Rafters. Battens.	 0.527 kN/sq.m 0.115 kN/sq.m 0.024 kN/sq.m	0.666 kN/sq.m	(14 psf)
CEILING SYSTEMS			
(Excluding Timber Framing) 10 mm Fibrous Plaster. 13 mm Gypsum Plasterboard. 5 mm AC sheeting. Suspended Acoustic tiles.	 0.086 kN/sq.m 0.215 kN/sq.m 0.072 kN/sq.m 0.033 kN/sq.m		 (1.8 psf) (4.5 psf) (1.5 psf) (0.7 psf)
WALLS			
(Area in wall, not plan area). 75 x 50 mm studs at 450 mm centres + 6 mm AC both sides. 75 x 50 mm studs at 450 mm centres + 13 mm gypsum board each side. 110 mm brick per skin. 200 mm hollow concrete block.	 0.320 kN/sq.m 0.330 kN/sq.m 2.151 kN/sq.m 1.912 kN/sq.m		 (45 psf) (40 psf)

5.10.2 *Live Loads*

The loads applied either continuously or periodically to a structure are called live loads.

Live loads = Furniture + people + machinery (and so on).

Examples of typical live loads applicable to school buildings to follow on table.

TABLE 9
TABLE 'B' - LIVE LOADS

SCHOOLS AND UNIVERSITIES	*UNIFORMLY DISTRIBUTED*		*CONCENTRATED LOAD*	
Building Element	*Load kPa*	*psf*	*Load kN*	*lbs*
Assembly Rooms	4.0	80	2.7	54
Class Rooms	3.0	60	2.7	54
Corridors	4.0	80	4.5	90
Dining Rooms	2.0	40	2.7	54
Kitchen	5.0	100	—	
Dormitories				
1 and 2 storeys	1.5	30	1.8	
over 2 storeys	2.0	40	1.8	
Gymnasiums	5.0	100	—	
Laboratories	3.0	60	6.7	
Toilet Rooms	2.0	40	1.8	

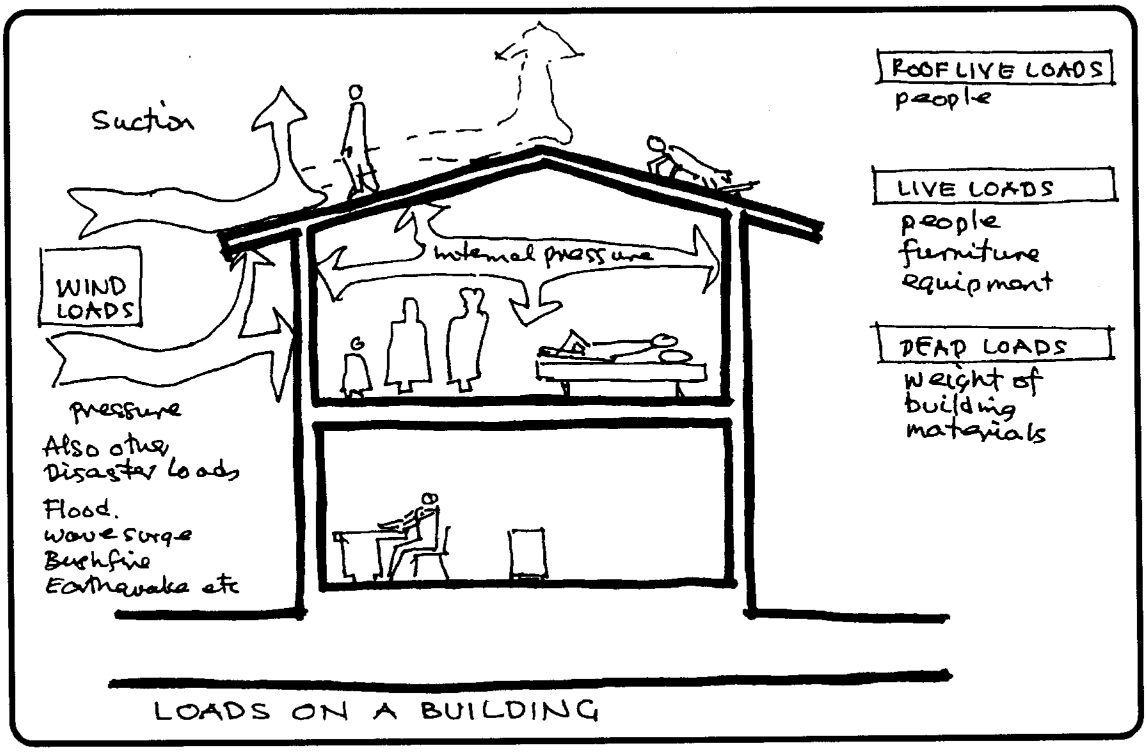
5.10.3 *Minimum Live Roof Loads*

The minimum live roof load is the load due to maintenance and construction and not due to the wind.

TABLE 10
MINIMUM LIVE ROOF LOADS

	ON ROOFS LARGER THAN 14 SQ.M	*ON ROOFS LESS THAN 14 SQ.M*
LIVE LOAD	= 0.25 kPa (5lb/ft^2)	= (1.8/A) x 0.12 kPa

A = the plan projection of the surface area of the roof in square metres.



5.11 BRITISH WIND LOAD TABLES

Following is a copy of the procedure for the calculation of Design Wind loads for selected locations. The procedure is an interpretation of the British Standards Institution Code BSI-CP3, Chapter V, Part 2, September 1972.

Ideally, the calculations should include all external walls and both the windward and leeward slope of the roof. But, since the windward slope of the roof and the side walls generally experience the greatest negative pressures, any building designed to withstand pressures experienced in these locations will more than adequately withstand those on the leeward slope or remaining external walls.

5.12 WIND LOADS ON BUILDINGS

5.12.1 British Standards Institution

"Basic data for the Design of Buildings, Chapter V – Loading," BSI - CP3, Chapter V, Part 2, September 1972.

This paper is attempting to provide simple tables that are useful in calculating forces on simple buildings, that is; buildings of domestic scale: one, two and perhaps three levels in height.

This should cover the majority of buildings on the planet and perhaps well over 90% of the residential buildings.

These buildings are those which receive the least professional input from Architects and Engineers who may be involved in less than 8% / 10% of the design of these buildings which house 100% of the world's population.

5.12.2 Formulae, Coefficients & Symbols

(a) Design Wind Speed, V_S

Factors for:
- Topography S_1 = shape (mostly 1.0)
- Ground roughness variations S_2 = site category & height
- Statistical factor S_3 = mostly 1.0

Design Wind Speed: $V_S = V \cdot S_1 \cdot S_2 \cdot S_3$

(V = 3 second gust at height 10 m at one in 50 year return period in open country or in terrain equivalent to an airport).

(b) Conversion of Design Wind Speed to Dynamic Pressure, q

Dynamic Pressure $q = k.V_s^2$ (of approaching wind).
Surface Pressure $P = C_p.q$ (pressure coefficient x q).

Total Force: $F = (C_{pe} - C_{pi}) \cdot q \cdot A$

(Sum of internal and external pressure coefficients by dynamic pressure for the area concerned).

(c) Load on Building, F

Load (Force): $F = C_f \cdot q \cdot A$

(Force co-efficient by dynamic pressure by frontal area).

5.13 BRITISH WIND CODE CP3 – CHAPTER V – PART 2 – 1972

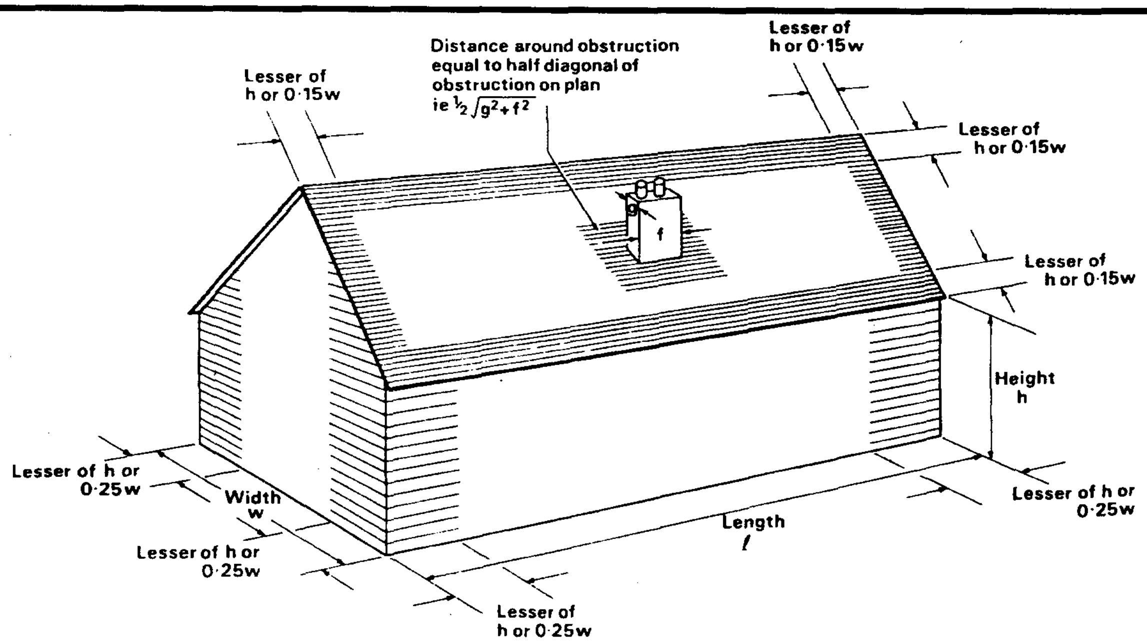
Symbols

V	=	Basic Wind Speed	b	=	breadth
V_S	=	Design Wind Speed	d	=	depth
P	=	Pressure on surface	h	=	height
P_e	=	external pressure	l	=	length
P_i	=	internal pressure	w	=	width
q	=	Dynamic Pressure	a	=	angle
C_f	=	force coefficient	S_1	=	topography factor
C_p	=	pressure coefficient	S_2	=	ground roughness factor
C_{p_i}	=	internal pressure coefficient	S_3	=	statistical factor
C_{p_e}	=	external pressure coefficient	F	=	force
A	=	Area of the surface			

k = 0.613 in SI Units (N/m² & m/sec).
k = 0.00256 in Imperial Units (psf & mph).

Note: For these tables, the values for S_1 and S_3 are both assumed to be equal to 1.0.

(Tables prepared and converted to V = 50 m/s by Mr. Rod Buchanan BE (Hons), MIEAust, RPEQ, CPEng & K J Macks, AM, Hon.D.Eng, ASTC)



AREAS WHERE HIGH SUCTIONS ON THE CLADDING MUST BE ALLOWED FOR
(Diagram Source: Newberry & Eaton 1974:44)

Table A ***DESIGN WIND SPEEDS & DYNAMIC PRESSURES***

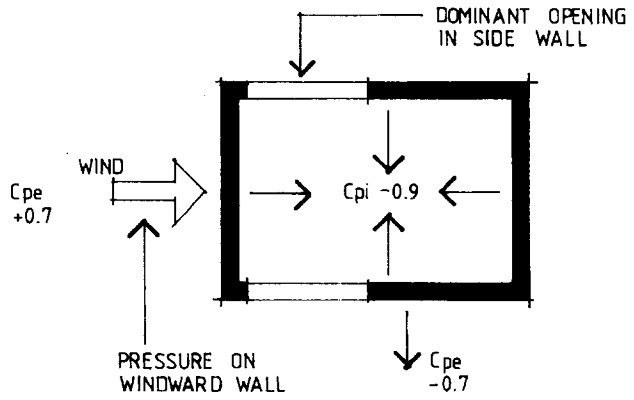
Conversion from Design Wind Speeds to Free Stream Dynamic Wind Pressures

TABLE 11
DESIGN WIND SPEEDS & DYNAMIC PRESSURES V = 50 m/s

GROUND ROUGHNESS CATEGORY	HEIGHT	CLASS A - CLADDING					CLASS B - STRUCTURE				
		S_2	Vs		q		S_2	Vs		q	
			m/s	mph	kPa	psf		m/s	mph	kPa	psf
1	15	1.03	51.5	115	1.63	34.0	0.99	49.5	111	1.50	31.4
1	10	1.00	50.0	112	1.53	32.0	0.95	47.5	106	1.38	28.9
1	5	0.88	44.0	98	1.19	24.8	0.83	41.5	93	1.06	22.0
1	3	0.83	41.5	93	1.06	22.0	0.78	39.0	87	0.93	19.5
2	15	1.00	50.0	112	1.53	32.0	0.95	47.5	106	1.38	28.9
2	10	0.93	46.5	104	1.33	27.7	0.88	44.0	98	1.19	24.8
2	5	0.79	39.5	88	0.96	20.0	0.74	37.0	83	0.84	17.5
2	3	0.72	36.0	81	0.79	16.6	0.67	33.5	75	0.69	14.4
3	15	0.88	44.0	98	1.19	24.8	0.83	41.5	93	1.06	22.0
3	10	0.78	39.0	87	0.93	19.5	0.74	37.0	83	0.84	17.5
3	5	0.70	35.0	78	0.75	15.7	0.65	32.5	73	0.65	13.5
3	3	0.64	32.0	72	0.63	13.1	0.60	30.0	67	0.55	11.5
4	15	0.74	37.0	83	0.84	17.5	0.69	34.5	77	0.73	15.2
4	10	0.67	33.5	75	0.69	14.4	0.62	31.0	69	0.59	12.3
4	5	0.60	30.0	67	0.55	11.5	0.55	27.5	62	0.46	9.7
4	3	0.56	28.0	63	0.48	10.0	0.52	26.0	58	0.41	8.7

Table B ***MAXIMUM WIND PRESSURES – WALL STRUCTURE – CLASS B***

MAXIMUM WIND PRESSURES – WALL STRUCTURE – LOADING CO-EFFICIENTS



$$P = (Cp_e - Cp_i).q$$

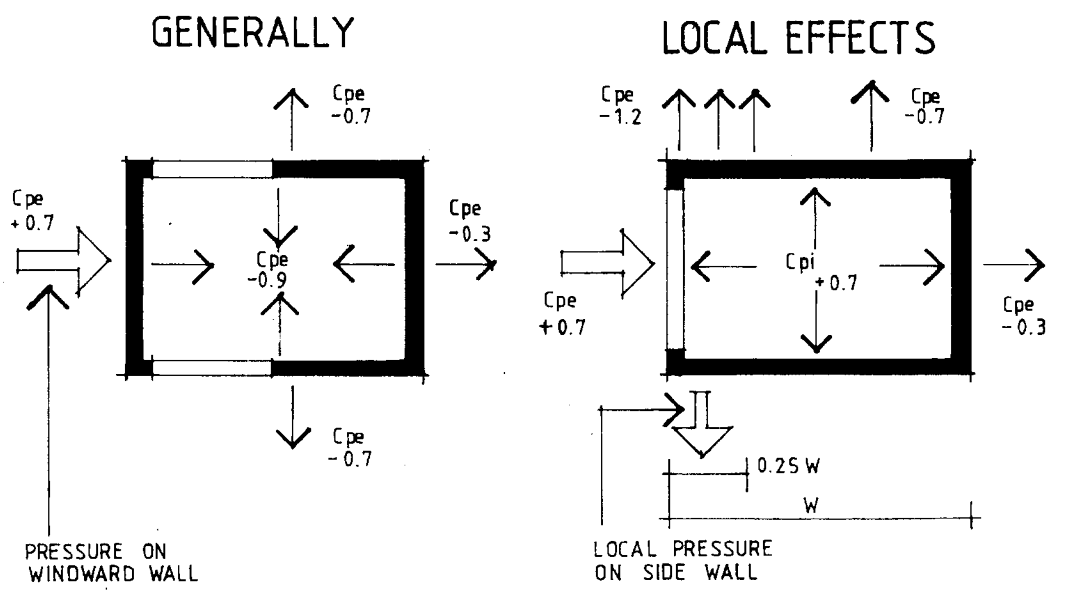
$$P = (+0.7-(-0.9))q = \mathbf{1.6q}$$

TABLE 12
MAXIMUM WIND PRESSURES - WALL STRUCTURE CLASS B

GROUND ROUGHNESS CATEGORY	*HEIGHT*	*DYNAMIC PRESSURE q*		*WIND PRESSURE P = 1.6 q*	
		kPa	*psf*	*kPa*	*psf*
1	15	1.50	31.4	2.40	50.2
1	10	1.38	28.9	2.21	46.2
1	5	1.06	22.0	1.69	35.3
1	3	0.93	19.5	1.49	31.2
2	15	1.38	28.9	2.21	46.2
2	10	1.19	24.8	1.90	39.7
2	5	0.84	17.5	1.34	28.0
2	3	0.69	14.4	1.10	23.0
3	15	1.06	22.0	1.69	35.3
3	10	0.84	17.5	1.34	28.0
3	5	0.65	13.5	1.04	21.6
3	3	0.55	11.5	0.88	18.4
4	15	0.73	15.2	1.17	24.4
4	10	0.59	12.3	0.94	19.7
4	5	0.46	9.7	0.74	15.5
4	3	0.41	8.7	0.66	13.8

Table C ***MAXIMUM WIND PRESSURES – WALL CLADDING – CLASS A***

MAXIMUM WIND PRESSURES – WALL CLADDING – LOADING CO-EFFICIENTS



$P = (Cp_e - Cp_i).q$
$P = (+0.7-(-0.9))q = \mathbf{1.6q}$

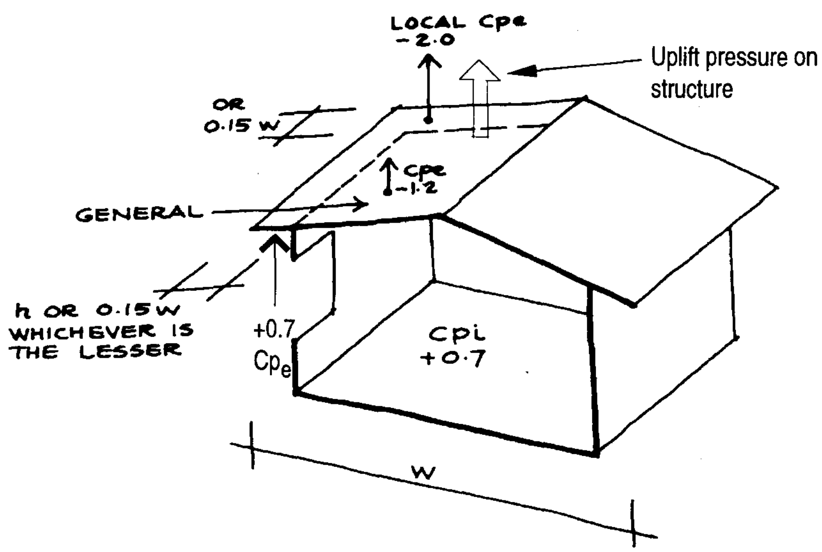
$P = (Cp_e - Cp_i).q$
$P = (-1.2-(+0.7))q = \mathbf{-1.9q}$

TABLE 13
MAXIMUM WIND PRESSURES - WALL CLADDING CLASS A

GROUND ROUGHNESS CATEGORY	*HEIGHT*	*DYNAMIC PRESSURE*		*(W) GENERALLY*		*(W/4) LOCAL EFFECTS*	
		q		*p = 1.6 q*		*p = 1.9 q*	
		kPa	*psf*	*kPa*	*psf*	*kPa*	*psf*
1	15	1.63	34.0	2.60	54.33	3.09	64.52
1	10	1.53	32.0	2.45	51.21	2.91	60.81
1	5	1.19	24.8	1.90	39.66	2.25	47.09
1	3	1.06	22.0	1.69	35.28	2.01	41.89
2	15	1.53	32.0	2.45	51.21	2.91	60.81
2	10	1.33	27.7	2.12	44.29	2.52	52.60
2	5	0.96	20.0	1.53	31.96	1.82	37.95
2	3	0.79	16.6	1.27	26.55	1.51	31.53
3	15	1.19	24.8	1.90	39.66	2.25	47.09
3	10	0.93	19.5	1.49	31.16	1.77	37.00
3	5	0.75	15.7	1.20	25.09	1.43	29.80
3	3	0.63	13.1	1.00	20.98	1.19	24.91
4	15	0.84	17.5	1.34	28.04	1.59	33.30
4	10	0.69	14.4	1.10	22.99	1.31	27.30
4	5	0.55	11.5	0.88	18.44	1.05	21.89
4	3	0.48	10.0	0.77	16.06	0.91	19.07

Table D **MAXIMUM WIND PRESSURES – ROOF STRUCTURE – CLASS B**

MAXIMUM WIND PRESSURES – ROOF STRUCTURE – LOADING CO-EFFICIENTS



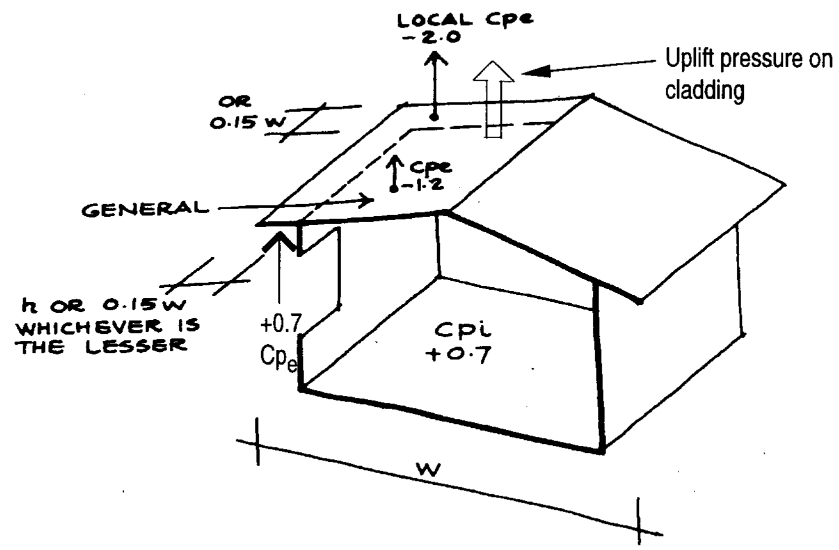
$$P = (Cp_e - Cp_i).q$$
$$P = (-1.2-(+0.7)q = \mathbf{-1.9q}$$

TABLE 14
MAXIMUM WIND PRESSURES - ROOF STRUCTURE CLASS B

GROUND ROUGHNESS CATEGORY	*HEIGHT*	*DYNAMIC PRESSURE*		*GENERAL WIND PRESSURE*	
		q		*P = 1.9 q*	
		kPa	*psf*	*kPa*	*psf*
1	15	1.50	31.4	2.85	59.60
1	10	1.38	28.9	2.63	54.88
1	5	1.06	22.0	2.01	41.89
1	3	0.93	19.5	1.77	37.00
2	15	1.38	28.9	2.63	54.88
2	10	1.19	24.8	2.25	47.09
2	5	0.84	17.5	1.59	33.30
2	3	0.69	14.4	1.31	27.30
3	15	1.06	22.0	2.01	41.89
3	10	0.84	17.5	1.59	33.30
3	5	0.65	13.5	1.23	25.69
3	3	0.55	11.5	1.05	21.89
4	15	0.73	15.2	1.39	28.95
4	10	0.59	12.3	1.12	23.38
4	5	0.46	9.7	0.88	18.40
4	3	0.41	8.7	0.79	16.44

Table E ***MAXIMUM WIND PRESSURES – ROOF CLADDING – CLASS A***

MAXIMUM WIND PRESSURES – ROOF CLADDING – LOADING CO-EFFICIENTS



GENERALLY	LOCAL EFFECTS
$P = (Cp_e - Cp_i).q$	$P = (Cp_e - Cp_i).q$
$P = q\,(-1.2-(+0.7)) = \boldsymbol{-1.9q}$	$P = q\,(-2.0-(+0.7)) = \boldsymbol{-2.7q}$

TABLE 15
MAXIMUM WIND PRESSURES - ROOF CLADDING CLASS A

GROUND ROUGHNESS CATEGORY	*HEIGHT*	*DYNAMIC PRESSURE q*		*WIND PRESSURE GENERAL p = 1.9 q*		*WIND PRESSURE LOCAL p = 2.7 q*	
		kPa	*psf*	*kPa*	*psf*	*kPa*	*psf*
1	15	1.63	34.0	3.09	64.5	4.39	91.7
1	10	1.53	32.0	2.91	60.8	4.14	86.4
1	5	1.19	24.8	2.25	47.1	3.20	66.9
1	3	1.06	22.0	2.01	41.9	2.85	59.5
2	15	1.53	32.0	2.91	60.8	4.14	86.4
2	10	1.33	27.7	2.52	52.6	3.58	74.7
2	5	0.96	20.0	1.82	38.0	2.58	53.9
2	3	0.79	16.6	1.51	31.5	2.15	44.8
3	15	1.19	24.8	2.25	47.1	3.20	66.9
3	10	0.93	19.5	1.77	37.0	2.52	52.6
3	5	0.75	15.7	1.43	29.8	2.03	42.3
3	3	0.63	13.1	1.19	24.9	1.69	35.4
4	15	0.84	17.5	1.59	33.3	2.27	47.3
4	10	0.69	14.4	1.31	27.3	1.86	38.8
4	5	0.55	11.5	1.05	21.9	1.49	31.1
4	3	0.48	10.0	0.91	19.1	1.30	27.1

5.14 LOAD AREAS

Load area is the area of wall or roof accepting loads. The whole of which are transferred to the supporting members.

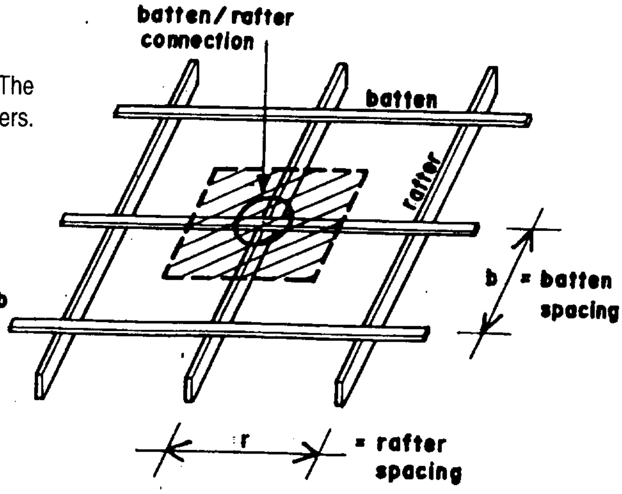
UPLIFT FORCES OF ROOFS

(1) connection between batten and rafter

contributing loaded area = r x b

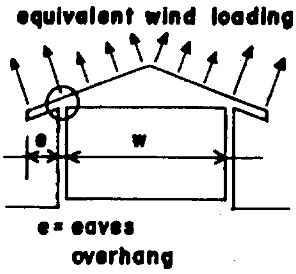
force = loading X r x b

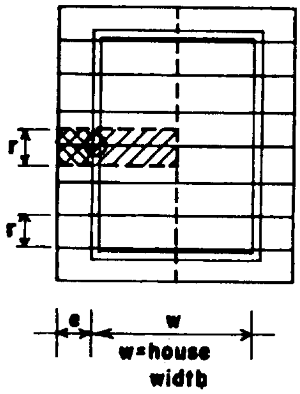
(kN) = (kPa) X (m²)



A. LOAD AREA – BATTEN (ROOF BATTEN LOAD AREA TRANSFER TO PURLIN OR RAFTER).

(2) connection of truss to wall





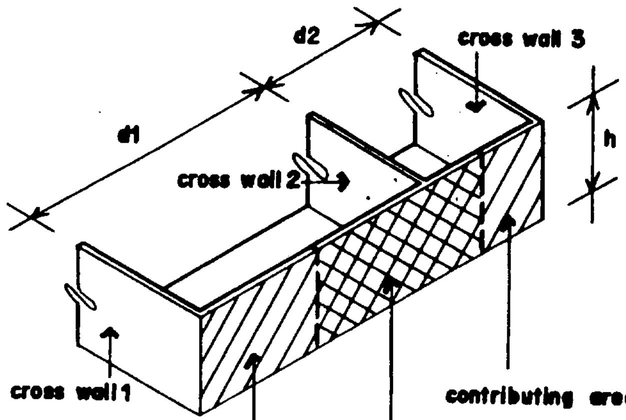
contributing area of overhanging eave = r x e

contributing area of general roof = r x ½w

$$\text{Force} = \left[\text{general loading} \times r \times \tfrac{1}{2}w\right] + \left[\text{eaves loading} \times r \times e\right]$$

$$(\text{kN}) = \left[(\text{kPa}) \times (\text{m}^2)\right] + \left[(\text{kPa}) \times (\text{m}^2)\right]$$

B. LOAD AREA – ROOF RAFTER (RAFTER LOAD AREA TRANSFER TO TOP PLATE).



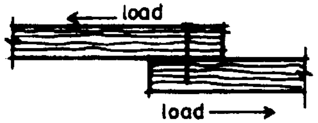
contributing area cross wall 3 = $h \times \frac{1}{2}d2$

contributing area cross wall 2 = $\left[h \times \frac{1}{2}d1\right] + \left[h \times \frac{1}{2}d2\right]$

contributing area cross wall 1 = $h \times \frac{1}{2}d1$

B. LOAD AREA – WALL PANEL (WALL LOAD AREA TRANSFER TO CROSS-WALL).

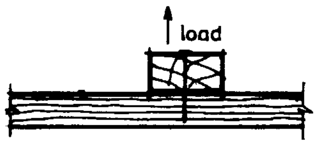
NAILS - LATERAL LOADS.



- PLAIN SHANK STEEL WIRE NAILS.
- GROUP STRENGTH J3 GREEN TIMBER.
- INCLUDES 100% OVERLOAD FOR CYCLONIC GUST CONDITIONS.
- NOT TO BE USED FOR NORMAL LOAD CONDITIONS.
- NAIL INTO SIDE GRAIN.
- 50 % PENETRATION INTO SECOND TIMBER.

METRIC			IMPERIAL		
NAIL SIZE	LOAD PER NAIL		NAIL SIZE		LOAD / NAIL
(millimetres)	(kilograms)	(Newtons)	gauge (S.W.G)	diam. (inch)	(pounds)
2·5 mm	46 kg	460 N	12 g	0·10	101 lb.
2·8 mm	53 kg	530 N	11 g	0·12	117 lb.
3·15 mm	66 kg	660 N	10 g	0·13	145 lb.
3·75 mm	90 kg	900 N	9 g	0·14	203 lb.
4·5 mm	121 kg	1210 N	7 g	0·18	267 lb.

NAILS - WITHDRAWAL LOADS.

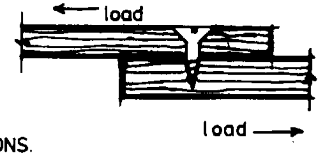


- PLAIN SHANK STEEL WIRE NAILS.
- GROUP STRENGTH J3 TIMBER - GREEN OR DRY.
- AVOID NAILING INTO END GRAIN.
- NO CAPACITY FOR OVERLOAD DUE TO GUST.
- THIS FIXING METHOD PREFERABLY AVOIDED.
- LOADS ARE GIVEN PER UNIT LENGTH OF PENETRATION.

METRIC			IMPERIAL		
NAIL SIZE	LOAD / NAIL / MILLIMETER		LOAD PER NAIL / INCH		LOAD / NAIL
(millimetres)	(kilograms)	(Newtons)	gauge (S.W.G)	diam. (inch)	(pounds)
2·5 mm	0·65 kg	6·5 N	12 g	0·10	36 lb.
2·8 mm	0·79 kg	7·9 N	11 g	0·12	44 lb.
3·15 mm	0·81 kg	8·1 N	10 g	0·13	45 lb.
3·75 mm	0·96 kg	9·6 N	9 g	0·14	54 lb.
4·5 mm	1·15 kg	11·5 N	7 g	0·18	64 lb.

Resistance Loads adapted from Standards Association of Australia (1988): **AS 1720.1**

WOOD SCREWS - LATERAL LOADS.

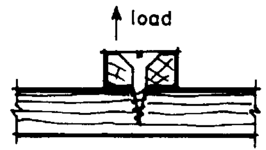


- GROUP STRENGTH J3 DRY TIMBER.
- SCREW INTO SIDE GRAIN.
- PENETRATION 7 TIMES SHANK DIAMETER.
- INCLUDES 100 % OVERLOAD FOR CYCLONIC GUST CONDITIONS.
- NOT TO BE USED FOR NORMAL LOAD CONDITIONS.

SCREW SIZE	METRIC			IMPERIAL	
	SHANK DIAM.	LOAD		SHANK DIAM.	LOAD
NO.	(millimetres)	(kilograms)	(Newtons)	(inches)	(pounds)
4	2·74 mm	4·8 kg	480 N	0·108	108 lb.
6	3·45 mm	7·6 kg	760 N	0·136	171 lb.
8	4·17 mm	10·6 kg	1060 N	0·164	238 lb.
10	4·88 mm	14·8 kg	1480 N	0·192	333 lb.
12	5·59 mm	19·6 kg	1960 N	0·220	441 lb.
14	6·30 mm	24·8 kg	2480 N	0·248	558 lb.
18	7·72 mm	37·4 kg	3740 N	0·304	842 lb

NOTE : FOR END GRAIN FIXING ALLOW $2/3$ OF ABOVE LOADS.

WOOD SCREWS - WITHDRAWAL LOADS.

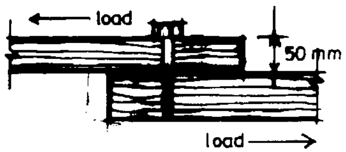


- SIDE GRAIN OF GROUP J3 DRY TIMBERS.
- INCLUDES 100 % OVERLOAD FOR CYCLONIC GUST CONDITIONS.
- NOT TO BE USED FOR NORMAL LOAD CONDITIONS
- LOADS GIVEN PER UNIT OF PENETRATION.

SIZE	METRIC				IMPERIAL		
	SHANK DIAM	LOAD/mm PENETRATION		MAX LOAD	SHANK DIAM	LOAD/INCH	MAX LOAD
NO.	(millimetres)	(kilograms)	(Newtons)	PER SCREW	(inches)	(pounds)	PER SCREW
4	2·74mm	3·3kg	33 N	730 N	0·108	164 lb	164 lb
6	3·45mm	4·2kg	42 N	1110 N	0·136	235 lb	250 lb
8	4·17mm	5·1 kg	51 N	1650 N	0·164	286 lb	370 lb
10	4·88mm	6·0 kg	60 N	2270 N	0·192	336 lb	510 lb
12	5·59mm	6·8 kg	68 N	2960 N	0·220	381 lb	665 lb
14	6·30mm	7·7 kg	77 N	3780 N	0·248	432 lb	835 lb
18	7·72mm	9·5 kg	95 N	5600 N	0·304	532 lb	1260 lb

NOTE : FOR END GRAIN FIXING ALLOW $2/3$ OF ABOVE LOADS.

COACH SCREWS - LATERAL LOADS.

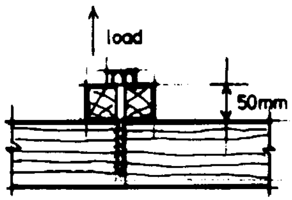


- GROUP STRENGTH J3 - GREEN TIMBER,
- PENETRATION INTO THE THICKER MEMBER TO BE 8 TIMES THE SHANK DIAMETER.
- INCLUDES 100% OVERLOAD FOR CYCLONIC GUST CONDITIONS.
- NOT TO BE USED FOR NORMAL LOAD CONDITIONS.
- SUBJECT TO CONDITIONS 4.5.1 IN A.S. 1720 - 1975.

METRIC					
DIAMETER	PENETRAT'N	LOAD - PARALLEL TO GRAIN.		LOAD - PERPENDIC. TO GRAIN.	
(mm)	(mm)	(kilogram)	(Newtons.)	(kilogram.)	(Newtons.)
6	50	151	1512	99	990
10	75	420	4200	165	1650
12	100	604	6040	198	1980
16	125	840	8400	264	2640
20	150	1050	10500	330	3300

IMPERIAL			
DIAMETER	PENETRAT'N	LOAD (POUNDS)	
(inches)	(inches)	PARALLEL TO GRAIN	PERPEND. TO GRAIN
0·25	2	340	223
0·38	3	945	371
0·5	4	1360	446
0·63	5	1890	594
0·75	6	2360	743

COACH SCREWS - WITHDRAWAL LOADS.



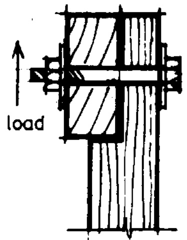
- GROUP STRENGTH J3 - GREEN TIMBER.
- INCLUDES 100 % OVERLOAD FOR CYCLONIC GUST CONDITIONS.
- NOT TO BE USED FOR NORMAL LOAD CONDITIONS.
- LOADS ARE GIVEN PER UNIT OF PENETRATION.

METRIC		
DIAMETER	LOAD PER MILLIMETRE OF PENETRATION	
(millimetres)	(kilograms)	(Newtons)
6 mm	6·6 kg	96 N
10 mm	9·0 kg	90 N
12 mm	9·8 kg	98 N
16 mm	11·4 kg	114 N
20mm	13·0 kg	130 N

IMPERIAL	
DIAMETER	LOAD PER INCH OF PENETRATION
(inches)	(pounds)
0·25	370 lb.
0·375	500 lb
0·5	550 lb
0·625	640 lb
0·75	730 lb

NOTE : FOR END GRAIN FIXING ALLOW $^2/_3$ OF ABOVE LOADS.

BOLTED JOINTS - LATERAL LOADS.

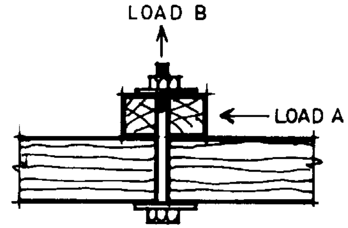


- GROUP STRENGTH J3 - GREEN TIMBER
- INCLUDES 100% OVERLOAD FOR CYCLONIC GUST CONDITIONS.
- NOT TO BE USED FOR NORMAL LOAD CONDITIONS.
- ALSO VALID FOR TIMBER TO STEEL JOINT
- STEEL WASHERS REQUIRED. HOLE DIAM = BOLT DIAM. $^{+1}_{0}$ mm.
- ONE BOLT IN SINGLE SHEAR. NOT TO BE USED FOR MULTIPLE BOLT JOINTS.

METRIC					
DIAMETER	WASHR SIZE	LOAD - PARALLEL TO GRAIN		LOAD - PERPENDIC. TO GRAIN	
(mm)	(mm)	(kilogram)	(Newtons)	(kilogram)	(Newtons)
6	28φ×1·6	151	1512	99	990
10	56φ×3	420	4200	165	1650
12	56φ×3	604	6040	198	1980
16	73φ×5	840	8400	264	2640
20	73φ×5	1050	10500	330	3300

IMPERIAL			
DIAMETER	WASHR SIZE	LOAD (POUNDS)	
(inches)	(inches)	PARALLEL TO GRAIN	PERPEND. TO GRAIN
0·25	1·1φ 16g	340	223
0·375	2·2φ 10g	945	371
0·5	2·2φ 10g	1360	446
0·625	2·9φ 6g	1890	594
0·75	2·9φ 6g	2350	743

BOLTS - BASIC WORKING LOADS



- ORDINARY STEEL BOLTS.
- NO ALLOWANCE FOR CYCLONIC OVERLOAD.
- LOAD GIVEN IS CAPACITY OF ONE BOLT.
- LOAD A = BOLT IN SHEAR
- LOAD B = BOLT IN TENSION.

METRIC				
DIAM.	LOAD A		LOAD B	
(mm)	(kilogram)	(Newtons)	(kilograms)	(Newtons)
12	900 kg	9,000 N	1,210 kg	12,100 N
16	1,610 kg	16,100 N	2,260 kg	22,600N
20	2,510 kg	25,100 N	3,530 kg	35,300N

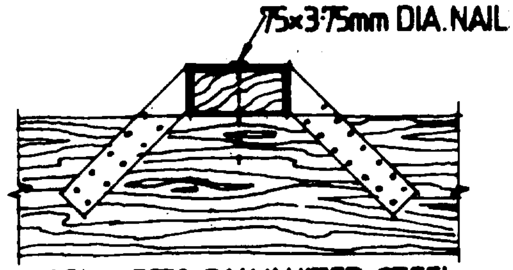
IMPERIAL		
DIAM.	LOAD (LBS)	
(inches)	LOAD A	LOAD B
0·5	2025 lb	2720 lb
0·625	3620 lb	5085 lb
0·75	5650 lb	7945 lb

Resistance Loads adapted from Standards Association of Australia (1988): **AS 1720.1**

CAPACITY OF FIXINGS

Adopted from Manufacturer's Catalogs

'PRYDA' WIND STRAP

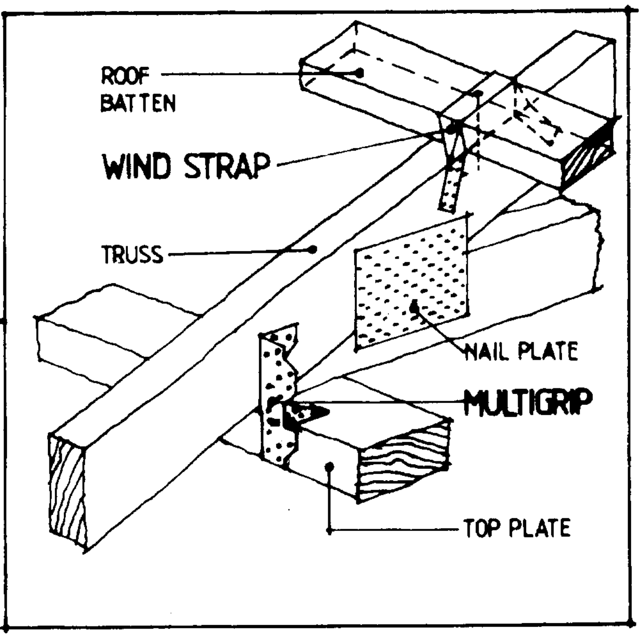


25mm×1·2mm G250 GALVANIZED STEEL PUNCHED TO TAKE 30mm×3·15mm GALV. NAILS

STEEL: ALLOWABLE TENSION	=	7·9kN
MINIMUM YIELD CAPACITY	=	14·0kN
	=	16·5kN

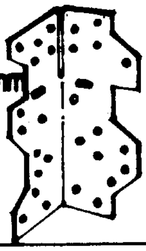
NUMBER OF NAILS IN EACH LEG	TOTAL BASIC NAIL LOAD	DEAD + WIND ALLOWABLE DESIGN	CAPACITY
4	3·4kN	6·3kN	16·5kN*
5	4·2kN	7·9kN	16·5kN*
6	5·0kN	9·5kN	16·5kN*

* Limited by steel strength.



'PRYDA' MULTIGRIP

EACH MULTIGRIP MUST BE FIXED WITH TWELVE 30×3·15mm NAILS OR THREE NAILS PER TAB. E.G. NINE NAILS IN FIG. 1.



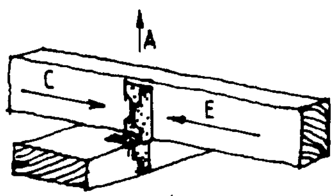


Fig. 1

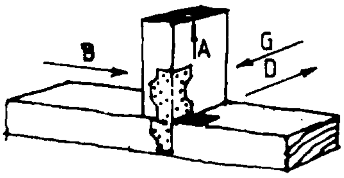


Fig. 2

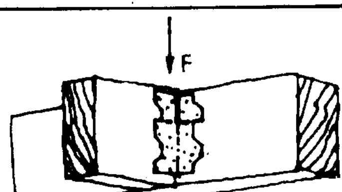


Fig. 3

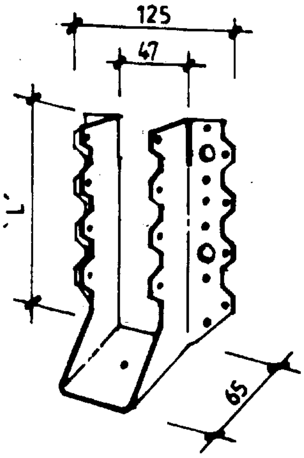
RECOMMENDED WORKING VALUES — VALUES ARE GIVEN FOR ONE MULTIGRIP IN KILONEWTONS

DIRECTION OF LOAD	A	B	C	D	E	F	G
ALLOWABLE DEAD + LIVE	1·3	1·1	0·5	0·8	0·5	1·9	0·6
ALLOWABLE DEAD + WIND	1·8	1·7	0·7	1·2	0·7	2·6	0·8

CAPACITY OF FIXINGS

Adopted from Manufacturer's Catalogs

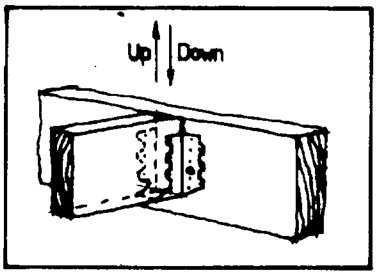
'PRYDA' FRAMING BRACKET



The 'L' values for each bracket type are as follows:
TYPE G = 65mm TYPE D = 134mm
TYPE B = 86mm TYPE F = 182mm

Bracket type	Design criteria	Load direction	Total Basic Nail Load	Number of nails	Allowable design	Capacity
	DEAD + LIVE LOADS					
G	Displace.	Down	330N	8	4·4kN	12·4kN
B	"	"	"	10	5·5kN	15·6kN
D	"	"	"	16	8·8kN	24·9kN
F	"	"	"	22	12·1kN	34·3kN
	DEAD + WIND LOADS					
G	Ultimate	Up	420N	4	3·1kN	9·3kN
B	"	"	"	5	4·0kN	11·6kN
D	"	"	"	8	6·3kN	18·6kN
F	"	"	"	11	8·7kN	25·5kN

IN ORDER TO ACHIEVE THE ABOVE LOADS, ALL NAIL HOLES IN EACH BRACKET MUST BE FILLED WITH 30mm×3·15mm DIA. GALV. NAILS.

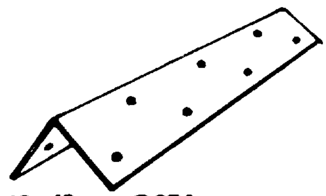


RAFTER TO WALL PLATE, RAFTER TO VERANDAH LINTLE BEAM, FLOOR JOIST TO BEARER

'PRYDA' ANGLE BRACING

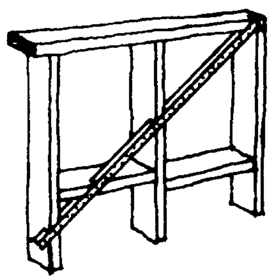
ALLOWABLE TENSION - NAILS IN ONE LEG ONLY.		
NUMBER OF NAILS EACH END	TOTAL BASIC NAIL LOAD	DEAD + WIND
3	890N	1·7kN
4	1200N	2·2kN

COMPRESSIVE LOAD	STUDS AT 600 CRS. BRACE AT 45°	BRACE AT 55°
Clear brace length	780mm	980mm
Ultimate buckling load	4·6kN	3·1kN
Allowable compressive load (with FS = 2)	2·3kN	1·6kN



19×19mm G250 GALVANISED STEEL.

NOTE: THIS BRACE OFTEN ACTS IN CONJUNCTION WITH WALL CLADDING MATERIALS ONCE CONSTRUCTION IS COMPLETE.

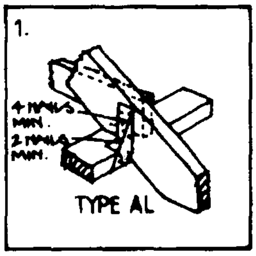


BRACING TO WALL FRAMING

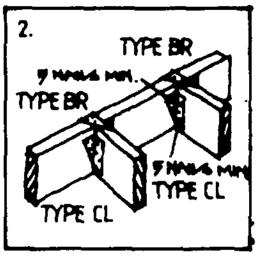
CAPACITY OF FIXINGS

Adopted from Manufacturer's Catalogs

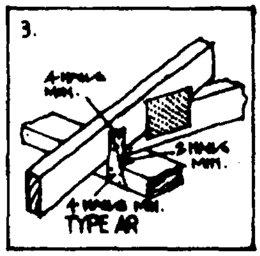
'TECO' TRIP-L-GRIP FRAMING ANCHOR



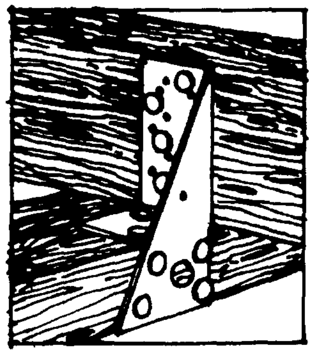
RAFTERS TO PLATE, JOISTS TO PLATE

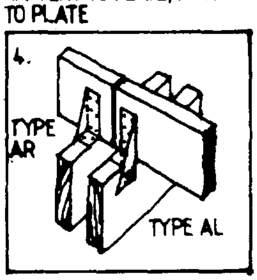


JOISTS TO TRIMMER, PLATE OR FASCIA

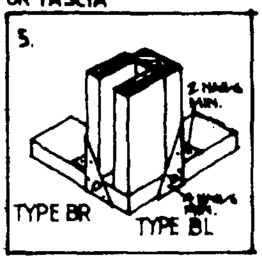


ROOF TRUSS TO PLATE

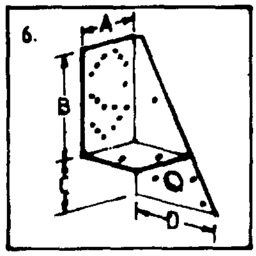




PURLINS TO HANGERS – HANGERS TO CEILING JOISTS



CORNER STUDS



A	38mm - 1½ in.
B	73mm - 2[illegible] in.
C	42mm - 1[illegible] in.
D	[illegible]mm - 2[illegible] in.

MANUFACTURED FROM 1·2mm GALVABOND STEEL & PUNCHED TO TAKE 2·[illegible]mm × 30mm GALVANISED NAILS

EACH TRIP-L-GRIP MUST BE FIXED WITH TEN (10) TECO NAILS FOR MAXIMUM BENEFIT! NAILING PATTERNS FOR TYPICAL TRIP-L-GRIP APPLICATIONS ARE SHOWN ABOVE.

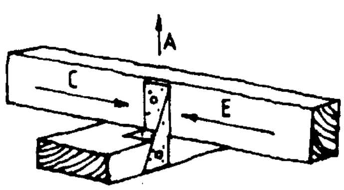


Fig. 1

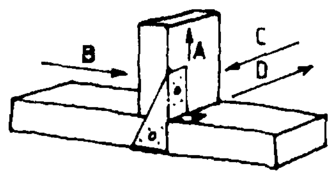


Fig. 2

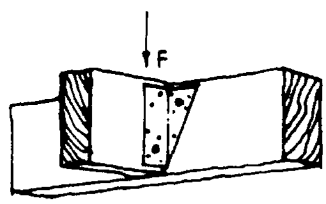


Fig. 3

RECOMMENDED WORKING VALUES (METRIC) — VALUES ARE GIVEN FOR ONE ANCHOR IN NEWTONS

Direction of Load	A	B	C	D	E	F
Long Term Loading	1335	2360	1290	890	1335	2000
Long Term & Maintenance (Live) Loads	1670	2950	1610	1110	1670	2500
Short Term Load	2000	3540	1935	1335	2000	3000

RECOMMENDED WORKING VALUES (IMPERIAL) — VALUES ARE GIVEN FOR ONE ANCHOR IN POUNDS

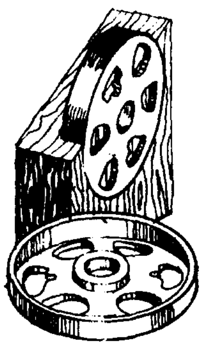
Direction of Load	A	B	C	D	E	F
Long Term Loading	300	530	290	200	300	450
Long Term & Maintenance (Live) Loads	375	663	362	250	375	562
Short Term Load	450	790	435	300	450	675

NOTE: THE ABOVE LOADS ARE BASED ON BASIC VALUES PUBLISHED IN THE 'TIMBER ENGINEERING DESIGN HANDBOOK' WITH MODIFICATION FACTORS FOR LOAD DURATION AS RECOMMENDED IN THAT DOCUMENT.

CAPACITY OF FIXINGS

Adopted from Manufacturer's Catalogs

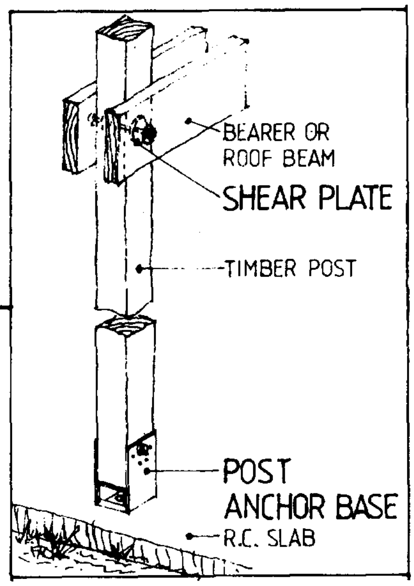
TECO' SHEAR PLATE



65mm & 100mm DIA.

SHEAR PLATES ARE MALLEABLE CAST PLATE DESIGNED FOR BOTH WOOD TO STEEL & WOOD TO WOOD APPLICATIONS AND ARE AVAILABLE IN 65mm & 100mm DIAMETERS.

THE BEARING AREA OF THE TIMBER IS INCREASED WHICH INCREASES THE LOAD CAPACITY OF THE BOLT.

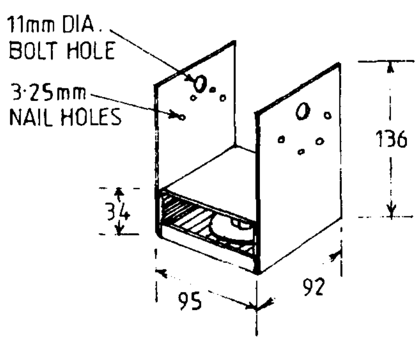


'TECO' POST ANCHOR BASE

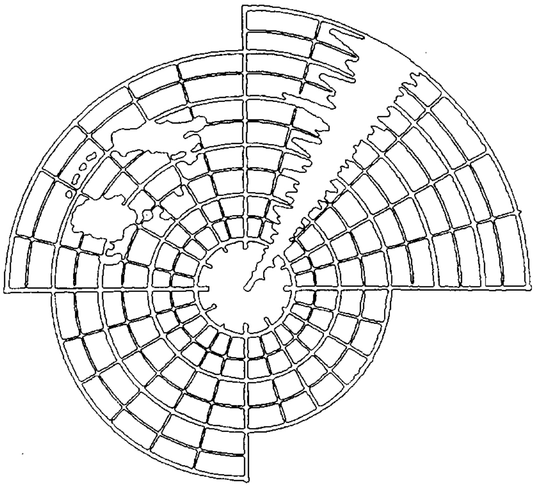
BASE MANUFACTURED FROM 2mm GALV. STEEL & RAISED SUPPORT FROM 3mm GALV. STEEL.

POST TO BASE CONNECTION WITH 1/M10 GALV. BOLT <u>OR</u> 8/3·15 FLAT HEAD GALV. NAILS.

BASE TO CONC. CONNECTION WITH 1/M12 EXPAND. MASONRY ANCHOR DESIGNED TO ADEQUATLY CARRY LOADS TABLED BELOW <u>OR</u> A PRE-SET ANCHOR BOLT 75mm MIN. INTO CONC..



LOAD TYPE	ALLOWABLE LOAD
WIND UPLIFT (TENSION)	6kN
DEAD & LIVE LOAD (COMPRESSION)	20kN



6 PROCEDURES AFTER DISASTER

CONTENTS

6.1 EVALUATION

Post Disaster Activity is primarily concerned with saving lives, evacuating homeless people, attending to the injured and providing food and comfort to the affected population.

Emergency work may be needed to attend to damaged and dangerous structures where quick decisions have often to be made to offer protection or to avoid further calamities.

Once this period is over it is important for those responsible for the construction industry to organise inspections and evaluations of the buildings in the areas affected by the disaster and to report to government and industry on their findings.

The extent of work should be kept in scale with the disaster event and designed to mitigate damages in future disasters as well as to identify technical solutions to the damaged building stock.

6.1.1 *Introduction*

Buildings already existing require a system of examination or investigation to establish whether they require upgrading to make them secure against wind loads.

6.1.2 *Inspection Teams & Equipment*

A leading group or groups should be established and set up in a base headquarter with adequate facilities, including offices, communication systems, transport, office staff, accommodation and the necessary authorities to operate and gain access.

The investigative teams to inspect building damages should be carefully selected from personnel experienced in the building industry and should include architects, engineers, builders, supervisors, inspectors and master tradesmen. Several teams of 3-4 people who can move about freely and quickly can inspect a large number of properties each day.

Teams should arrange adequate equipment.

6.1.3 *Recording*

Teams should properly record and photograph the key components of the constructions inspected to give a picture of the condition of the roofs, walls, floors and other elements and to comment on their status.

Evaluation forms should be designed to suit the local construction methods typical for the country concerned.

They should be pre-printed and readily available.

A sample set of survey forms and questionnaires for inspectors is enclosed on the following pages.

6.1.4 *Reporting*

Reporting should be carried out in an organised way and there should be some commonality in the systems and methods adopted so that second stage reporting and evaluation is made easier.

Reporting on damages and construction failures can include suggestions for improvements to construction techniques.

6.1.5 *Fixings & Fasteners*

Newly erected buildings, even those that are cyclone secure need to be inspected on a regular basis to check the integrity of the important and critical:

a.	ANCHORAGE	of components to the foundation.
b.	BRACING	of wall and roof plane surfaces.
c.	CONTINUITY	for fixings, fastenings and tie down systems.

These elements can deteriorate over time, where exposed to rust, salt attack and where building movement and shrinkage occur; all of which can affect the basic integrity of the buildings. They also may lack basic structural integrity.

Reports should be completed that pinpoint where weakness exists and detail alternative optional solutions to bring the building(s) up to date.

A set of sample 'before' and 'after' details and photographs could be assembled as a broad approach to the problem.

6.1.6 *Innovation and Imagination*

The designer should be encouraged to use some imagination in seeking solutions. It is relatively easy, in most cases to find innovative and imaginative solutions to problems once the designer has developed a broad understanding of:

i. The wind loads;

ii. Tables of resistance of fastenings, and;

iii. Design and construction techniques.

Solutions may need to take account of the fact that the building may be used or occupied during reinstatement as the cost of relocation of the users may add heavily to the cost of the repair.

6.2 SUMMARY

The details from the inspection team reports should be passed through to the central management headquarters where the overall evaluations are examined and assessed.

Subsequent reports should consolidate the reporting and make detailed observations and recommendations and establish broad budgets for repair and / or reconstruction or demolition.

Headquarters team should report their recommendations to relevant government authorities for action and funding.

NOTE: this paper does not purport to investigate and report on disaster management procedures in detail.

Comments made above are a preamble to lead into the technical material covered hereafter to help educate communities to mitigate the damages by improvement of design and construction techniques.

6.3 MAINTENANCE OF EXISTING BUILDING

The maintenance of existing buildings covers two areas:

a. General maintenance from year to year to prevent the building from falling into a state of disrepair. Budgets for this work will vary depending on the nature and quality of the construction materials.

   However, annual budgets for general maintenance should be set in the order of from 0.5% to 1.5% to 2.0% of the current replacement value of the building.

b. Specific maintenance of a building also should include any upgrading or renovation required to maintain the building to a state where it is up to date, not only for its specific use from time to time but also to enable the building to meet adequate codes or standards of construction as they are developed and especially to enable the building to resist disaster events such as cyclones, earthquakes, fires and floods.

Upgrading of buildings is not always a major cost compared to the budgets required to replace them, a decision which is often taken when adequate knowledge and experience in upgrading is not available. An old building in reasonable structural condition can be recycled to serve a new function and upgraded to current regulations for from 25% to 50% of the cost of replacement.

The cost of upgrading buildings, in reasonable condition, to resist cyclones or high winds can be done for values of from 5% to 15% of the value of the building. The initial inspection should be made by experienced personnel, preferably an architect or engineer. Proper details and drawings or illustrations of the existing building are essential. These should be examined prior to final decisions on possible solutions.

It is often possible to find solutions that are able to be carried out without vacating the building. Even where a basic structural integrity is not present it may be possible to superficially implant a structural system of load transferring elements into the building to give it sufficient security. Each case should be examined individually as it is often possible to find an innovative solution to the problem.

Upgrading of buildings damaged in cyclones requires an examination and assessment by experienced personnel to determine whether it is economical to rehabilitate the building or to demolish the damaged structure.

The size and design of the original building and its classrooms should be assessed as well as the need to change room sizes when investigations of foundations may also be required.

6.3.1 Maintenance Inspection Reporting

The scope of a maintenance inspection report should include, but not necessarily be limited to, investigation of the site and surroundings, wall framing and cladding, roof framing and cladding, windows and doors and the cyclone 'tie-down' system.

The format of a Maintenance Inspection Report should be designed to promote the active participation of building inspectors in the process of upgrading and / or maintaining the level of cyclone resistance in buildings.

The proceeding draft 'Maintenance Inspection Report' has been designed to encourage this participation by the use of 'YES / NO' questions and 'GOOD / SATISFACTORY / POOR' qualitative assessment of the structure of an existing building. At the end of each section of questions is a paragraph of 'Remedial Action' that may be necessary to update construction to the required standard.

It is suggested that such forms, reviewed and extended as required, could be carbonized and copies circulated to the client, architect and contractor.

6.4 MAINTENANCE INSPECTION SURVEY FORM

PROJECT STATISTICS

SCHOOL BUILDING(S) .... TYPE.........................

FLOORS .... AREA.........................

LOCATION .... TOWN.........................

INSPECTOR .... DATE.........................

PART A THE SITE

A.1 Observe surround terrain and re-establish 'ground roughness'

Ground Roughness Category 1 e.g. airport .... ❑

Ground Roughness Category 2 e.g. rural .... ❑

Ground Roughness Category 3 e.g. urban .... ❑

Ground Roughness Category 4 e.g. town centre .... ❑

If ground roughness has changed from that under which the school was built, what structural updating required to comply with new ground roughness category

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		YES	NO
A.2	Observe structural condition of neighbouring buildings and surrounds. Could these buildings break-up and become flying debris during a cyclone? (i.e., loose roofing, broken windows, etc...).	❑	❑
A.3	Observe condition and proximity of nearby trees.	❑	❑
	Could trees fall or lose limbs during a cyclone? (i.e., dead trees, brittle branches, etc...).		
A.4	Observe condition of school grounds. Is there any loose material or rubbish littered about?	❑	❑

A.5 Note remedial action required to repair or remove:

a. dilapidated neighbouring buildings;
b. dangerous trees, or;
c. loose material on school grounds

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PART B THE ROOF

A thorough maintenance inspection will require an investigation of both the exterior roof surface and roof structure from beneath (i.e., in the ceiling space).

Type of Roof

❑ Gable ❑ Hip ❑ Skillion ❑ Other

Roof Construction

❑ Concrete Slab ❑ Steel Trusses ❑ Timber Trusses
❑ Post & Beam ❑ Beam & Framing ❑ Other

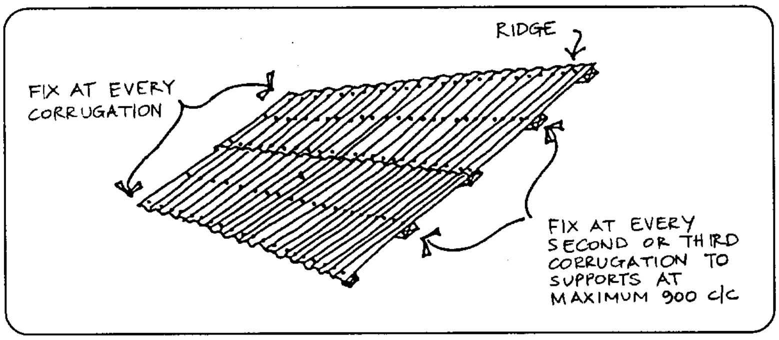
Roof Cladding

❑ Concrete ❑ Tiles ❑ Iron Sheeting
❑ Fibre Cement ❑ Shingles ❑ Thatch
❑ Other

B.1 ***Exterior Roof Surface***

B.1.1 Observe and note condition of the following roof elements:

		GOOD	ADEQUATE	POOR
a.	Roof cladding (i.e. rusting, holes or debris)	❑	❑	❑
b.	Roof fixings and fasteners (i.e., correct type, spacing of screws, none loose).	❑	❑	❑



		GOOD	ADEQUATE	POOR
c.	Gutters and downpipes.	❑	❑	❑
d.	Flashing and ridge capping (i.e., adequately fixed and sealed).	❑	❑	❑
e.	Roof Ventilators (i.e., clear of nests or vegetable matter - is it adequately fixed?)	❑	❑	❑
f.	Exposed timber work (i.e., split or rotten boards or eaves timber).	❑	❑	❑

B.1.2 Note remedial action, required to upgrade exterior roof surface

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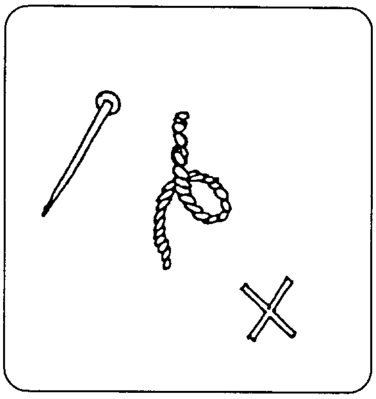
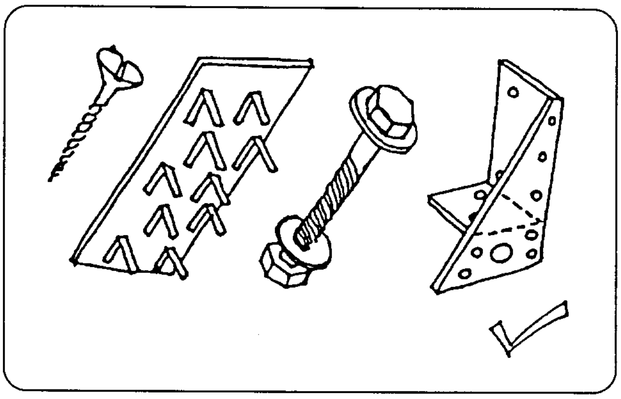
B.2 **Roof Structure**

B.2.1 Inspect and note condition of the following roof structural members (i.e., damp rot, insect infestation, cracking, etc... and their fixings to their supporting member).

	GOOD	ADEQUATE	POOR
a. Purlins and battens	❏	❏	❏
b. Rafters	❏	❏	❏
c. Trusses	❏	❏	❏
d. Fixing methods (i.e., correct type, location of fasteners).	❏	❏	❏





FIXING ELEMENTS & CONNECTORS

B.2.2 Observe and note condition of the underside of roof cladding (i.e., rusting, denting from debris, etc...).

GOOD	ADEQUATE	POOR
❏	❏	❏

B.2.3 Note remedial action required to upgrade roof structure

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PART C WALLS

Walls should be inspected to check their integrity and ability to accept and transfer disaster loads.

- Examine tie down systems of roof and wall construction.
- Is there a bond beam or ring-beam at the top of the walls?
- Is it tied down to foundations and at what centres?
- What is material and method of tie down systems?
- What is length of unsupported walls?
- What lateral bracing is available? Are corners braced?
- Note extent and height of gable walls and support of same.

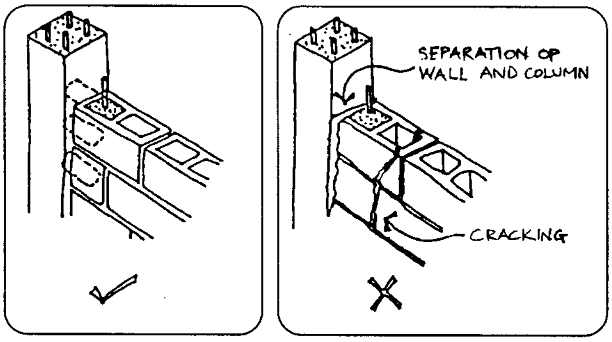
Type of Wall

❑ Concrete	❑ Concrete Block	❑ Solid Brick
❑ Cavity Brick	❑ Timber Frame	❑ Concrete Frame
❑ Steel Frame	❑ Other	

C.1 ***Block or Brick Walls***

C.1.1 Inspect and note general condition of brick or block walls.

		YES	NO
a.	Are there any settlement or movement cracks through bricks or mortar joints?	❑	❑
b.	Has water penetrated into any cracks and rusted reinforcing steel? (i.e., rust stains).	❑	❑
c.	Is there any cracking or separation between any 'insitu-cast' concrete columns and brick / block walls?	❑	❑



CONNECTION – BLOCK WALL TO COLUMN

C.1.2 Inspect wall top plate or bond beam:

		YES	NO
a.	Is timber top plate and / or bond beam in satisfactory condition? (i.e., no cracking, rust in steel or rot in timber).	❑	❑
b.	Are all 'tie-down' bolts / cast-in rods correct type and spacing?	❑	❑
c.	Are 'tie-down' bolts / cast-in rods rust free and securely fastened?	❑	❑

C.1.3 Check that core filling has been carried out satisfactorily. ❑ ❑

C.1.4 Note remedial action required to repair brick / walls

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C.2 *Timber Frame Walls*

		GOOD	ADEQUATE	POOR
C.2.1	During ceiling inspection of roof structure, check and note condition of top plate (i.e., wood rot, insect infestation, splitting, etc...).	❑	❑	❑
C.2.2	Are the correct type and spacing of 'tie-down' bolts / rods passing through the top plate provided.	❑	❑	❑
C.2.3	Are 'tie-down' bolts / rods securely tightened and corrosion free?	❑	❑	❑
C.2.4	If building elevated on stumps or posts, inspect and note condition of bottom plate connection to floor substructure.			
	a. Are the 'tie-down' rods securely fixed to floor substructure and securely tightened?	❑	❑	❑
	b. Is there adequate cross bracing between stumps or posts?	❑	❑	❑

C.2.5 Note remedial action required to repair timber wall framing

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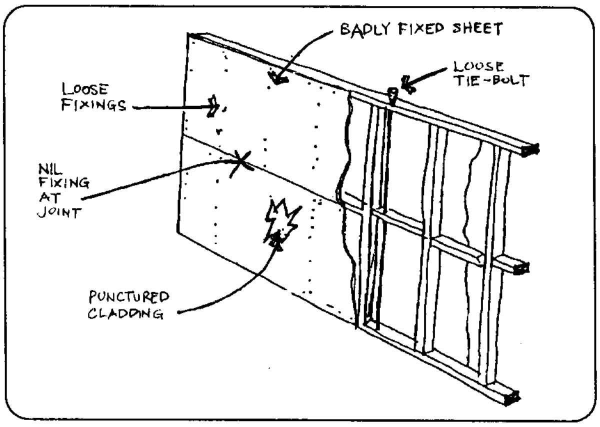
C.3 *Wall Cladding*

		GOOD	ADEQUATE	POOR
C.3.1	Inspect and note condition of cladding (i.e. rotten chamfer boards, debris damage, moisture penetration at joints, etc...).	❑	❑	❑

C.3.2 Inspect fixings and fastening method of securing cladding to timber wall framework:

	YES	NO
a. Are fixings the correct type, number and spacings?	❑	❑
b. Is cladding securely fixed to timber framework? (i.e., no loose or rusty screws or nails).	❑	❑



C.3.3 Note remedial work required to repair cladding

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PART D WINDOWS, DOORS & SHUTTERS

Inspect these elements internally and externally and check their operation.

❑ Timber ❑ Aluminium ❑ Steel ❑ Other

Check type and record details of:

- Framing to door and window openings.
- Glazing, thickness, size. Method of fixing.
- Reinforcement around openings.
- Size of openings.
- Types of beams or lintels over opening.
- Describe generally, including fixing details.

....

....

....

D.1 *Windows and Window Frames*

D.1.1 Inspect windows and window frames and note general condition:

		YES	NO
a.	Are there any broken louvres or window panes?	❑	❑
b.	Are frames secure and fixed firmly into wall opening?	❑	❑
c.	Are fixings of correct type and number to adequately secure frame against cyclonic winds?	❑	❑

D.1.2 Note remedial work is required to repair windows and window frames

....

....

....

D.2 *Doors and Door Frames*

D.2.1 Inspect doors and door frames and note general condition:

		YES	NO
a.	Are door surfaces intact and free from punctures or indentation?	❑	❑
b.	Are door frames secure and firmly secured into wall opening?	❑	❑
c.	Are door stops and door hinges adequate to secure door and frame against cyclonic winds? (i.e., ensure screws are in all hinge holes).	❑	❑

D.2.2 Note remedial action required to repair doors and door frames

....

....

D.3 *Cyclone Shutters*

D.3.1 Inspect and note condition of cyclone shutters:

		YES	NO
a.	Are the shutters free of wood rot and hinges free of rust?	❑	❑
b.	Do shutters open easily and close securely?	❑	❑
c.	Are shutter hinges (or tracks if sliding) securely fixed to wall?	❑	❑

D.3.2 If shutters not permanently attached to exterior walls:

		YES	NO
a.	Are they adequately stored?	❑	❑
b.	Are they in good state of repair?	❑	❑

PART E FLOOR SYSTEMS & FOUNDATIONS

Check the nature and type of floor systems and the material and stability of the natural foundations in addition to the condition of the artificial foundation.

....

....

E.1 ***Floor Systems***

Upper Floors

❑ Concrete ❑ Steel Beam & Joists ❑ Timber Joists ❑ Other

Lower Floors

❑ Concrete Slab on Ground Fill ❑ Suspended Slab ❑ Timber Bearers and Joists
❑ Timber Floor Boards ❑ Plywood Flooring ❑ Other Systems

Describe in general, including fixing details.

....

....

E.2 ***Foundations***

Type

❑ Concrete ❑ Stone ❑ Brick ❑ Timber Post ❑ Other

Bearing Material

❑ Rock ❑ Gravel ❑ Good Ground ❑ Clay ❑ Silt

Comment on stability
(Describe in general - include comment on damp proof courses and moisture movement).

....

....

PART F GENERAL COMMENTS

The following additional matters will assist in the overall evaluation of damages and in the assessment and evaluation.

F.1 ***Costing***

- Establish overall building area.
- Assess current replacement cost pre-cyclone.
- Establish unit rates for reconstruction (per m^2).
- Add margin for reconstruction in post disaster period.
- Establish extent of damages and values of same.
- Assess approximate cost to make good where possible.

F.2 ***Debris Damage***

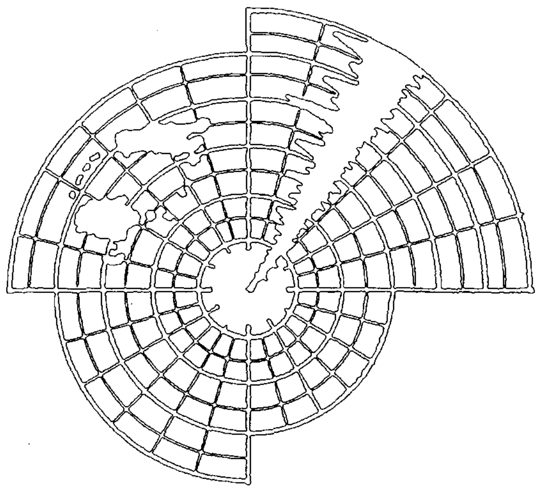
Examine and evaluate extent of debris and damages caused by flying debris:

❑ 10% ❑ 30% ❑ 50% ❑ 70% ❑ 90%

F.3 ***Infrastructure & Services***

• Identify and comment on primary problems common in the regions affected by the disaster, e.g.:

- wind damage
- debris damage
- wave surges
- flooding
- poor access to site
- power lines blown down
- ....
- ....
- ....
- power services
- sewerage services
- water supply services
- telephone services
- transport to region
- tree debris
- ....
- ....
- ....



PART TWO RESOLVING THE PROBLEM

7 FACTORS AFFECTING PERFORMANCE

CONTENTS

DISASTERS

WIND | SURGE | FLOOD | FIRE | QUAKE | VOLCANO

↓

GENERATE FORCES ON BUILDINGS
AND THE ENVIRONMENT

↓

RESISTED BY

↑

KNOWLEDGE OF FORCES DEVELOPED

on

INDIVIDUAL LOAD AREAS

made up of many

CONNECTION DETAILS OF ELEMENTS

needing knowledge of

CAPACITIES OF FIXING ELEMENTS
NAILS, SCREWS, BOLTS, CLIPS, GLUES

and design skills in

COMPONENT FIXING & DESIGN OF
BUILDING CONSTRUCTION ELEMENTS

7.1 FACTORS AFFECTING PERFORMANCE

There are many factors that affect the performance of buildings and their construction methods in resisting forces caused by cyclones. The principal factors to be considered are:

7.1.1 *Understanding the Forces*

There is, in the design and construction industry, and in the administration and political fields associated with building development, a general lack of understanding of the real forces caused by tropical cyclones.

The actual forces are often three and four times greater than the forces envisaged by inexperienced personnel.

This is more prevalent where the capital city and major population bases are remote from the tropical cyclone regions.

7.1.2 *Type of Forces*

There is also a lack of understanding of the different types of forces involved, such as "structural" forces and "cladding" forces.

Engineers are often involved in preparing designs for the structural loads on a building, but are seldom involved in the design, selection or detailing of the various claddings.

This is left to the architect or the building contractor or tradesmen to select and specify.

The forces on the claddings can be 50% greater than the forces on the structure.

Therefore, there is a need to educate the architects, builders and tradesmen to understand these forces and to devise better fixing methods to secure these claddings.

7.1.3 *Design*

The design of the building involves details of construction methods for connection of the building materials used.

The designer should specify the materials to be used together with quality of materials and methods of connection.

Lack of knowledge or skill can affect performance.

Other factors that lead to poor design include:

- Pressure of work affecting quality control.
- Using out of date codes or no code reference.
- Lack of in-service staff training and professional development.

7.1.4 *Construction*

The contractor should purchase only quality approved materials and should provide experienced tradesmen to put them together. He should supervise the construction and be experienced in the details needed for cyclone areas.

Lack of performance can be caused by:

- Volume of work.
- Methods of employment of staff.
- Lack of supervision.
- Inadequate quality control.
- Bad workmanship.
- Use of incorrect fasteners and fixings.
- Bad material supply.

7.1.5 *Quality of Materials*

a. Timber

- Is timber graded to acceptable stress levels?
- Are the tradesmen familiar with these standards?
- Are joints exposed to the weather or covered?

b. Concrete

- Is the sand, aggregate and cement checked for quality?
- Is the formwork for concrete properly put together and supported?
- Is the reinforcement kept in its correct position?
- Is the concrete placed correctly and vibrated?

c. Steelwork

- Is steel free from rust?
- Is steel correctly supported and fixed?
- Does steel need to be galvanised?

d. Roofer

- Are the roof materials selected fit for the task?
- Will they carry the loads received by the codes?
- Is the method of fixing known and understood?

e. Fixings

- Are nails, screws, bolts and steel fixing plates galvanised?
- Are the nails used the correct size and length?
- Are thin metal plate connectors of the correct thickness?

7.1.6 *Supervision and Inspection*

Whilst the builder supervises his tradesmen, the professional consultant architects and engineers inspect the works from time to time.

It is essential that the inspectors are experienced in cyclone construction loads and methods of construction that will resist these loads.

Local authority inspectors also need to be aware of their responsibilities to achieve code performance.

7.1.7 Manufacturers

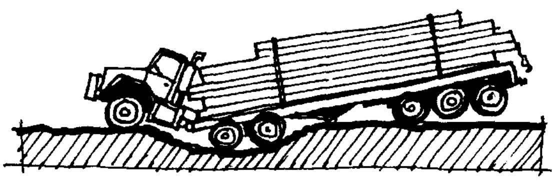
They should provide quality products to the industry, together with recommended methods of fixing that are proven to be adequate to resist the likely wind loads to be encountered.

They should inspect projects from time to time to monitor the effect of their fixing recommendations.

Lack of adequate instructions lead to failure.

7.1.8 Transport Difficulties & Ordering

Specified materials unable to be delivered to remote sites or unavailable in the region where the building is to be erected.



Specified materials too expensive.

Incorrect ordering of materials resulting in incorrect material or inadequate material arriving on site.

7.1.9 Debris

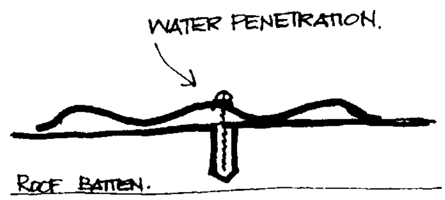
Damages caused by flying debris causing internal pressure to be activated.

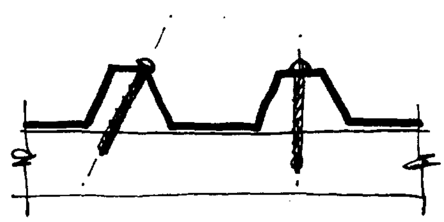
Builders should keep sites clear in cyclone season.

Debris damages can be controlled.

7.1.10 Workmanship

- Deficiencies occur in workmanship with insufficient sized washers on bolt fixings or insufficient screws or washers that are too small where the cladding material pulls through the fixing under severe loads or where bolts pull through timber.
- Overdriving of lead head nails or roofing nails or over-drilling of screw holes.
- Deterioration of roofing timber by water penetration through screw or nail hole.

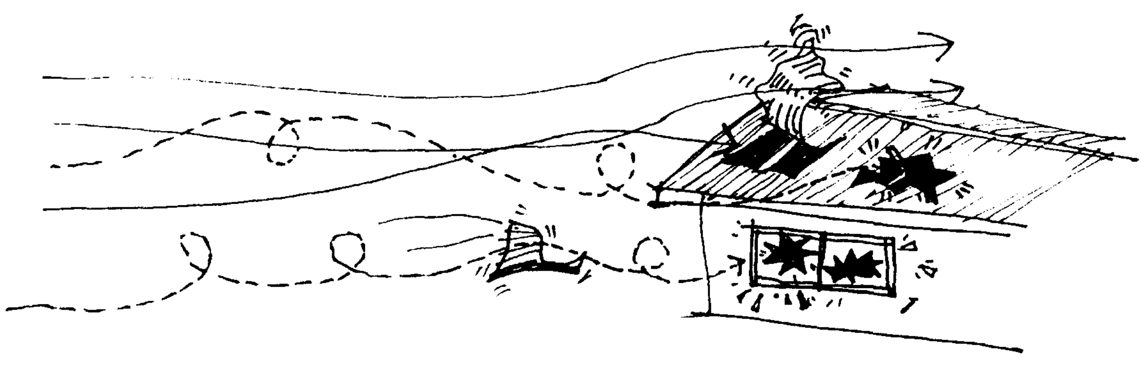




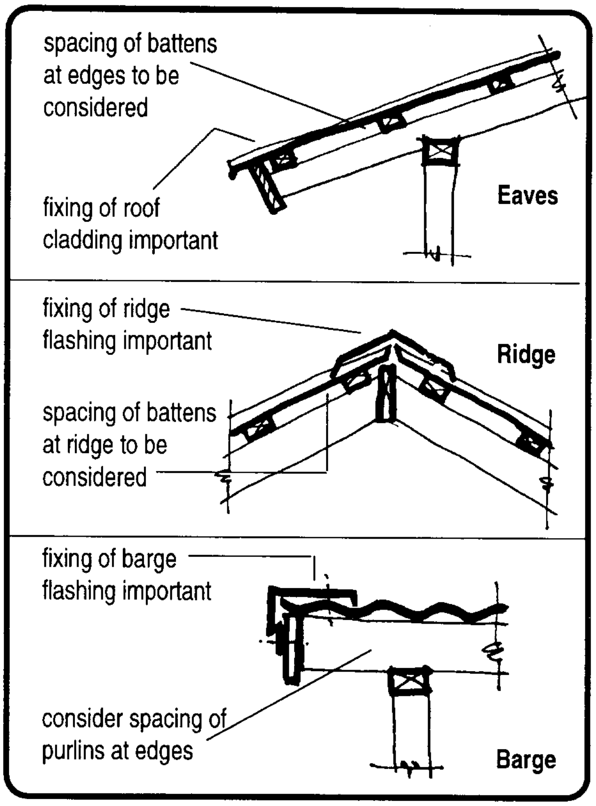
- Roof screws failing in torsion where not driven plumb, (especially in high rib roofing).

  Also, "creeping" can occur where long length roof sheeting shifts in position along the roof.
- Awkward fixing locations, such as at chimneys or roof penetrations, changes in roof shape where it is difficult to apply the correct fixings at the cladding to roof frame or roof frame to roof structure.
- Lack of fixings in tile roofs where it is difficult to provide adequate fixings at the lowest three tiles and at ridges and valleys.

  It is important to fully investigate tile roofs in cyclone areas.



- Lack of attention to fixings at ridges, barges and eaves.

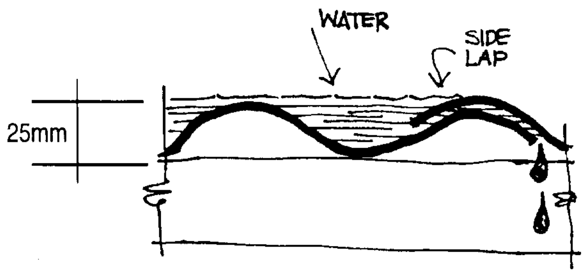


- Difficulties in providing fixings where roof insulation membranes are used on top of roof purlins or battens.

  This system also can prevent inspectors from viewing roof fixings and clips.

7.1.11 Documentation

- Using roof pitches that are too low where pans of roof sheeting can fill up with water under heavy rain with subsequent side flow of water under laps in roof sheeting and severe leaking to roof system causing consequential damages.



  Use of undersize timber roof members for battens, rafters or purlins causing deflection.

  Expansion causes weakness at roof cladding fixings allowing water entry and deterioration of fixing and its strength by rotting, etc...

- Using roof sheeting that is too thin, e.g., galvanised iron or aluminium where sheets can tear away from fixings.

- (Closer spacing of purlins or battens can reduce the loads to be resisted at each point of support).

7.2 POINTS TO PONDER

- The wind load acting on the site of a typical single level three classroom school 5.0 m high and 20 m long is sufficient to over-turn an unreinforced building.

- At 35 m/s (78 mph) (128 kph) the suction (uplift) forces on a roof are greater than the dead weight of the roof tiles and roof framing. Therefore, above these wind speeds we can expect roof damage unless we take steps to "tie down" the roof and its cladding.

- If you use shutters for protection, you have to be home to close the shutters.

  If you live in the tropics where windows are much larger the shutters are larger and separately stored. The occupants have to attend to the erection of these shutters, when the cyclone alert occurs.

- The force of the wind at 70 m/s (150 mph) (250 kph) is strong enough to move light concrete slabs.

The school is often the largest building in the village with no one to take care of it. People may always relate closely with their home and property but in some countries, they feel little responsibility to protect the government's school buildings.

7.3 PROBLEMS TO AVOID

7.3.1 Examples of Typical Failures

There are many failures in building construction in cyclone areas.

The most common are:

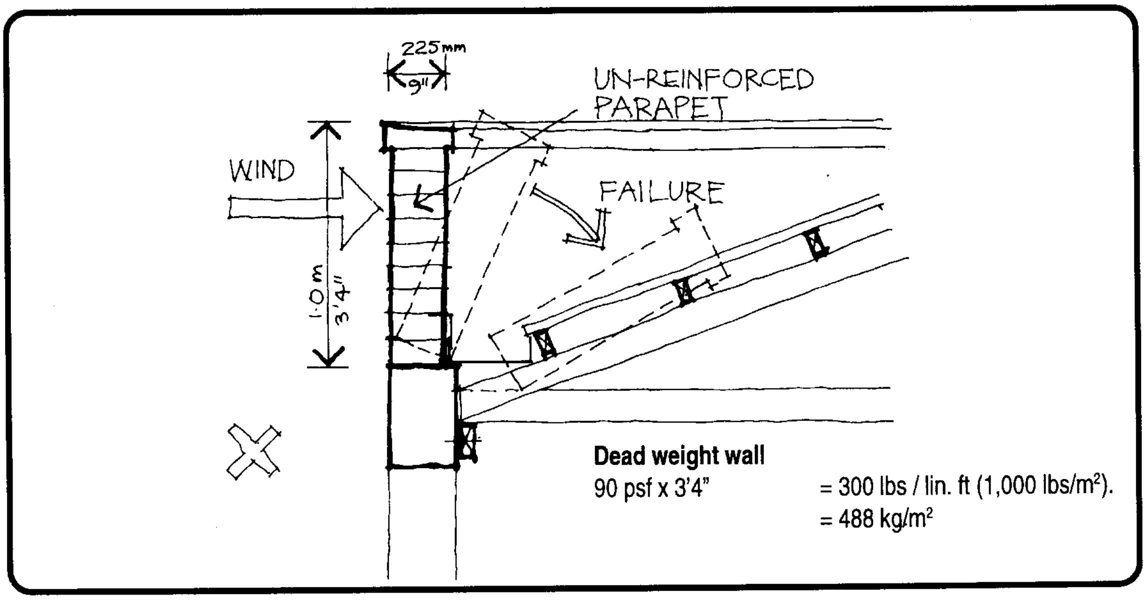
- Roof sheeting removed from purlins.
- Roof sheeting and purlins removed from rafters.
- Roof sheeting, purlins and rafters removed from wall frames (i.e., whole of roof structure removed).
- Roof structure removed, walls distorted.
- Whole wall, roof removed or destroyed.
- Whole structure intact but distorted due to inadequate bracing.
- Failure of brick or block walls due to inadequate stiffening at tops of walls and inadequate vertical reinforcement.

Apart from these typical failures, there are other modes of failure that can cause damages.

7.3.2 Brick Parapets – Fixing

The following diagrams describe situations where damages have occurred due to failure of a component or method of construction. The consequential damages caused by the collapse have been costed at many times the value of the damaged component.

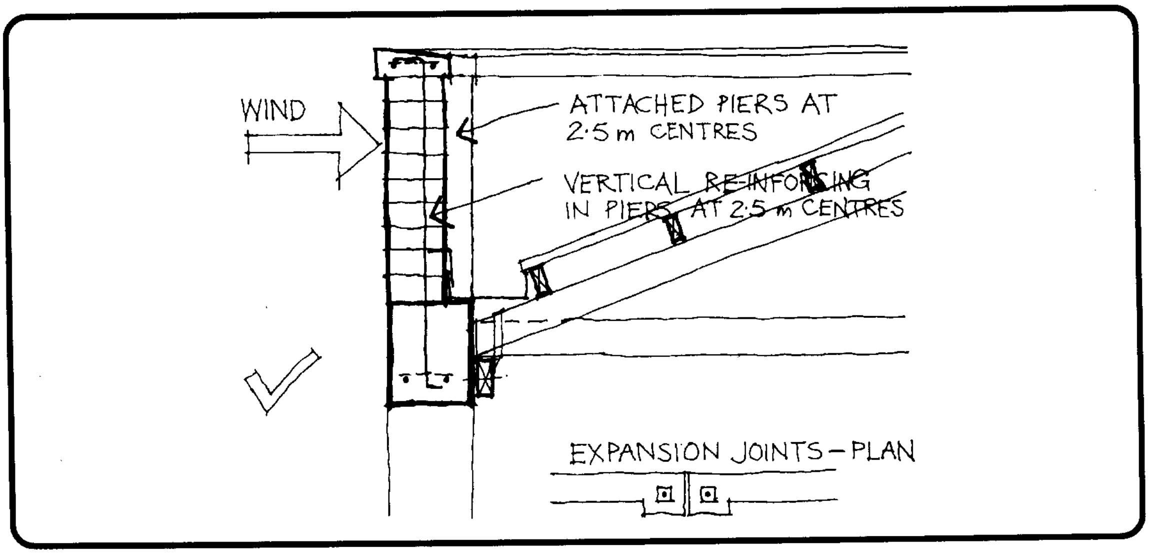
Un-reinforced brick parapet walls are dangerous and prone to collapse under wind loads.



Where the wall is laid above the beam as shown it is a vertical cantilever and will collapse at moderate wind forces. If a damp proof course is laid in the wall it is substantially weaker (up to 50%).

If the wall is 30 m long x 1.0 m high its weight is 14,650 kg and can cause damage to other parts of a building when it collapses.

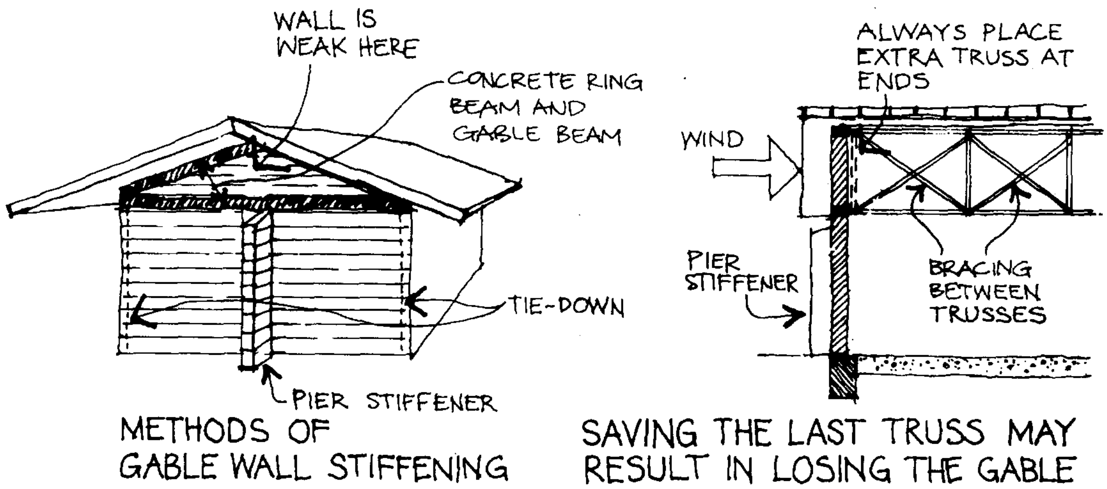
- The writer has seen an example where a 50 m long parapet as modelled above existed on the boundary wall of the second floor of a 6,000 m² city department store. When the brick parapet collapsed it fell onto a series of steel roof trusses, cracking the weld on 10 trusses with the shock load of impact. The bricks fell through the false ceiling to cause damage to the Fashion Department.



The wall should be topped with a concrete bond beam itself tied down to the base at regular centres and at edges of expansion joints and ends of wall panels.

Return walls or stiffening nibs should be provided at regular intervals (say 2.0 to 3.0 m apart).

Normal expansion joints should occur to avoid longitudinal expansion problems. Piers at joints should be reinforced vertically.



7.3.3 Gable Walls

Gable wall designs continue to ignore the wind loads placed on the gable wall, especially at the apex of the gable. Many collapse throughout Asia and elsewhere. The gable end wall needs to have proper support. The practise of saving the cost of a truss against the wall is not warranted as the truss can, with bracing from other trusses, provide good lateral support to the top of the wall.

Long brick walls can also benefit from the addition of attached piers and concrete bond beams and columns.

Brick walls can gain lateral support from braced trusses. Always place extra truss at gable wall.

7.3.4 Clip on Fascia Cladding

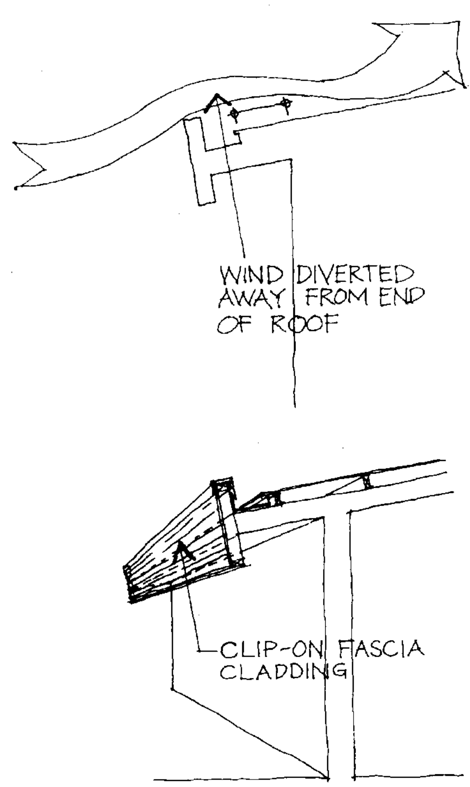
When fascias to roof systems are deepened as shown there is an advantage in distribution of wind load. The normal roof has a higher wind load at the eaves of 2.6 to 2.7 **q** compared to 1.6 to 1.7 **q** in the body of the roof.

The introduction of a deep fascia (and hidden gutter) as illustrated, will divert the high pressure winds away from the eaves and allow a lesser wind pressure to impact some distance away from the eaves. This may even out the overall pressure on the roof to a more even wind suction load throughout. This will suggest that all roof fixings may be similar and is a detail worth considering.

However, the framing of this fascia (or barrier to divert the wind) should be well constructed.

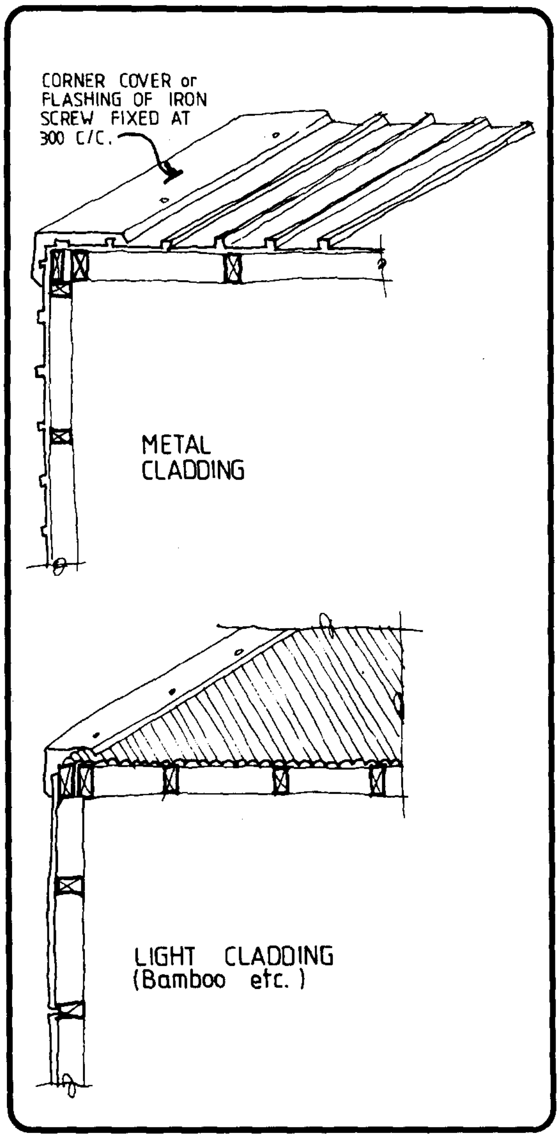
In addition, the cladding of the fascia and its flashings will need high quality fixing to its sub-frame by screwing of the sheet to the supports.

Current traditional sheet clipping systems have proven inadequate and will de-index under the wind loads, thus exposing the roof areas to progressive degradation. This failure occurred at a University in Australia in the 1971 Cyclone Althea.



7.3.5 Corner Protection to Cladding

Removal of corner flashing and barge flashing led to loss of wall and roof cladding in the loft of a television studio with consequential loss of expensive control room equipment and two weeks "off air".



It is important to give protection to salient edges or corners in lightly framed buildings as it is at these corners where the turbulent wind pressures on the wall claddings are greatest (called the cladding load).

They are 50% greater than the structural wind loads (those wind loads for which the building's structural framework is designed by the Engineer).

Where the corner claddings are not properly considered, detailed cover moulds and / or flashings can be easily removed by the wind leading to progressive degradation of the adjacent cladding which is often lightly fixed behind the cladding.

7.3.6 Platforms on Roofs

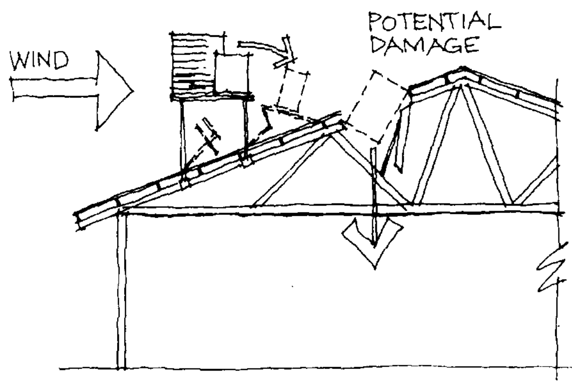
Many contemporary buildings save floor space by mounting equipment such as water tanks, solar hot water panels, air-conditioners and the like on the roof, often on frames built above roof level.

In the typical case of air-conditioning units, installers believe that the weight of the unit was sufficient not to worry about securing the unit to the frame or the roof structure.

In cyclones, wind loads will overturn these units which can fall through roof sheeting and damage the sheeting, framing, ceiling, lighting and stores, etc... in the building.

Subsequent rain and wind can cause consequential damage to the interior of the building and its equipment which can be many times the value of the building damage.

All roof mounted plant must be properly strapped and held onto adequate roof framing platforms mounted above roof sheeting and adequately supported through the roof to properly transfer loads.



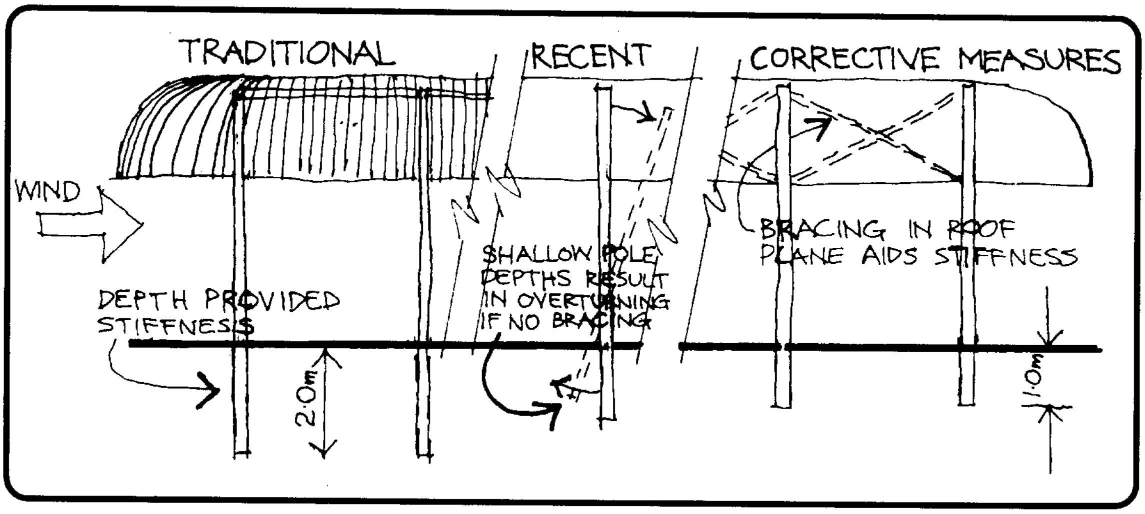
It is better in cyclone areas to avoid such roof mounted equipment.

The case examined was a newspaper printing establishment where roof mounted air-conditioning equipment loosely mounted on a frame was blown off and fell through an asbestos cement roof. Among the damages was the loss of over 100 one ton coils of newsprint paper, a three months supply to the plant located in a remote area.

7.3.7 *Fale Construction*

In traditional fale or bure construction in the Pacific Islands, the poles were well treated and buried up to 2.0 m into the ground.

This system provided stiffness to the pole and avoided the need for roof plane bracing. The style became the custom.



In more recent times, poles have been installed at much shallower depths (presumably to save money), also without roof bracing. Many failures occurred due to the loss of integrity of the vertical cantilever previously adopted.

Where one system passes through a transition period into another system, we must identify the integrity of the original system and, if deleted, replace it with a new system of integrity.

7.3.8 *Brick Wall Overturning*

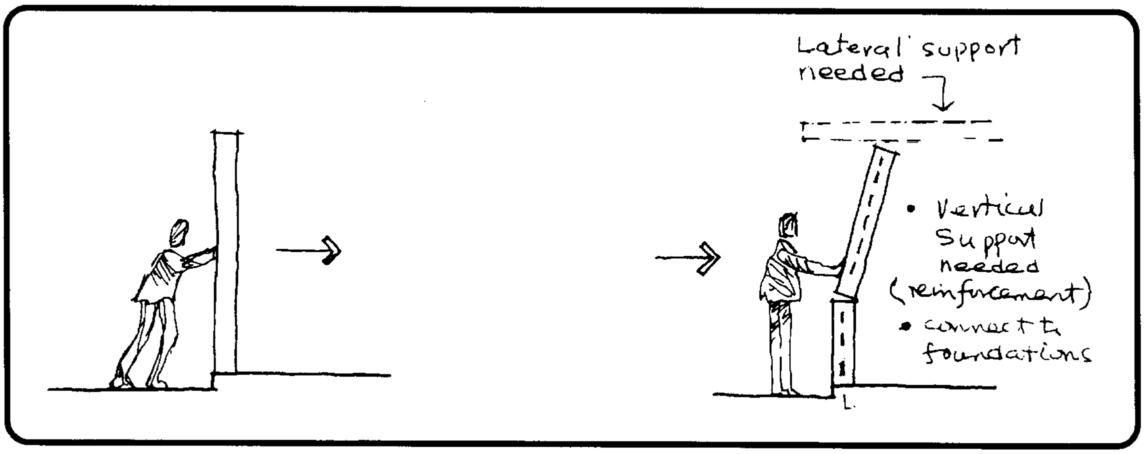
Brick walls are often erected, especially, in low rise one and two level buildings, with inadequate attention to their restraint and need for support.

In cyclone regions we see many screen walls and property boundary walls 1 m to 2 m in height which simply blow over.

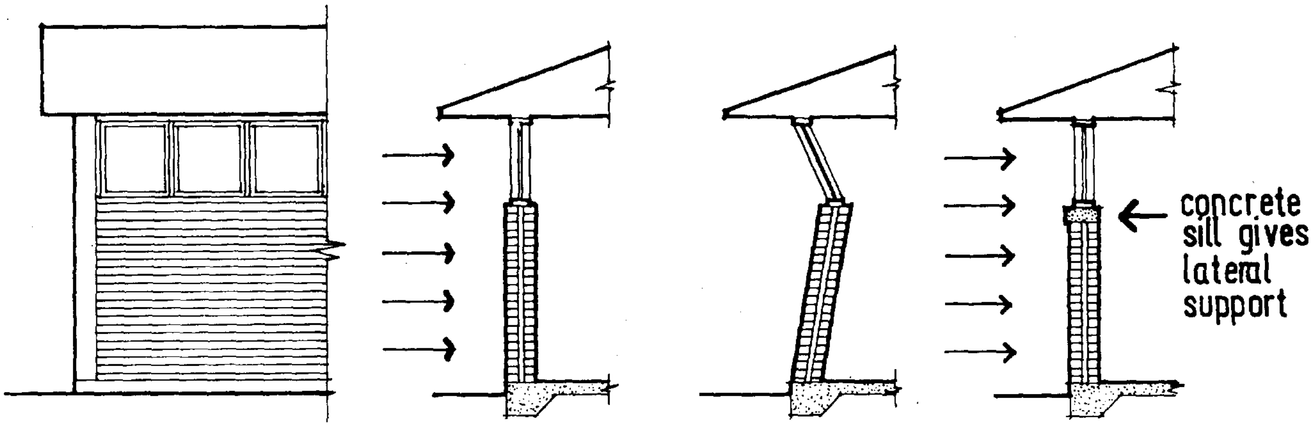
In buildings, it is often popular to separate concrete columns from brick walls to enable full height windows to be placed each side of the column for aesthetic reasons of delineation of the column and to let light into the building (see sketches on page 98). If there is no restraint or lateral support at the top of the wall then the wall is a simple vertical cantilever and can easily blow over.

This, in fact, occurred in a University residential building in Townsville in 1971 where a series of 2.0 m wide 270 thick cavity walls 3.0 m high leaned inwards 300 mm during a cyclone.

The sketches following illustrate the problem and offer solutions.



7.3.9 *Half Height Walls*



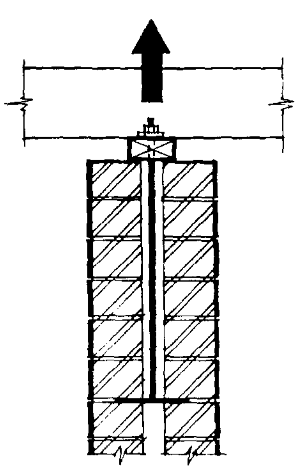
Wall unstable as sill plate is not given adequate lateral support

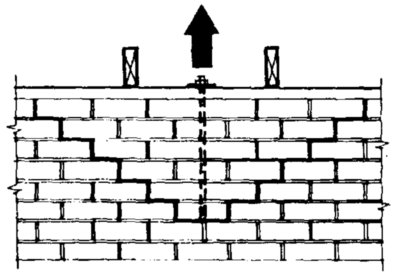
Long lengths of half height walls are often designed to allow long strips of windows for light and ventilation reasons. These can topple over in high winds unless they are restrained with attached piers, columns or stiffener posts and possibly a reinforced concrete sill tied between floor to roof supports.

7.3.10 *Inadequate Tie-Down*

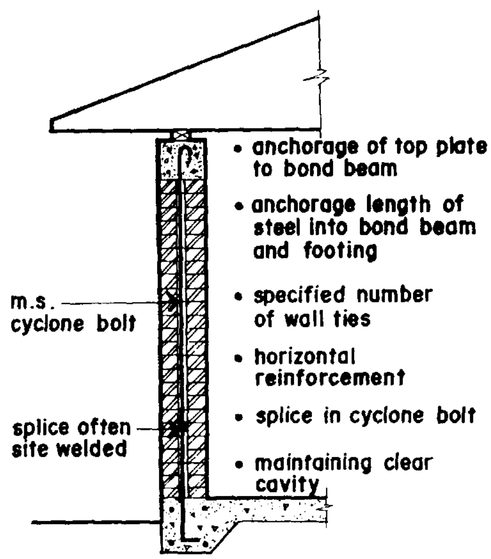
It is common practice in non-cyclonic areas to tie top plates down some 5 or 6 courses into brick walls. The 500 deep section of wall with a weight of about 250 kilograms is unable to restrain uplift forces of 1,500 kgs or more.

The holding down bolts to the top plates should extend right down to the foundations.





Typical failure pattern – insufficient anchorage.
Insufficient anchorage leads to loss of roof and top of wall, then collapse of wall. Top plates / bond beams must be anchored to footings for adequate restraint of top plate/bond beam and intervening wall.

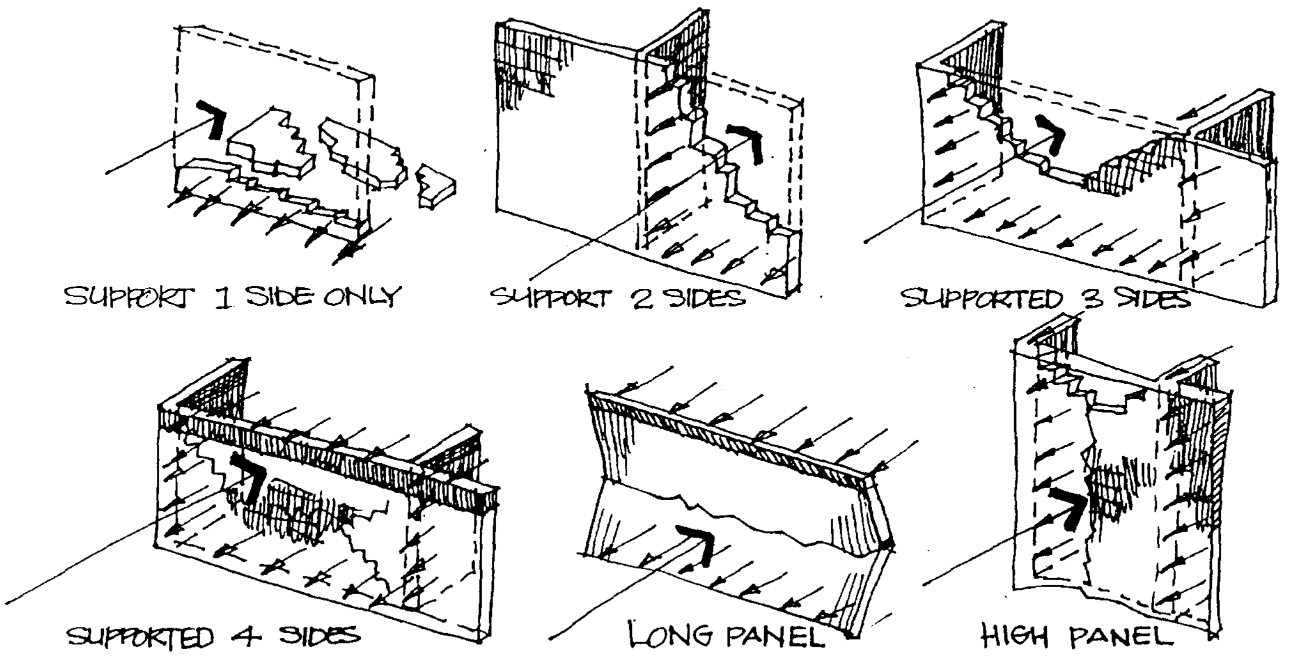


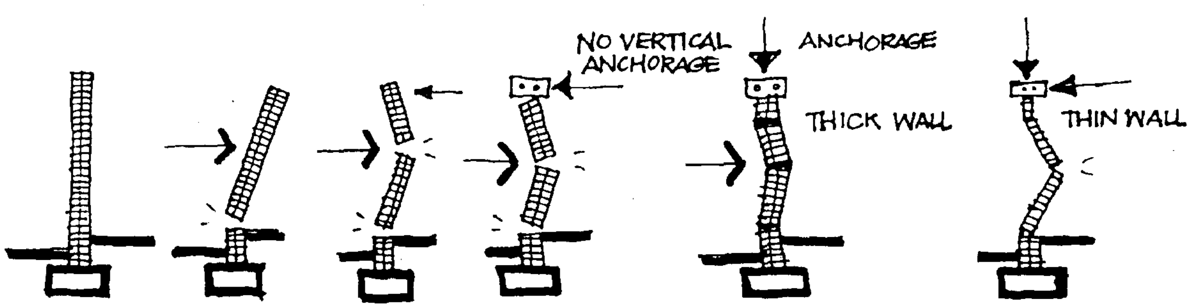
Points to watch for.

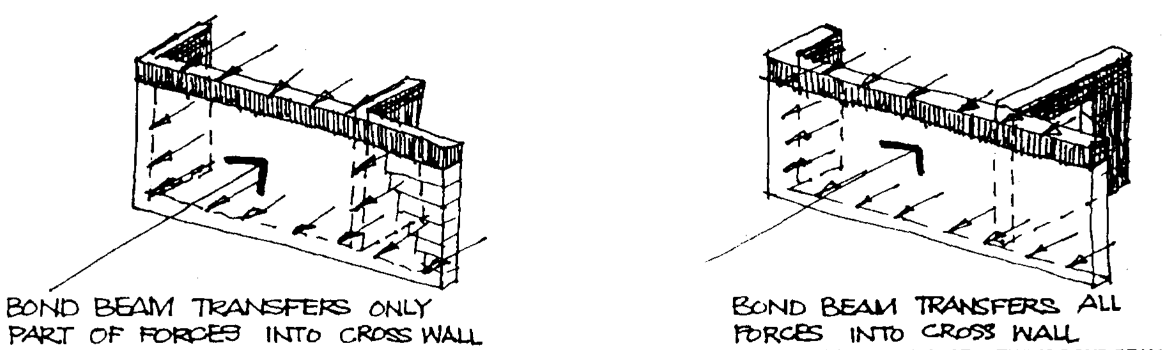
Common Problem Areas and Faults in Cavity Brick Walls

7.3.11 *Wind Action on Brick Walls*

The page of sketches illustrates the need for careful design of brick walls where length, height, size and reinforcement are critical factors if the wall is to resist nature's forces.

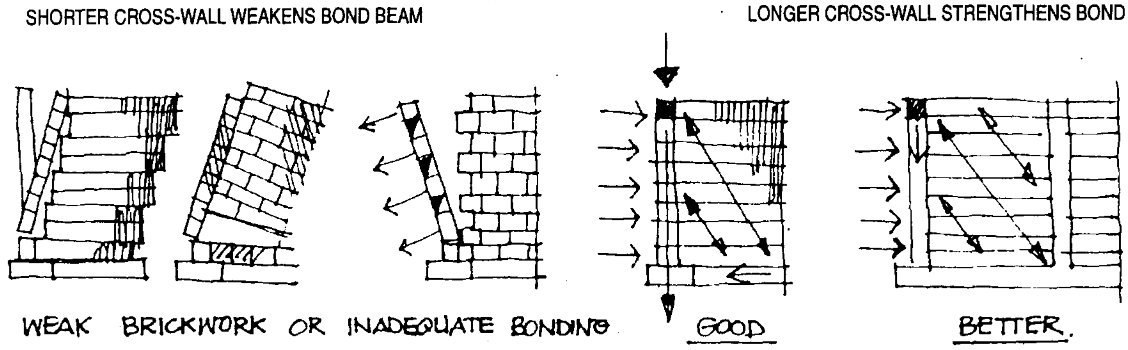






SHORTER CROSS-WALL WEAKENS BOND BEAM

LONGER CROSS-WALL STRENGTHENS BOND BEAM



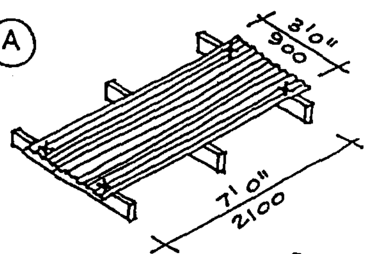
7.3.12 *Inadequate Fixing of Roof Cladding*

The above test was carried out on two occasions in 1979 in Sri Lanka after the 1978 cyclone. The impact of the testing was dramatic where the asbestos cement sheet cracked noisily on failure and the people loading the sheet fell 6" to the floor. The 'J' bolts (5–6 mm Ø) bent under the load of the 4 people.

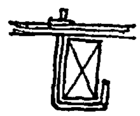
INADEQUATE FIXING OF ROOF CLADDING

1. ROOF SHEET FIXING - TYPE 'A'

(A)

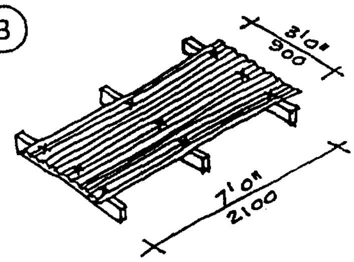


- ONE FIXING AT EACH CORNER USING 'J' BOLT FIXING
- 4 FIXINGS

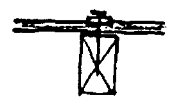


ROOF SHEET FIXING - TYPE 'B'

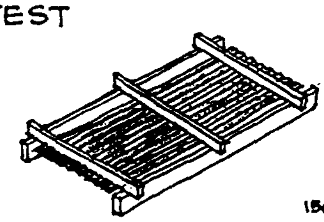
(B)



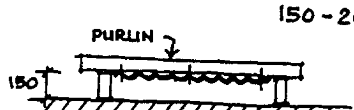
- THREE SCREWS AT EACH PURLIN CROSSING
- 9 FIXINGS



2. TEST



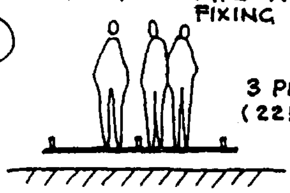
PROP 150mm OFF FLOOR



TEST BY LOADING PEOPLE ON INVERTED ROOF SHEET FIXED TO PURLINS PROPPED 150-200 ABOVE FLOOR

3. LOAD TEST - TYPE 'A' ROOF SHEET FIXING

(A)

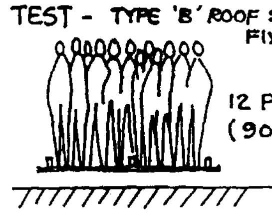


3 PEOPLE (225 KG.)

WILL SUPPORT 3 PEOPLE BEFORE FAILURE.
SHEETING CRACKED.
'J' BOLTS BENT.

LOAD TEST - TYPE 'B' ROOF SHEET FIXING

(B)



12 PEOPLE (900 KG.)

WILL SUPPORT 12 PEOPLE BEFORE FAILURE.
SHEETING FAILED BY PULLING THROUGH ON SCREW HEAD

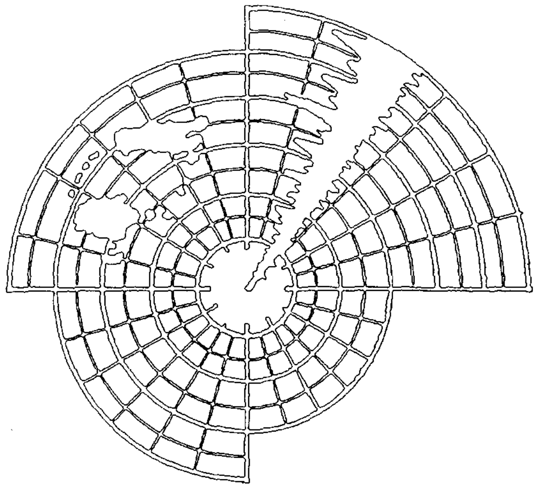
NB.
AVERAGE CYCLONE LOAD.
MANY ROOFS HAVE TO CARRY MORE LOAD & NEED CLOSER PURLIN SPACING AND MORE FIXING.

4. COST

IN A TYPICAL SCHOOL IN SRI LANKA (38m x 9m)
180 ROOF SHEETS OF THIS SIZE ARE NEEDED
MODEL 'A' NEEDS 720 FIXINGS
MODEL 'B' NEEDS 1620 FIXINGS
EXTRA COST IS 900 FIXINGS

IN 1979 IN SRI LANKA
ONE 'J' BOLT COST 1 RUPEE
ONE SCREW COST 1 RUPEE
900 SCREW COSTS 900 RUPEES
WEEKLY WAGE 250 RUPEES

ONE TRADESMAN'S PAY FOR LESS THAN ONE MONTH TO CARRY 4 TIMES THE LOAD



8 CALCULATION EXAMPLE — MODEL CLASSROOM BLOCK

CONTENTS

8.1 SCALE OF WIND LOADS – EXAMPLE ON SCHOOL BUILDING

The same school building in the following four situations has to withstand different load conditions on each site.

8.1.1 *Procedure*

The Basic Wind Speed (**V**) recorded can be translated into a Design Wind Speed (**V_S**) after applying factors for topography, site category or ground roughness, height, and importance of structure.

The Design Wind Speed is converted into a Dynamic Pressure (**q**).

The Dynamic Pressure is then converted by appropriate pressure co-efficients into a pressure (**p_e**) acting on any point on the surface of a building.

This pressure can be a positive pressure, acting toward a surface, or a negative suction from the surface.

The pressures or suctions are greater within 15% of corners of walls and edges of roofs. These wind pressures act over a surface to produce a wind force.

Internal wind forces add to the external suction forces to arrive at the total wind load or pressure.

This is then applied to a point or to whole surface areas such as walls or roofs.

The resulting pressures are those which should be considered in design.

Finally, it should be noted that the forces on the claddings, glazing and roofing (called Class A) are greater than the forces on the structure of the building (called Class B for building up to 50 m long or high) and Class C for the larger buildings.

Reference – British Code CP3 – 1972

8.1.2 *Variations in Wind Loads due to Ground Roughness and Wind Speed*

TABLE 16
DESIGN DATA FOR SCHOOL SITES

Basic Wind Speed	(V)	50.0 m/s		50.0 m/s		50.0 m/s		40.0 m/s	
Height to Ridge	(H)	5.0 m		5.0 m		5.0 m		5.0 m	
Site Ground Roughness	(S_2)	1		2		3		3	
DESIGN WIND SPEEDS	(V_s)	m/s	mph	m/s	mph	m/s	mph	m/s	mph
Class B	– for structure	41.5	93	37.0	83	32.5	73	26	59
Class A	– for cladding	44.0	98	39.5	88	35.0	78	28	63
DYNAMIC WIND PRESSURES	(q)	kPa	psf	kPa	psf	kPa	psf	kPa	psf
Class B	– for structure	1.05	22.1	0.84	17.6	0.65	13.6	0.41	8.9
Class A	– for cladding	1.19	24.6	0.96	19.8	0.75	15.6	0.48	10.2
MAXIMUM WIND PRESSURES									
CLASS B - STRUCTURE	(q)								
Wall Structure	1.6 q	1.68	35.4	1.34	28.2	1.04	21.8	0.66	14.2
Roof Structure	1.9 q	1.96	42.0	1.60	33.4	1.24	25.8	0.78	16.9
CLASS A - CLADDING	(q)								
Wall Cladding	– General 1.6 q	1.90	39.4	1.54	31.7	1.20	25.0	0.77	16.3
	– Corners 1.9 q	2.26	46.7	1.84	37.6	1.43	29.6	0.91	19.4
Roof Cladding	– General 1.9 q	2.26	46.7	1.84	37.6	1.43	29.6	0.91	19.4
	– Corners 2.7 q	3.21	66.4	2.59	53.5	2.03	42.1	1.30	27.5

Statements:

1. On the type 3 site at basic wind speed 40 m/s; the loads are approximately half those on the type 2 site at 50 m/s.
2. On the type 1 site at basic wind speed 50 m/s; the loads are 25% higher than those on the type 2 site at 50 m/s.
3. The loads on the type 1 site at basic wind speed 50 m/s are 250% higher than those on the type 3 site at 40 m/s.

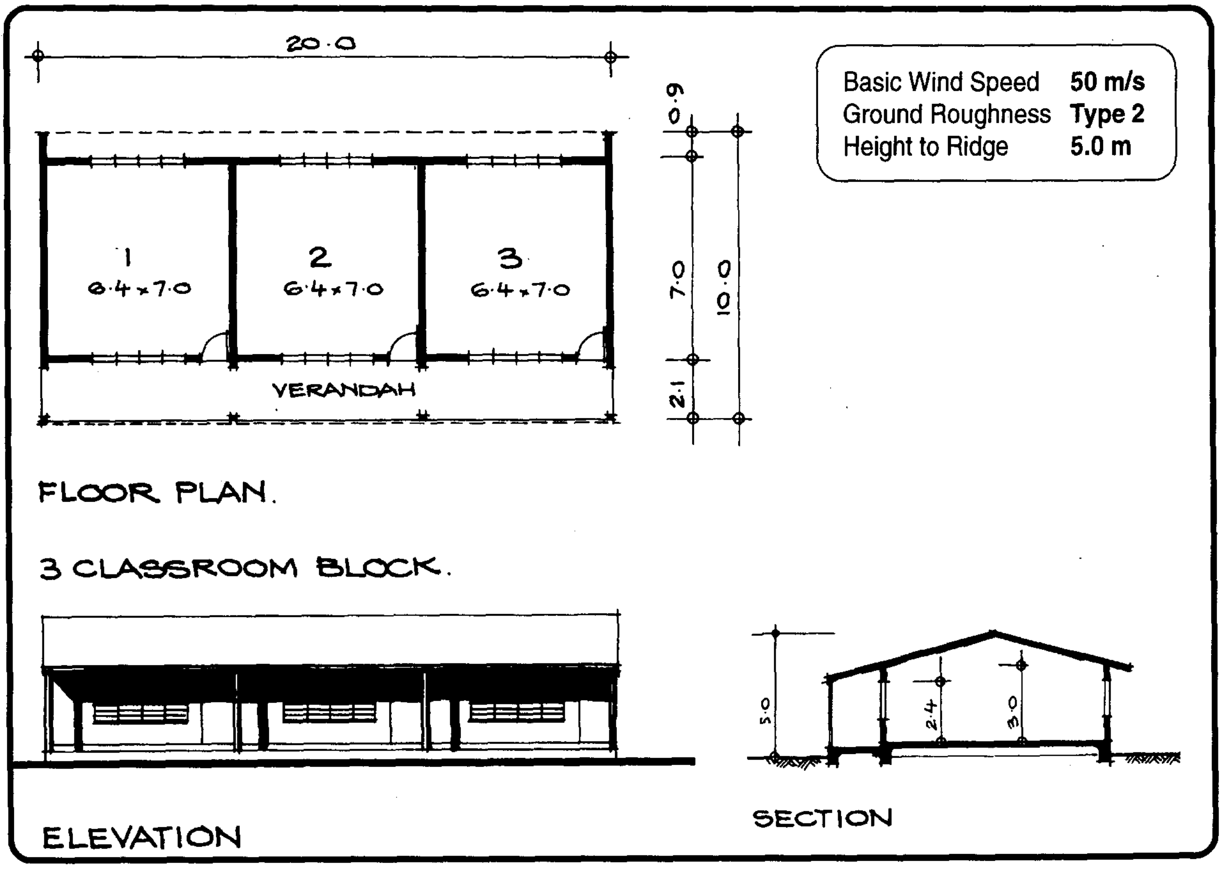
8.1.3 *Example of Wind Loads*

How can we understand the wind loads involved in a cyclone? Hereunder are some examples, using as a model a simple 3 classroom block – 20.0 m long by 7.0 m wide, plus a 2.1 m wide balcony on one side.

(a) *Wind Force*

Assume the wind speed applies to the following areas:

Face wall area	20 x 3 =	60 m^2
Face roof area	20 x 10 =	200 m^2

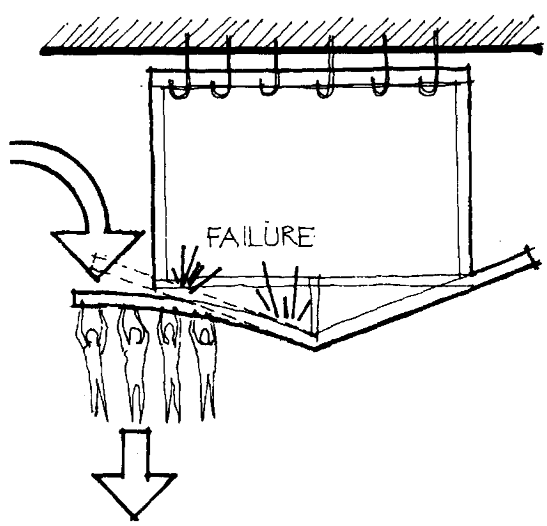


(b) *Global Loads*

Front wall area	60 m^2	x	1.34 kPa =	84 kN load	(18,600 lbs)	> 8 tonnes.
Roof area	200 m^2	x	1.60 kPa =	320.0 kN load	(72.628 lbs)	> 32 tonnes.

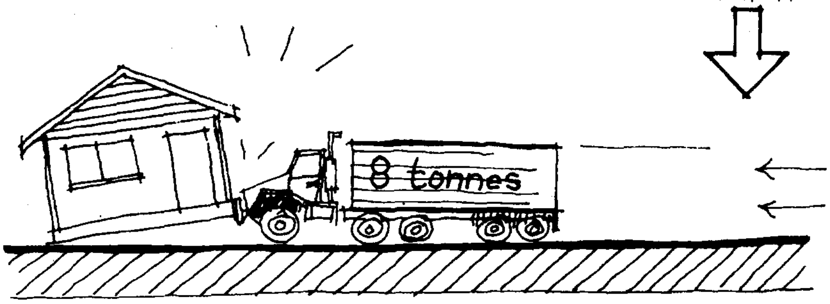
Roof Load

The total structure load on the roof is equal to two people per m^2 hanging on the roof. The cladding load tending to pull sheeting off equals four people /m^2.



Wall Load

The total structure load on the wall is equal to the mass of eight (8) one-tonne trucks acting on the wall.



8.1.4 *Calculate Loads to Assist in Holding Down from Roof to Floor Slab (Model School)*

Data taken from British Code Tables A – E (refer Section 5).

Ground Roughness **Site Category 2**, Height to Roof Ridge **5.0 m**, Wind Speed **50 m/s**

Pressure Co-efficients

Walls	1.6 to 1.9 q	for Class A – Wall Claddings
	1.6 q	for Class A – Wall Structure
Roof	1.9 to 2.7 q	for Class A – Roof Cladding

Wind Pressures

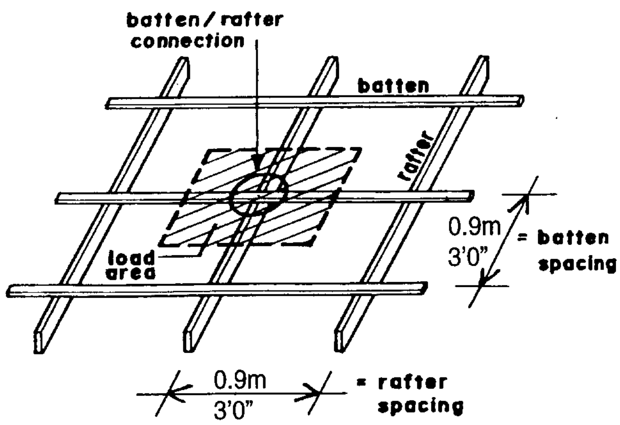
Walls	1.54 to 1.84 kPa	(31.7 to 37.6 lbf/ft²)	for cladding.
	1.34 kPa	(28.2 lbf/ft²)	for structure.
Roof	1.84 to 2.59 kPa	(37.6 to 53.5 lbf/ft²)	for cladding.
	1.60 kPa	(33.4 lbf/ft²)	for structure.

Resistance capacities taken from Timber Research and Development Advisory Council of Queensland (1990): **TRADAC W50 Manual**, Australia

A. *Roofing Batten to Rafter Connection*

A.1 Load Area

0.9 x 0.9 = 0.81 m².
3'0" x 3'0" = 9 sq.ft.



A.2 Load or Force

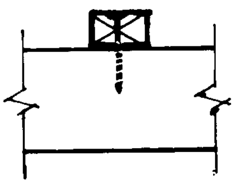
Class A Roof Load

1.84 x 0.81	=	1.5 kN
2.59 x 0.81	=	2.1 kN
37.6 x 9	=	338 lbf
53.5 x 9	=	482 lbf

A.3 Fixing Choices – Batten to Rafter

i. Screw fix

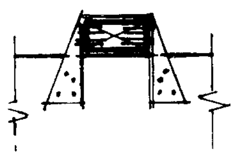
Strength 2.0 kN to 3.5 kN
(for timber grades F11 to F14).
Unseasoned timber 2.0 – 3.5 kN
Seasoned timber 1.4 – 2.5 kN.



ii. Metal framing anchors

2/metal framing anchors.
4/2.8 mm nails – each leg.

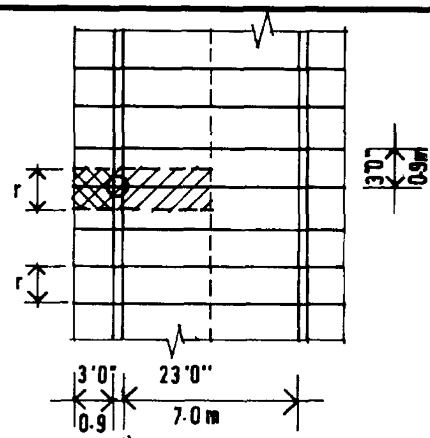
Unseasoned timber	2.5 to 4.0 kN.
Seasoned timber	2.6 to 5.1 kN.



B. *Rafter to Wall Top Plate*

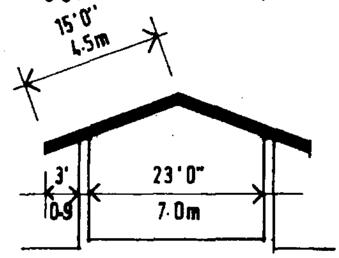
B.1. Load Area

44 x 0.9	=	3.96 m²
14'6" x 3'0"	=	43.5 sq.ft



B.2. Load or Force – Class B Structure

1.6 kPa x 3.96 m²	=	6.34 kN
33.4 lbf/sq.f x 43.5	=	1,453 lbf



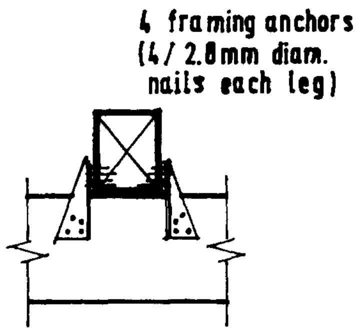
B.3. Fixing Choice

i. Metal framing anchor

4 Framing Anchors
4/2.8 mm nails each leg

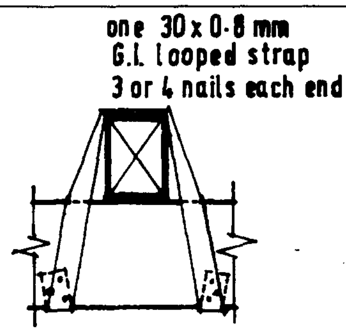
Capacity – Max. 1820 lbs

Capacity – Seasoned timber depending on timber quality.	4.7 to 7.5 kN
Capacity – Unseasoned timber depending on timber quality.	4.7 to 9.3kN



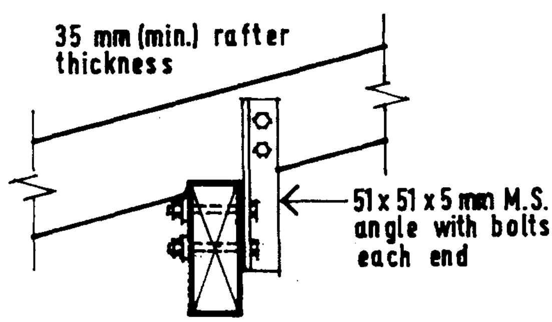
ii. Metal cyclone strap

One-strap 3/4 nails each end
Capacity – 7.2 kN



iii. Steel angle and bolts

50 x 50 x 5 MS angle with 2 x M10 bolts.
Capacity – Unseasoned timber 5.0 to 9.5 kN depending on timber quality.
Use better quality timber.



C. *Top Plate to Foundation*

Vertical tie down bolts at 1.8 m or 6'0" cc.

C.1 Load Area (Roof Uplift – Structure)

1.8 x 4.4	=	7.92 m^2
6'0" x 14'6"	=	87 sq.ft

C.2 Load or Force

Class B Structures

1.6 kPa x 7.92 m^2	=	12.7 kN
33.4 lbf/sq.ft x 87 sq.ft	=	2,906 lbf

C.3 Fixing Choices

i. Half-Inch Tie-Down Bolt

Capacity

One M12 Ø	=	12.1 kN
One $^1/_2$" Ø	=	2,720 lbf

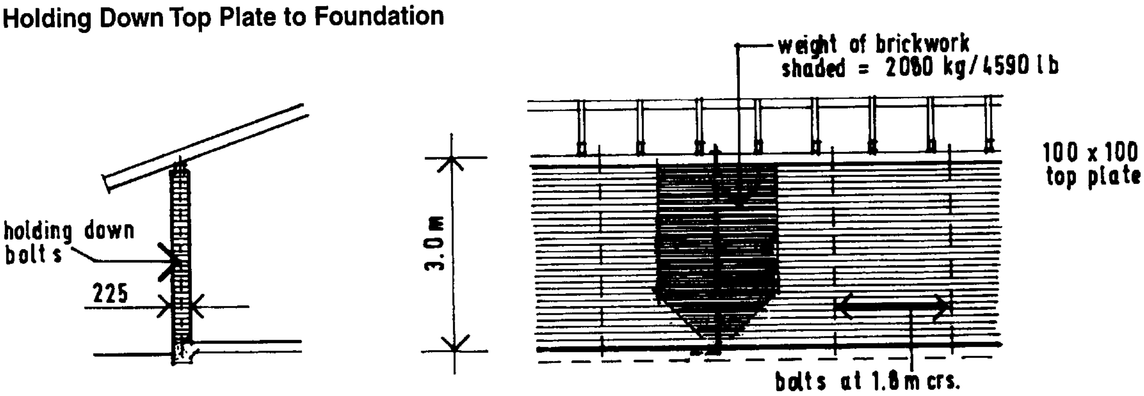
ii. Five-Eighth Inch Bolt

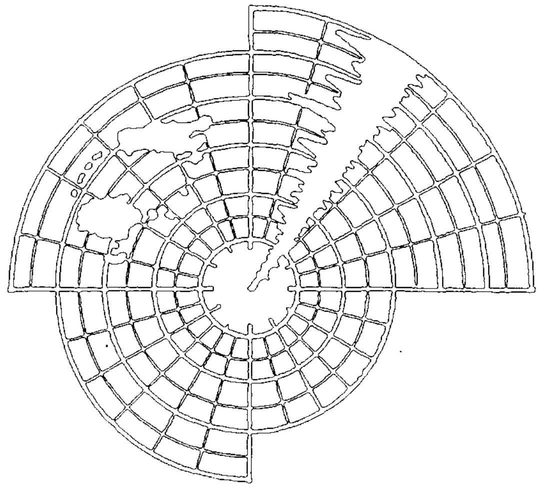
Capacity

One 16 Ø bolt	=	22.6 kN
One 5/8" Ø bolt	=	5,085 lbf

Check size (depth) of top plate to support load between bolt supports (force above less dead load of roof) for span of 1.8 m and roof span of 4.4 m (suggest 100 x 100).

Holding Down Top Plate to Foundation





9 REPAIR AND REHABILITATION

CONTENTS

9.1 SOLVING THE PROBLEM

The problem of developing standard solutions and the details required to upgrade or maintain the integrity of an existing building is difficult because of the variety of shapes, designs, and construction techniques used in individual buildings.

Each case should be looked at independently and a solution worked out for that particular building.

The strong and weak points in each building need to be identified as the building construction methods used by different builders vary so much.

However, the following methods may be used as a guide when examining existing buildings which need upgrading.

The examiner must use his imagination when inspecting in order to identify quickly the global loads and the existing elements which can be tied together. Simple solutions are best. Simple lines of load transfer are preferred. A regular grid of support is better in appearance than scattered or haphazard supports.

Try and get the support down to at least the floor to gain the advantage of the dead load or weight of the building. Do not forget that bracing can be provided by the existing wall and ceiling cladding in a lot of cases.

It is often possible to find solutions that are able to be carried out without vacating the building. Even where basic structural integrity is not present it may be possible to superficially implant a structural system of load transferring elements into or onto the building to give it sufficient security. Each case should be examined individually as it is often possible to find creative solutions to the problem.

9.2 PRACTICAL SOLUTIONS

This section will provide sketches of construction details that offer practical solutions to the problem of the provision of resistance to cyclone forces.

It will be dealt with by dealing with the following elements.

- General methods of design.
- Wall construction and hold down methods.
- Roof framing and connections.
- Bracing and use of diaphragms.
- Doors and windows.

It will also include case studies to illustrate where innovative, simple and economical methods were employed to save buildings from demolition or to extend their useful life.

As mentioned earlier, it is essential that the decision to demolish or rebuild is made by architects, engineers or building operatives experienced in the field.

The degree of partial demolition to provide access to enable strengthening procedures to be adopted is also an important decision where sound knowledge of construction and costing is needed.

9.3 GENERAL METHODS OF DESIGN

The designer should be logical when designing for cyclones.

It is better to design a "framing system" to transfer loads from roof to foundation rather than simply allow construction to proceed on the "gravity system" where reliance on the dead load of the building materials is likened to the sticking together of many components to provide a link or chain of integrity (the "stitching" method).

Framing systems can consist of many varieties which may include:

- Pole construction where timber or concrete posts or poles are set deeply into the ground and cantilever up to the top plate level, (traditional Pacific Island method).

  – Alternate

- Brick walls bearing on concrete or stone foundations with bond beam at top of wall reinforced down to foundations at regular centres.

  – Traditional

- Post and beam or portal frame construction in timber, concrete or steel with bracing walls of timber framing, brick or block.

  – Preferred

  This system has been widely used for industrial and commercial work for many years and is, in the writer's opinion, the best and most economical method of providing the maximum security. A sketch of a simple system in timber frame is shown. The shape and pitch of roof may alter according to the designer's taste.

All framing systems and all structures (including wall framing and roof framing) require to be braced in the plane of the wall or roof to set up a diaphragm action to resist racking forces.

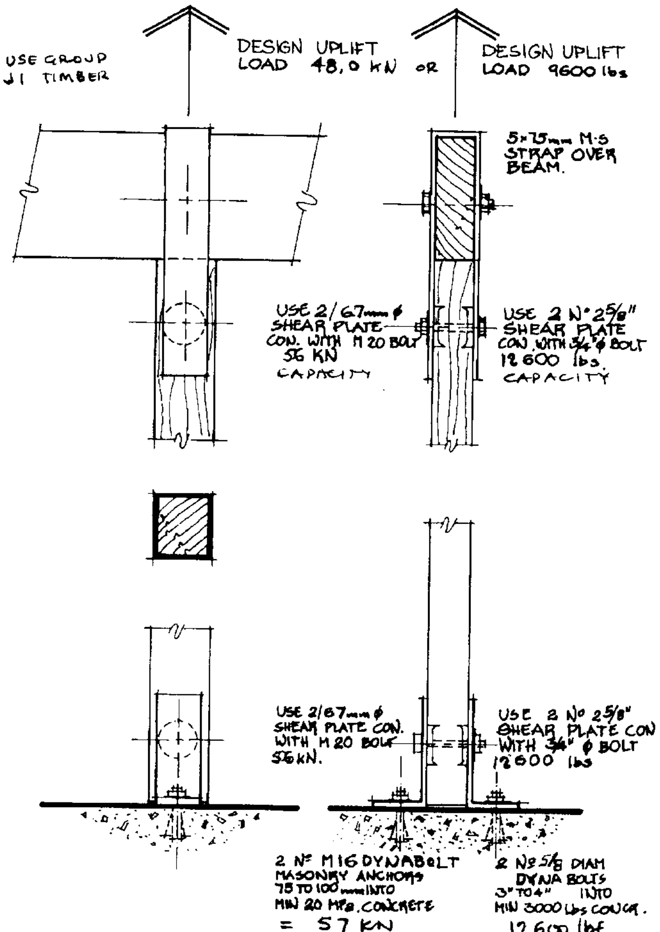
In addition, external walls need lateral support when spans along the length of the wall become too long for safety. These buttress type cross walls provide stiffness.

All systems need vertical ties from the top to the bottom of all walls and therefore they need a continuous element at the top of the wall, a bond beam, ring beam, tie beam or top plate.

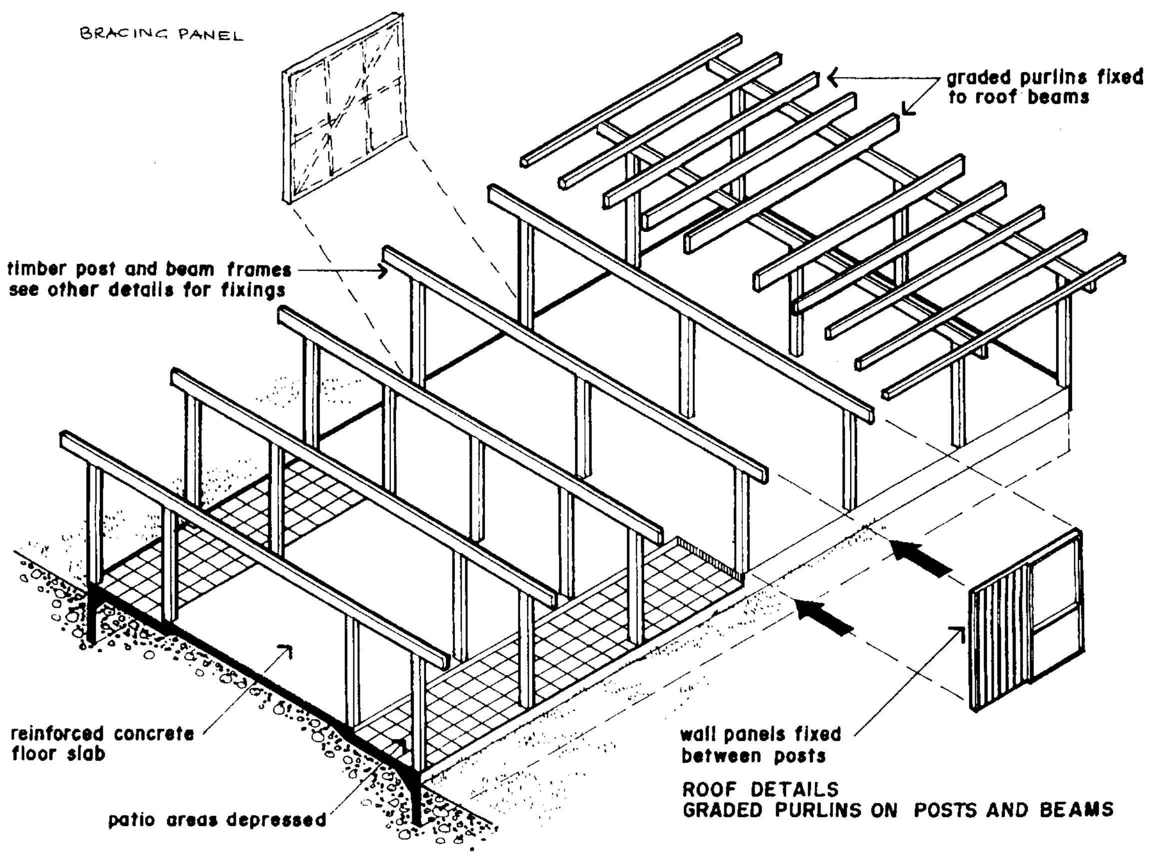
9.3.1 *Post & Beam*

The post and beam system has the advantage that there are fewer key joints or connections to inspect to ensure safety has been achieved than the case where the inspector has to examine practically every timber connection, in a stud wall for example, to ensure security of construction. Additional advantages are that the roof is pitched earlier than in conventional construction, offering shade during building, and a quicker completion.

The strength in a simple timber post and beam design can be seen in the attached sketch where the post detail can transfer 57 kN or approximately 5.6 tonnes.



POST AND BEAM CONNECTIONS - FIXINGS.
(Can transfer 57 kN or approximately 5.6 tonnes)



ROOF DETAILS
GRADED PURLINS ON POSTS AND BEAMS

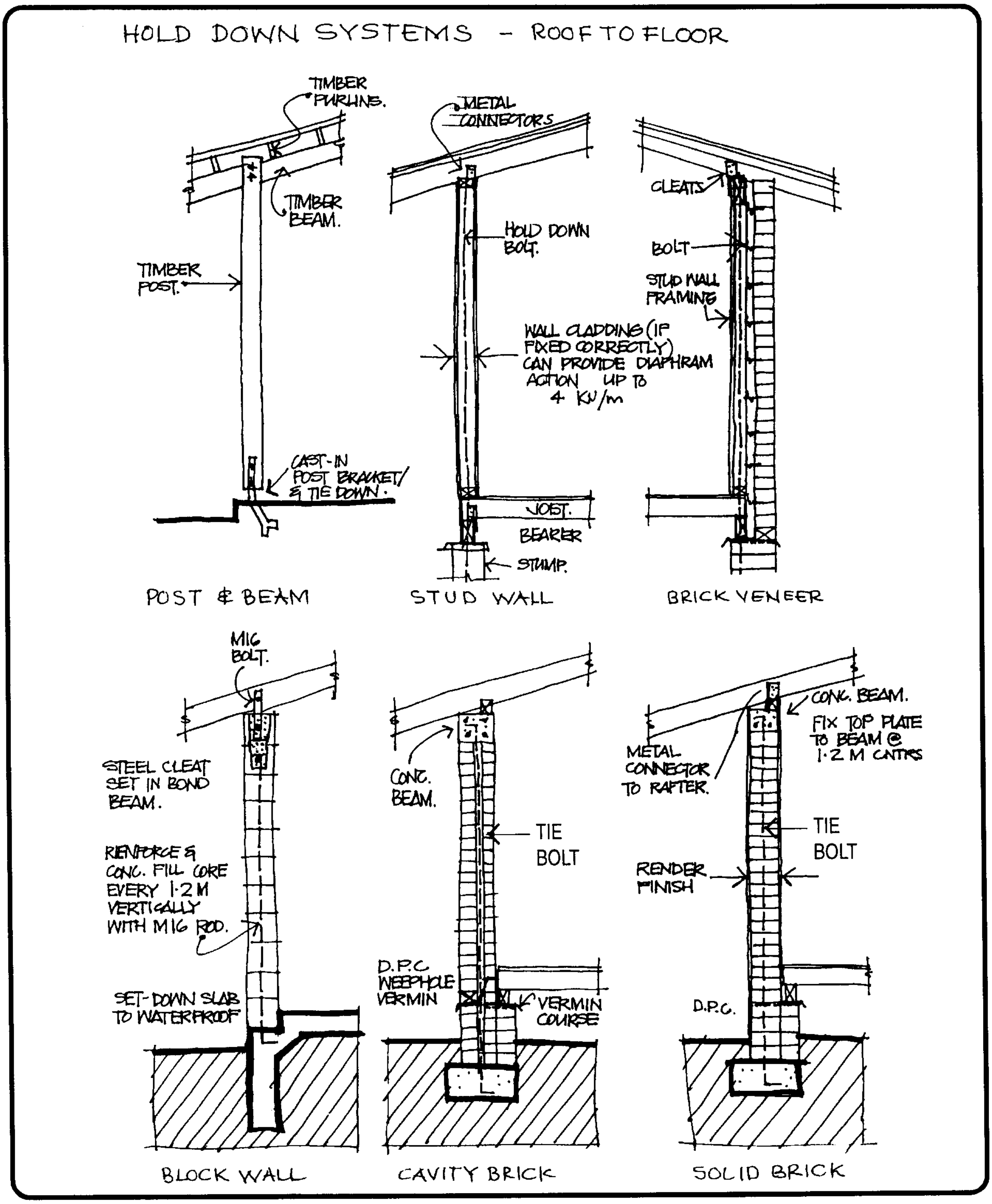
9.4 WALL CONSTRUCTION AND HOLD DOWN SYSTEMS

If existing buildings are selected for repair and rehabilitating, then weakness in wall construction requires upgrading by:

- Stiffening of wall where too thin for the length or height.
- Installation of bracing wall where walls are too long between supports.
- Installation of innovative "hold down" methods which transfer loads from roof plane to foundation such as the surface frame system.

9.4.1 Traditional Methods

Traditional methods of holding down are illustrated hereunder.



9.4.2 *Surface Frame System*

In existing buildings selected for rehabilitation it is often possible to surface mount structural frames to the external or internal walls to provide simple load transfer from roof frame level to foundation level.

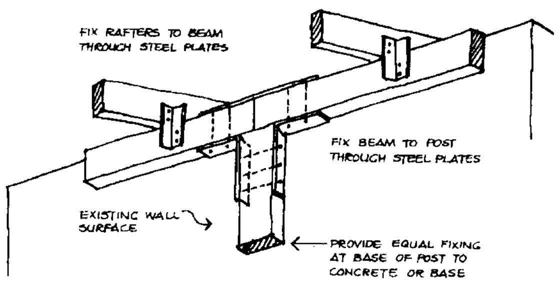
These systems need not detract from the aesthetic appearance and may even be seen as improvements.

The following sketches show how a system can be applied to external walls.

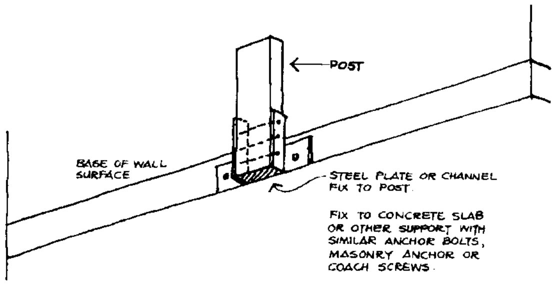
There is a need also to check if a frame system can be installed in corridors inside a building to provide tie down where the span between external walls is great.

External Walls

FRAME BUILDING - USING TIMBER POST



SURFACE MOUNTED POST & BEAM SYSTEM

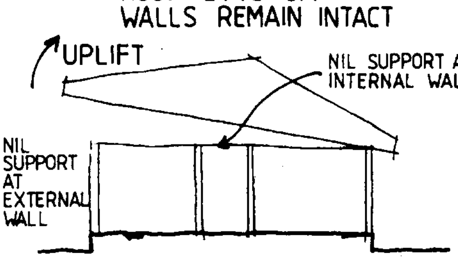


DETAIL AT BASE

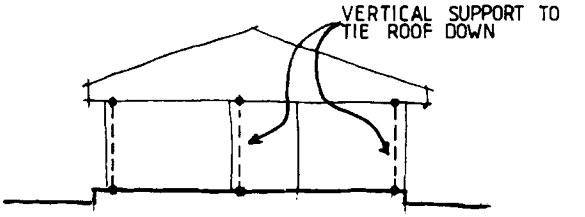
REINFORCEMENT DETAILS

HOLD DOWN SYSTEMS ROOF TO FLOOR

ROOF LIFTS OFF WALLS REMAIN INTACT

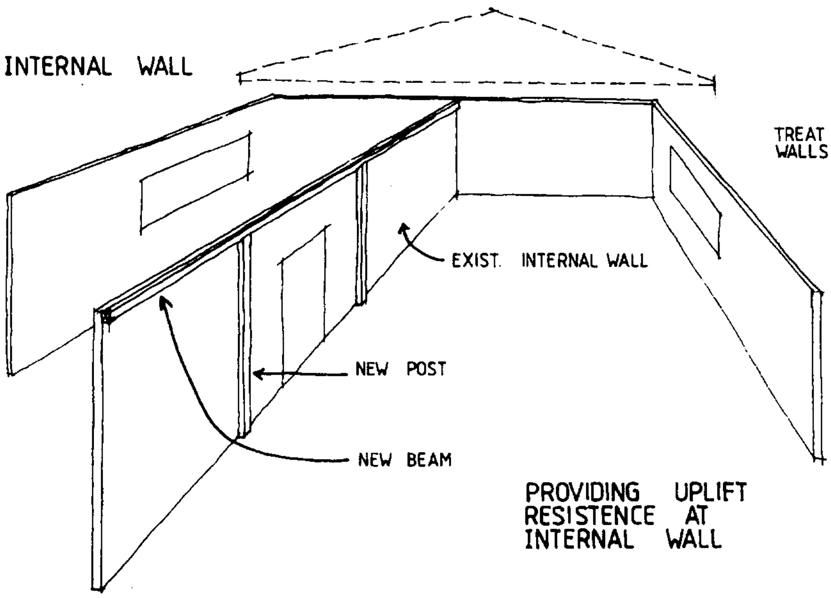


UNSAFE



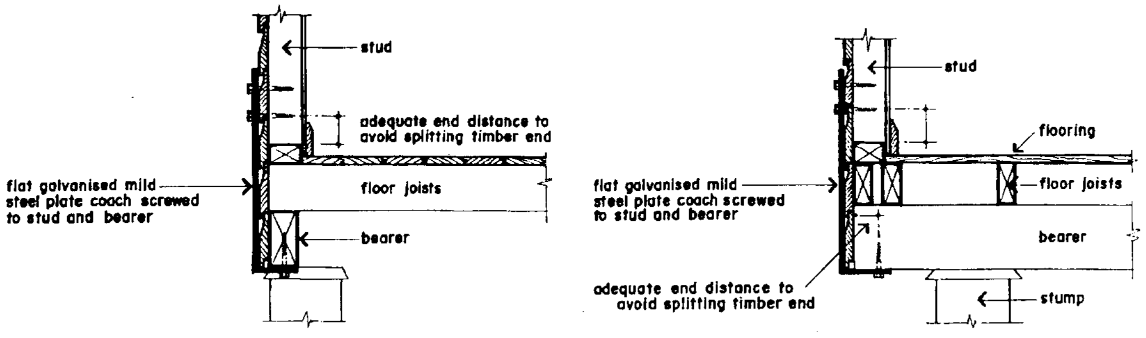
SAFE

INTERNAL WALL



PROVIDING UPLIFT RESISTENCE AT INTERNAL WALL

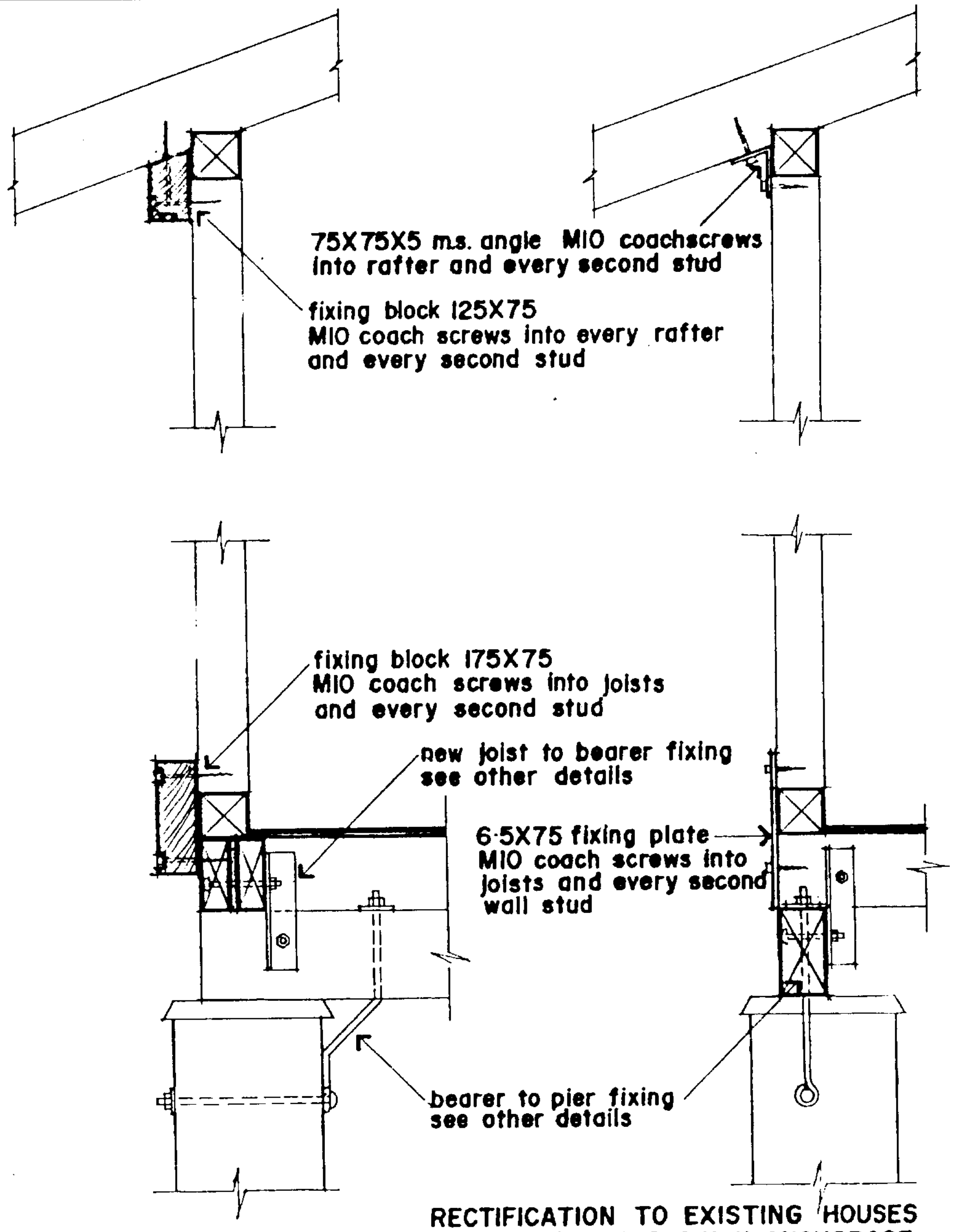
The spacing of the posts will depend on the load to be carried and the ability to find adequate fixings at the base to transfer the load.



DETAIL WITH BEARER PARALLEL TO WALL

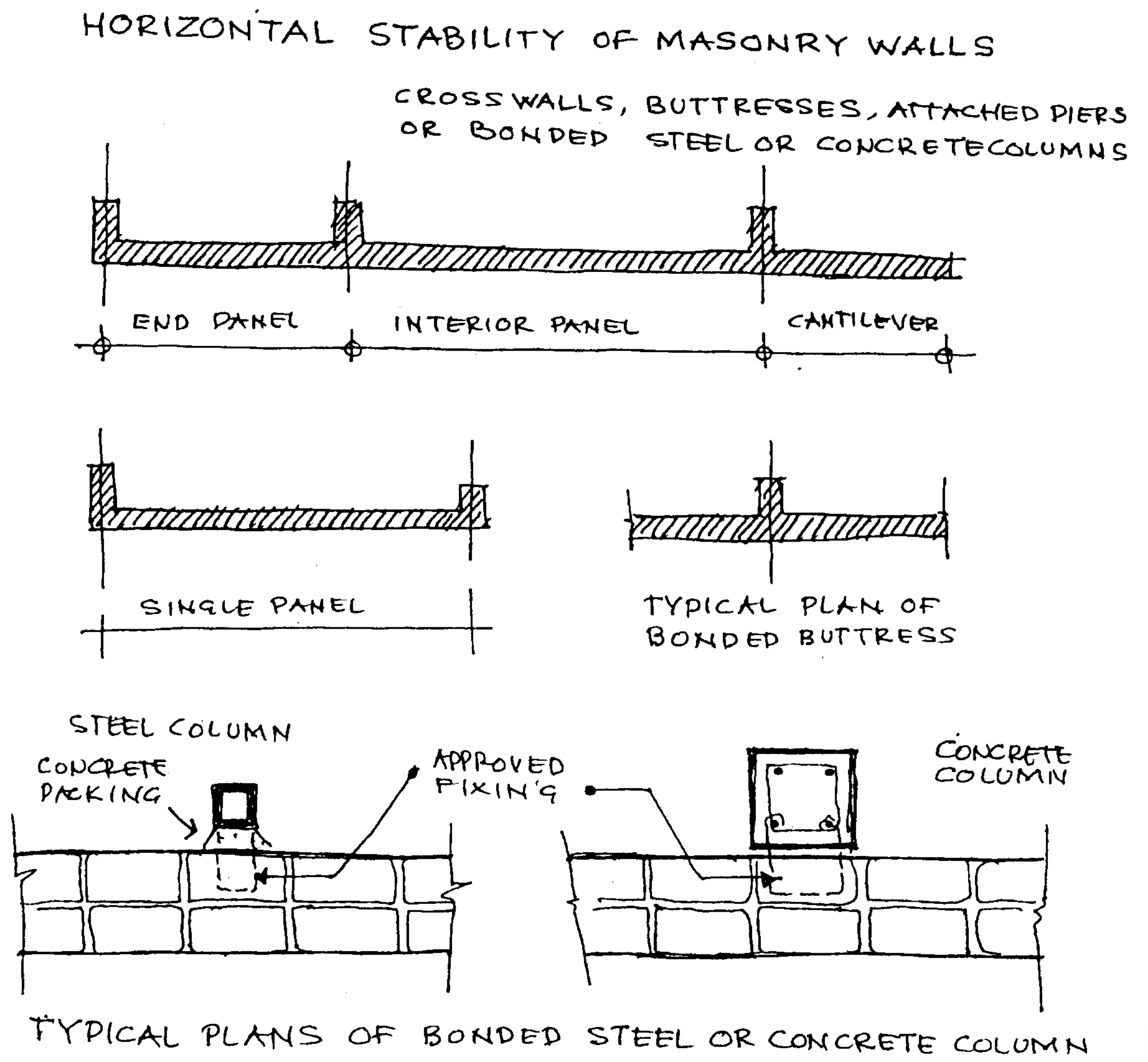
DETAIL WITH FLOOR JOISTS PARALLEL TO WALL

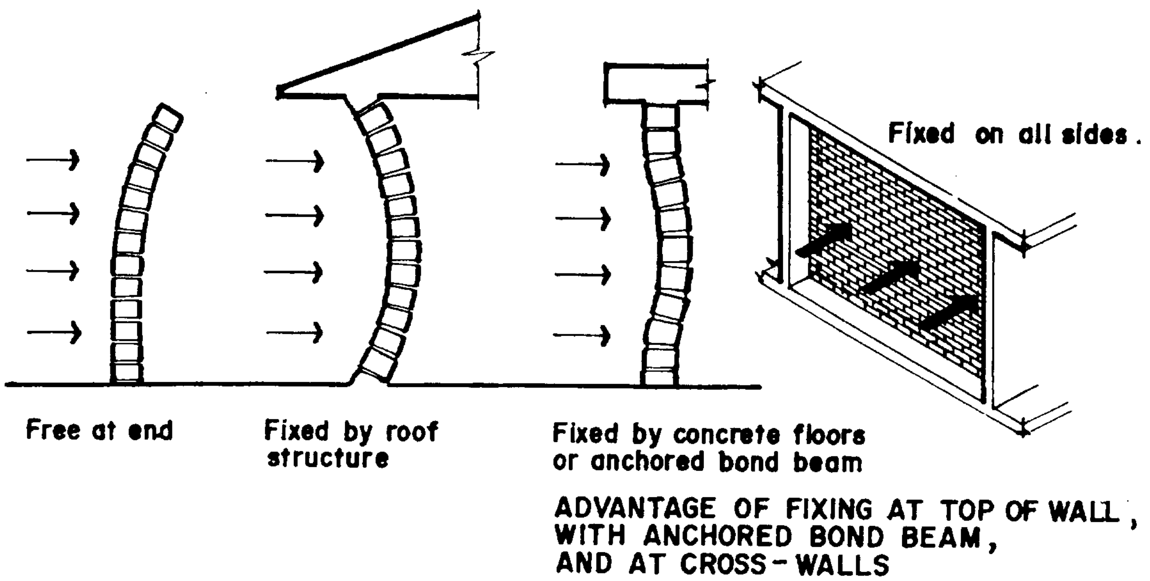
CONNECTION OF STUD TO BEARER WHERE ROOF ANCHORAGE IS PROVIDED THROUGH STUDS

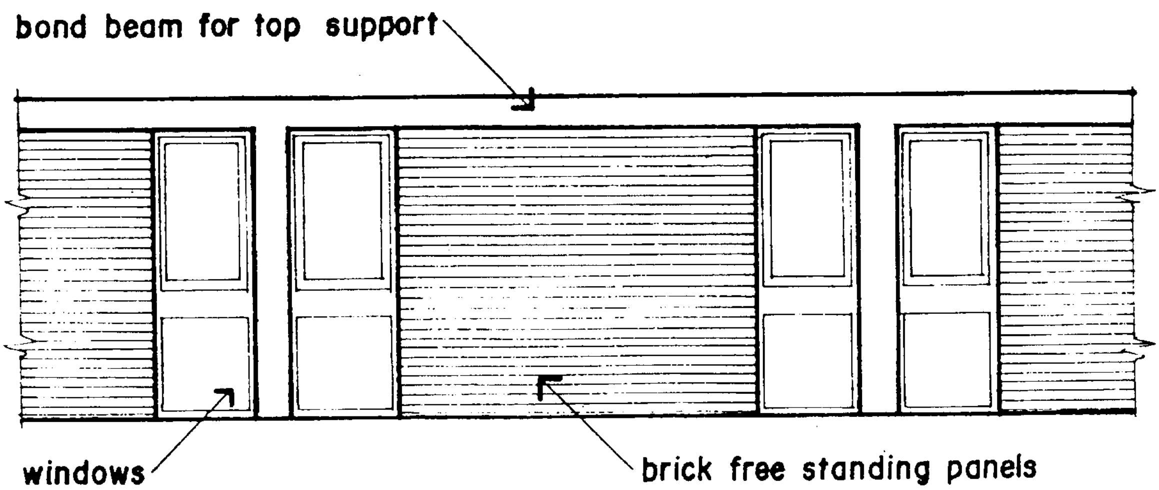


RECTIFICATION TO EXISTING HOUSES TO PROVIDE HOLD-DOWN ANCHORAGE

9.4.3 *Masonry Walling*

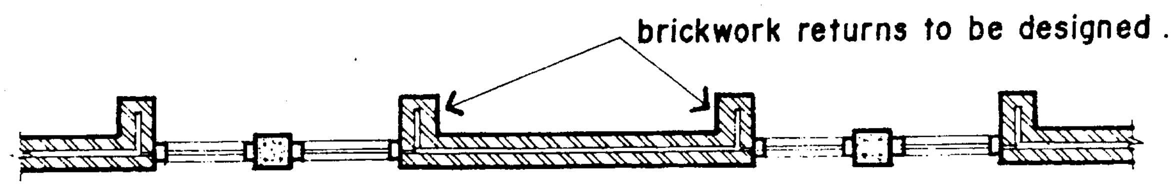






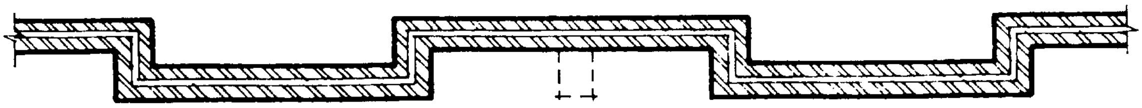
ELEVATION

PLAN – Not Recommended

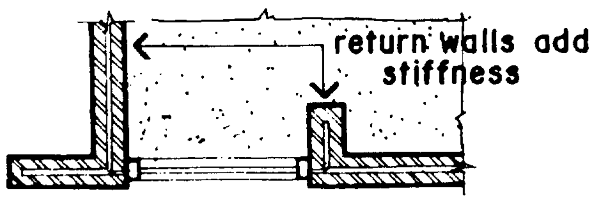


PLAN – Recommended

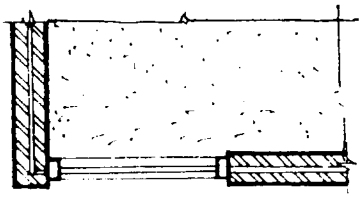
Stagger walls without openings or use attached piers.



PLAN – Recommended



Recommended
PLAN AT CORNERS



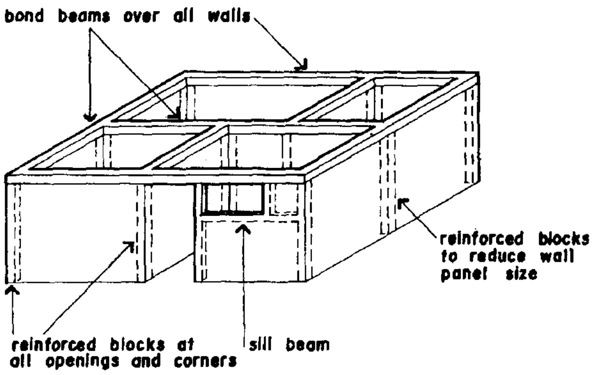
Not Recommended

BRICK WALL STIFFENING

9.4.4 *Concrete Masonry Walls*

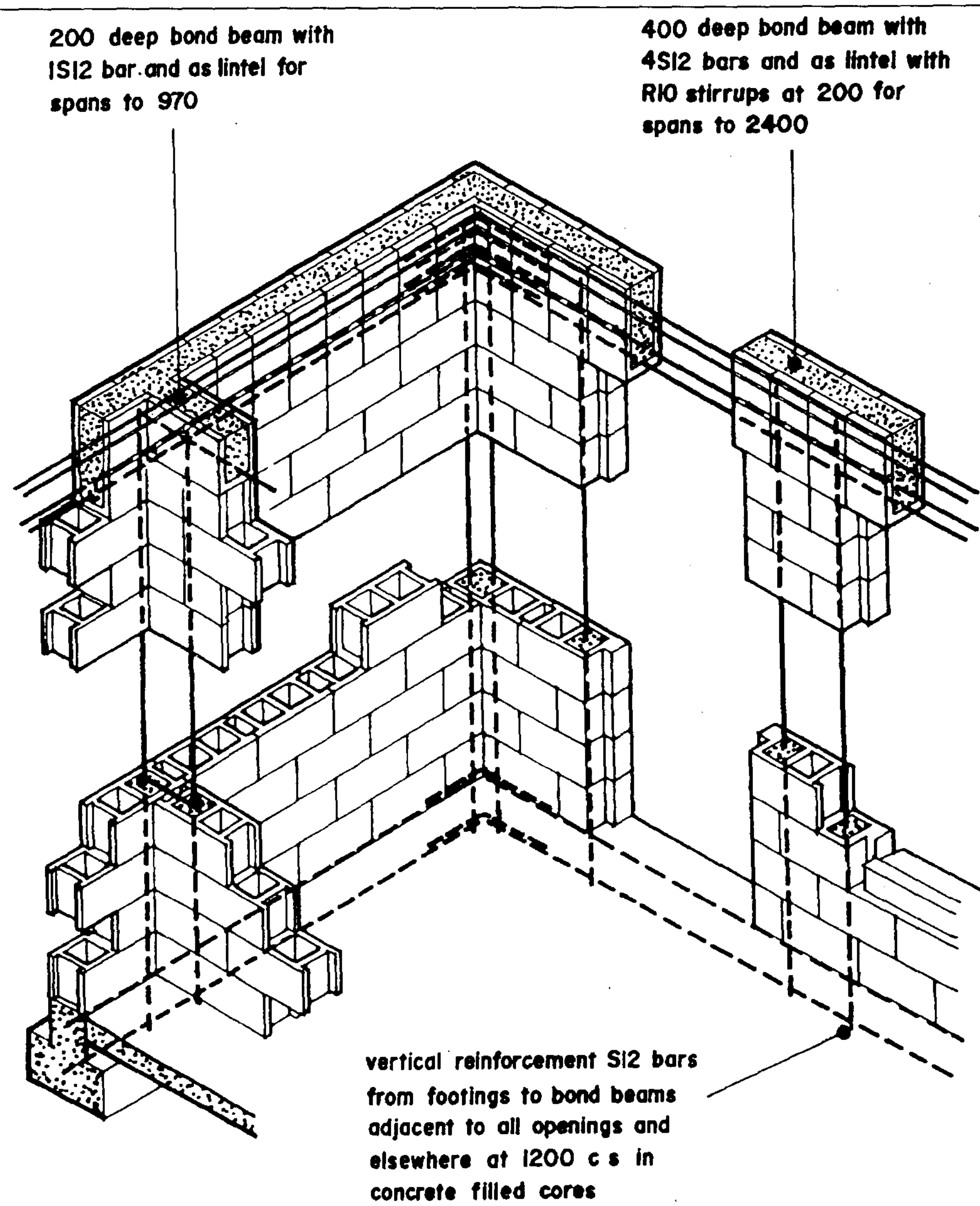
It is essential that hollow concrete masonry walls are reinforced and with adequate reinforcing to resist the wind forces imposed.

The following sketches illustrate the key elements of reinforcing, bonding and tie bar or anchor placement.

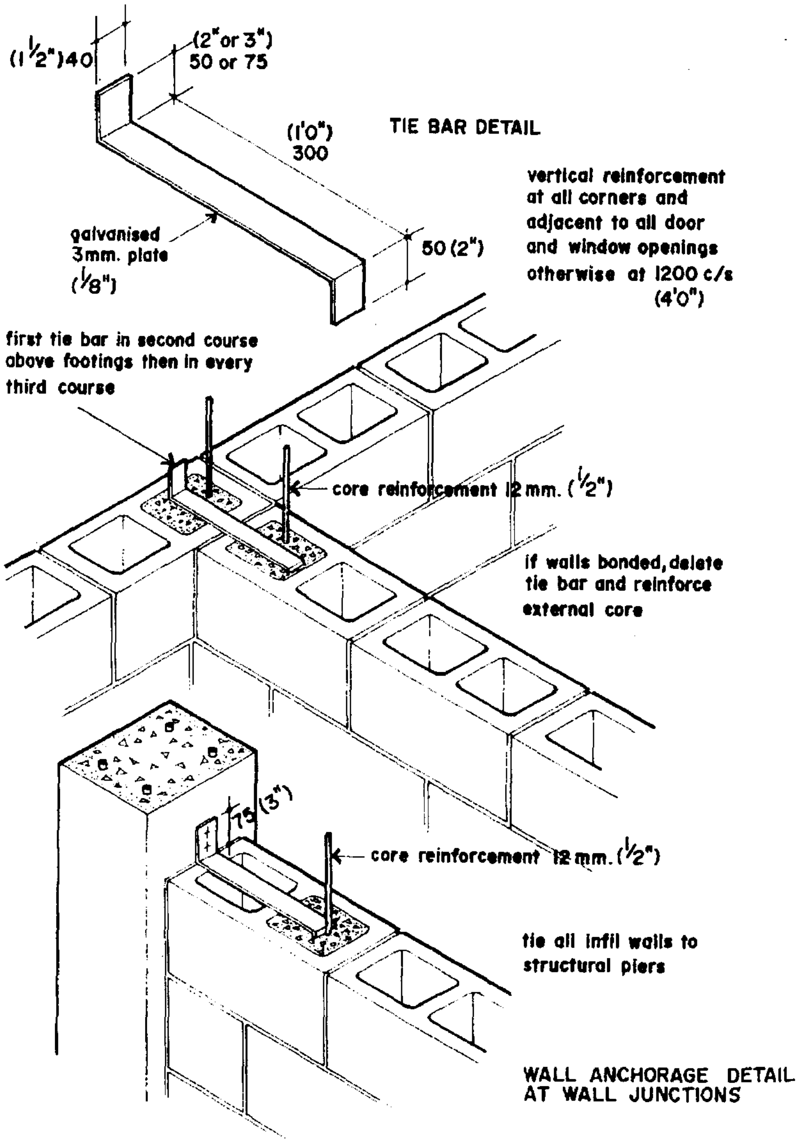


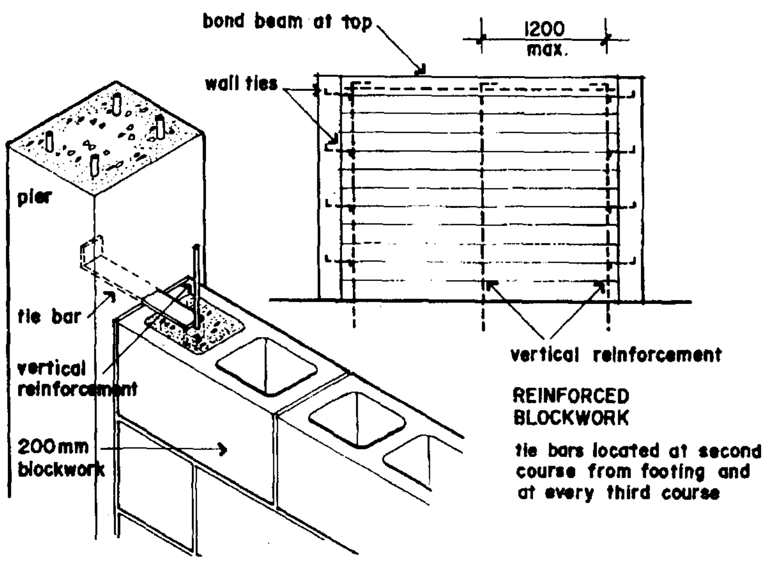
HOUSE STRENGTHENED USING BOND BEAM REINFORCED BLOCKS, SILL BEAMS, HORIZONTAL REINFORCED WALLS

NOTE: for reinforced walls the importance of horizontal reinforcing is of special significance, i.e. 6mm dia., 9mm dia. or special fabric, built into corners. ensure correct anchorage and lap.



REINFORCED CONCRETE MASONRY


(1½")40
(2" or 3")
50 or 75
(1'0")
300
TIE BAR DETAIL
galvanised
3mm. plate
(⅛")
50 (2")
vertical reinforcement
at all corners and
adjacent to all door
and window openings
otherwise at 1200 c/s
(4'0")
first tie bar in second course
above footings then in every
third course
core reinforcement 12 mm. (½")
if walls bonded, delete
tie bar and reinforce
external core
75 (3")
core reinforcement 12 mm. (½")
tie all infill walls to
structural piers
WALL ANCHORAGE DETAIL
AT WALL JUNCTIONS

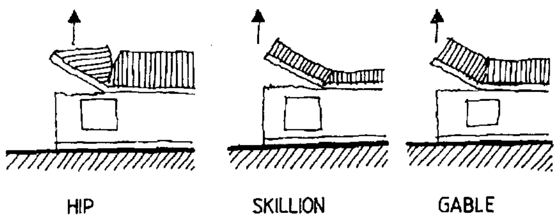

bond beam at top
1200
max.
wall ties
pier
tie bar
vertical
reinforcement
200mm
blockwork
vertical reinforcement
REINFORCED
BLOCKWORK
tie bars located at second
course from footing and
at every third course

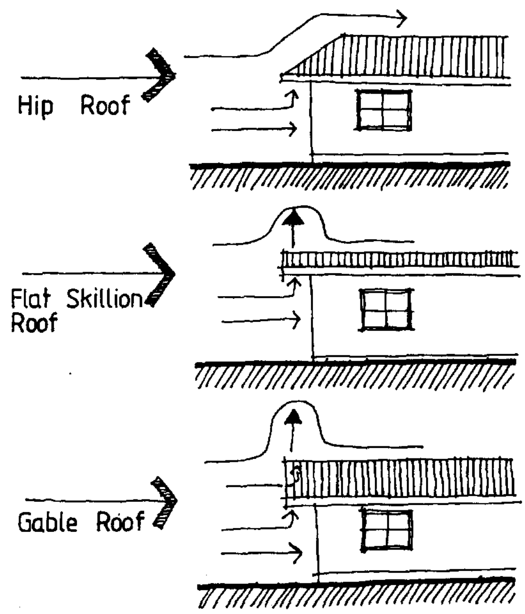
9.5 ROOF FRAMING & CONNECTIONS

9.5.1 *Roof Shapes*

In theory, the wind action and wind pressures vary, depending on roof shape and direction of wind.

Note! A badly fixed hip roof will blow away a few minutes after a badly fixed gable roof or a little later again after a badly fixed flat roof.





9.5.2 *Averaging The Forces*

We can even out the wind pressures on the roof by changing the spacing of the battens or purlins to create even cladding pressures over the roof.

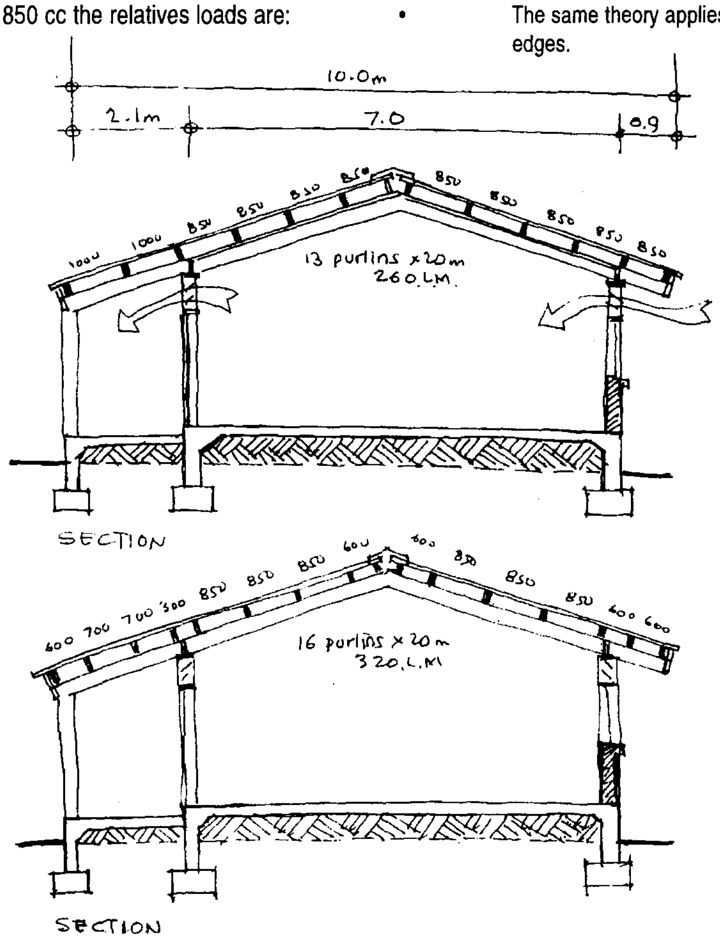
For example, we know that within 15% of the edges of the roof cladding forces are 2.7q, whilst in the general areas of the roof the forces at 1.9q.

If batten or purlins are spaced at the edges at 600 cc and in general areas of 850 cc the relatives loads are:

Edge	0.6 m x 2.7q	= 1.62q
General	0.85 m x 1.9q	= 1.62q

Margins are near enough to allow all connections to be designed similarly instead of having different designs at different parts of the roof.

- If the roof is steep then similar tactics should be used near the ridge.
- The same theory applies at wall corners and edges.



9.5.3 Roof Framing — Connection Details

It is important to detail the requirements for each of the roof frame connections.

It is also important that the work is inspected to ensure compliance with the details.

It should be remembered that a chain is only as strong as it's weakest link and in roof framing the chain of integrity calls for:

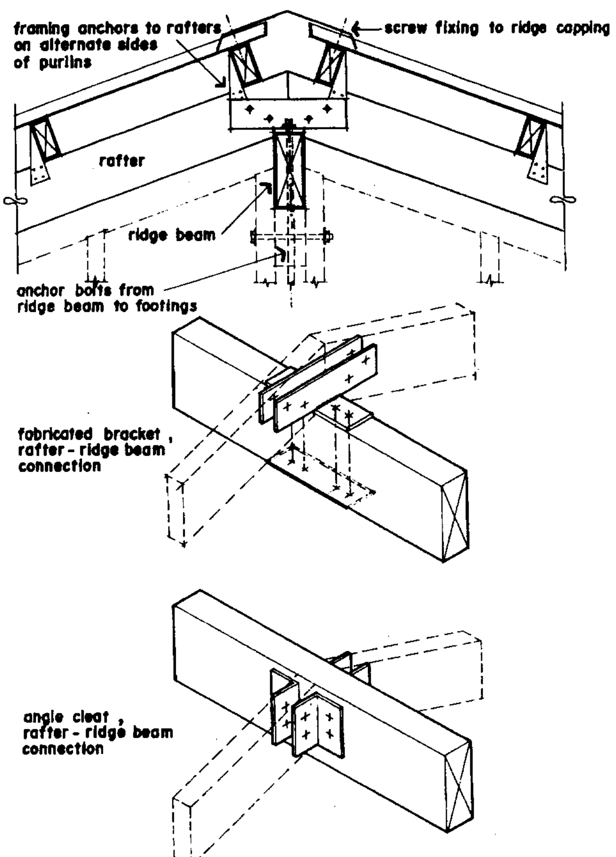
1. Fix roof sheeting to battens or purlins.
2. Fix battens to purlins or rafters.
3. Fix purlins to rafters or bearers.
4. Fix rafters or beams to wall top plates.
5. Fix top plates through to foundations.

It is equally important that each of the connections is capable of transferring the loads placed on the joint concerned.

The following sketches show typical details used in cyclone areas.

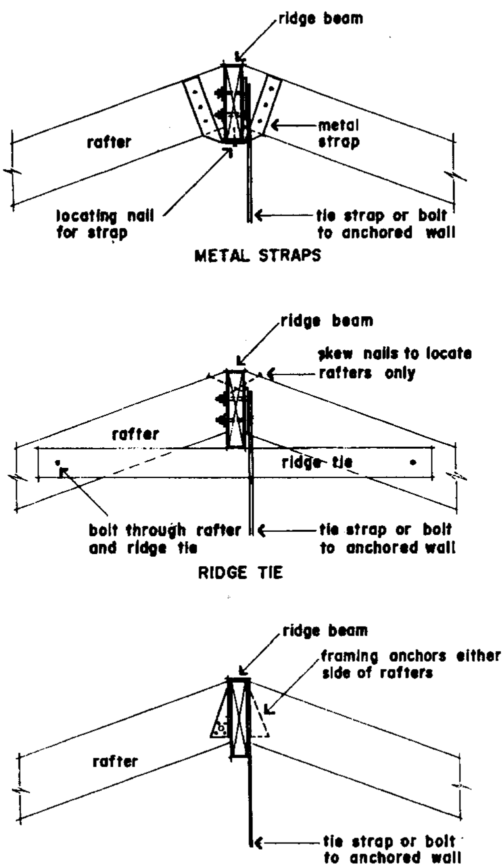
Existing roofs can be made good if framing is in position and lacking only good connections.

Where fixings are inadequate, remove the roof, eaves or ceiling sheeting to gain access to enable the upgrading to be properly done.

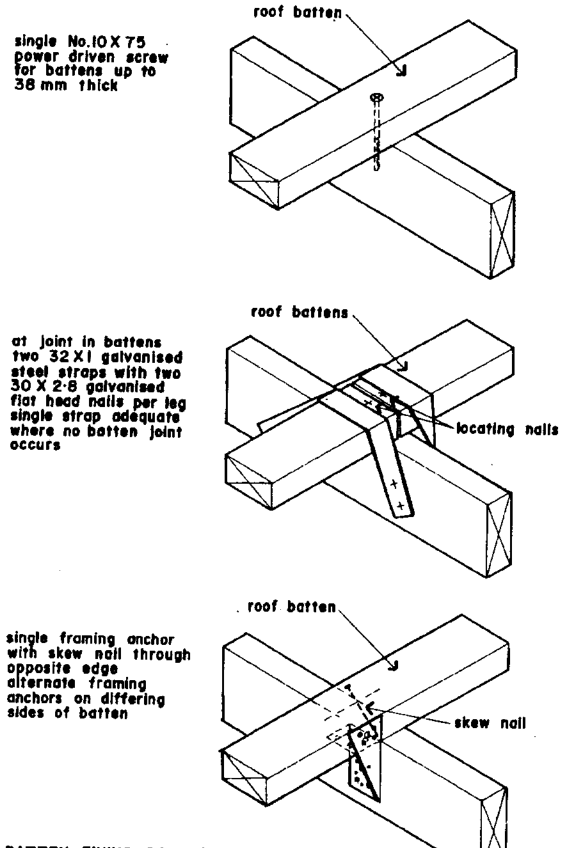


ROOF DETAILS
PURLINS ON ROOF BEAMS

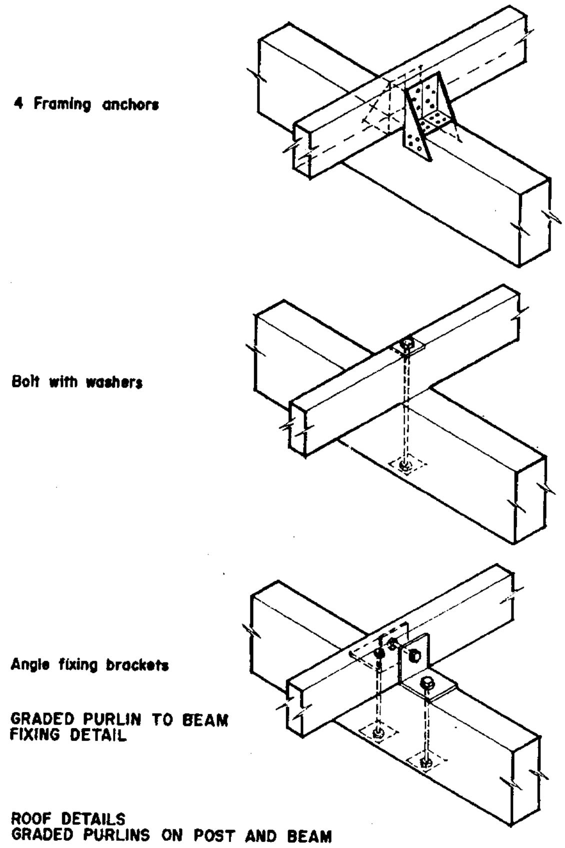
RAFTER-RIDGE BEAM
CONNECTION DETAIL



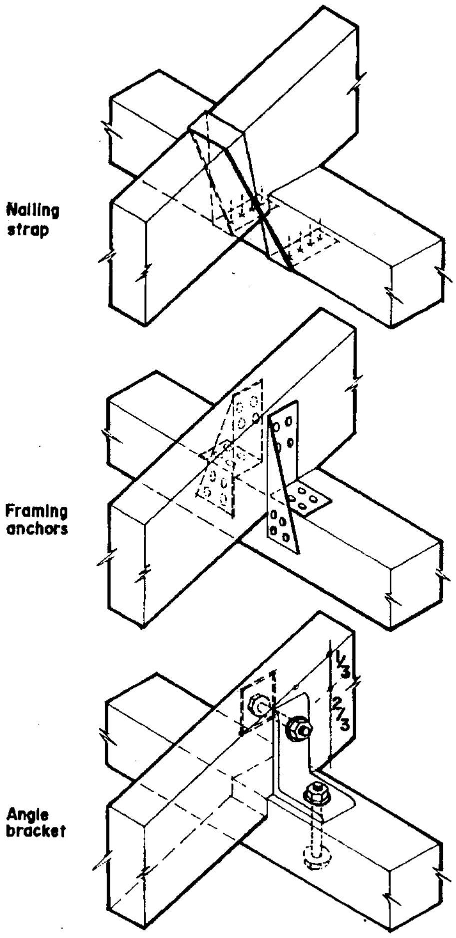
FRAMING ANCHORS
RAFTERS TO RIDGE BOARD
FIXING DETAILS



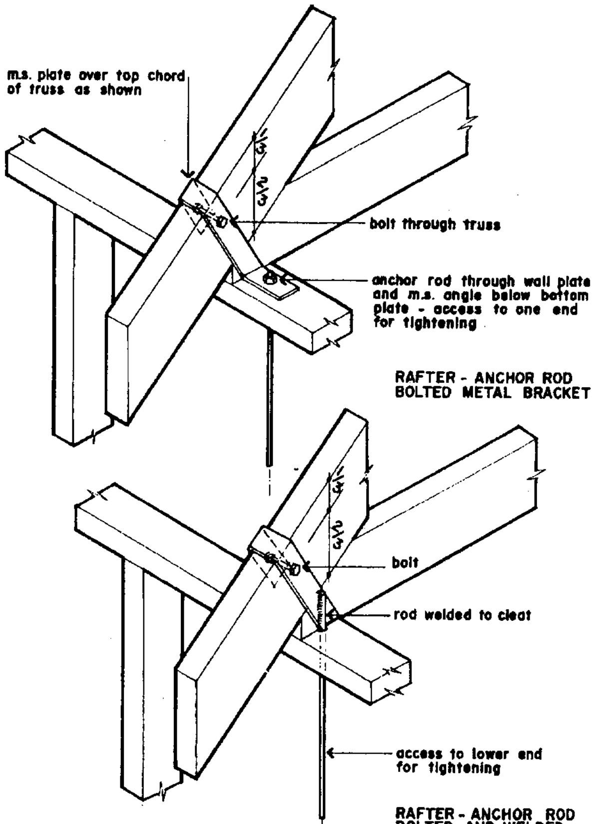
BATTEN FIXING TO TRUSS OR RAFTER AT 900 SPACING



ROOF DETAILS
GRADED PURLINS ON POST AND BEAM



RAFTER - TOP PLATE FIXING DETAIL

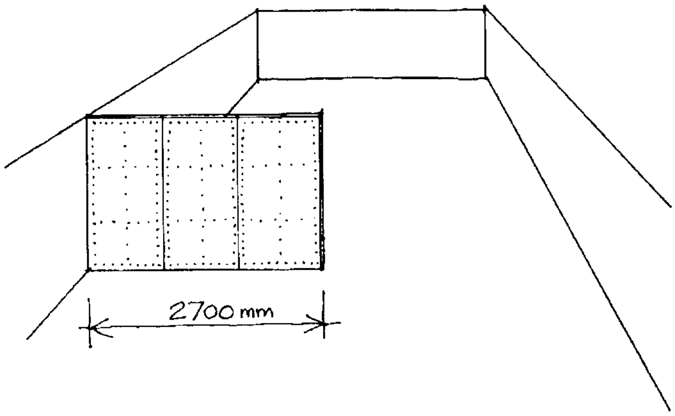


RAFTER TO TIE-ROD CONNECTIONS

9.6 BRACING & DIAPHRAGMS

9.6.1 Bracing Walls

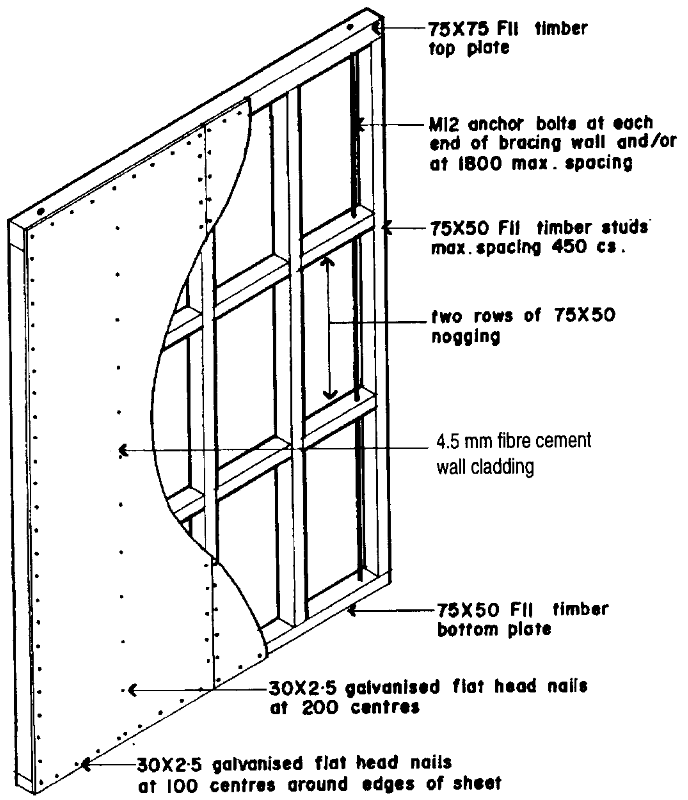
The need for support of external walls by cross walls can be resolved by the installation of bracing walls, the examples are for timber walls. Brick walls can equal or exceed these transfer forces.



SKETCH OF BRACING WALL

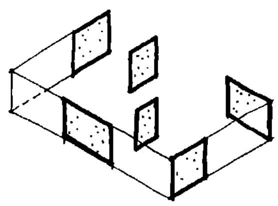
BRACING PANELS – TIMBER STUDS CLADDED WITH PLYWOOD, HARDBOARD, CEMENT FIBRE.

RESISTANCE = 2.7 x 4.0 kN/m
= 10.8 kN APPROX.

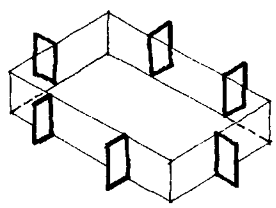


BRACING WALL DETAIL
THIS WALL CAN RESIST FORCES OF 4 kN / LINEAL METRE

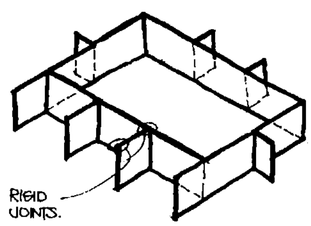
BRACING



BRACING WALLS IN FRAME BUILDING

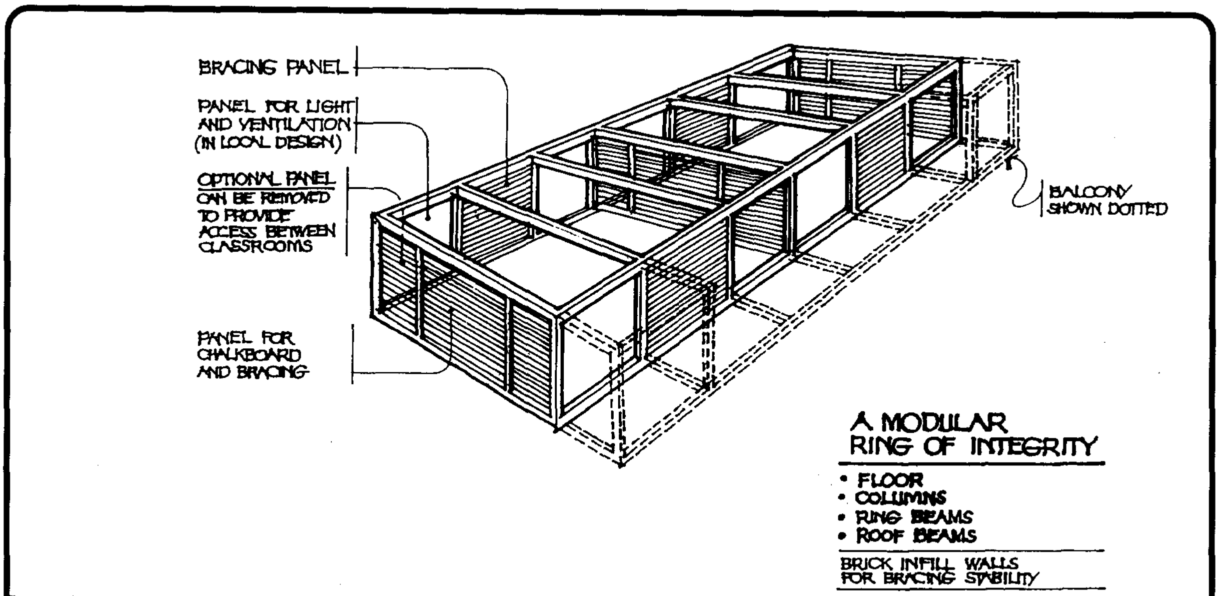


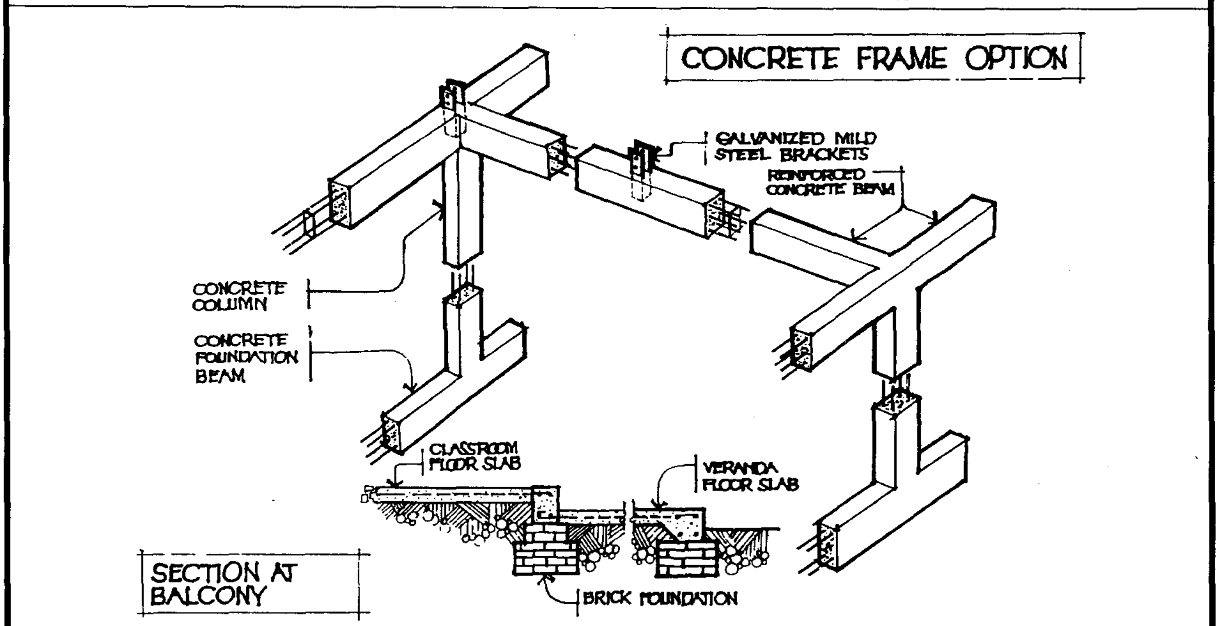
BRACING SYSTEMS

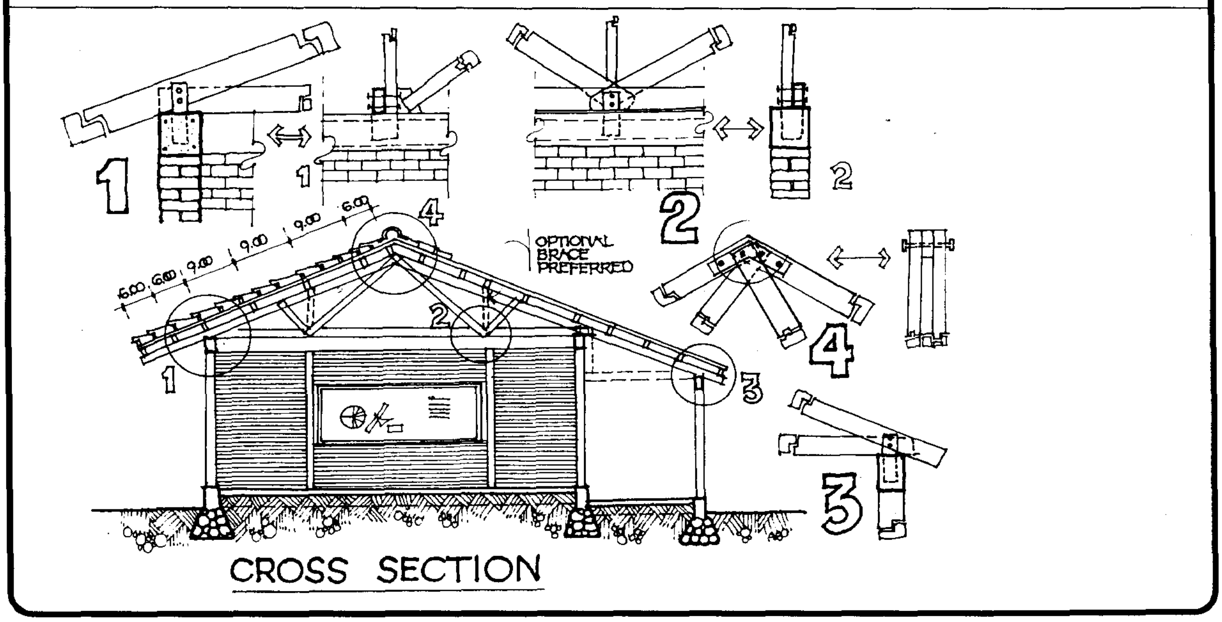


9.6.2 *Modular Wall Construction*

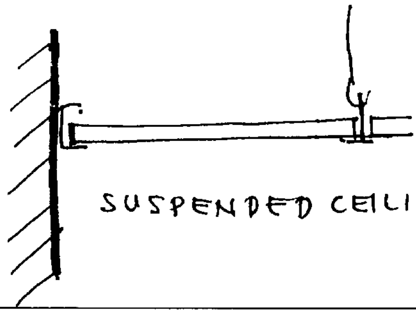
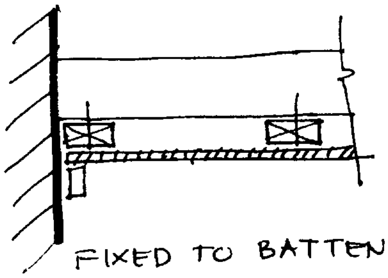
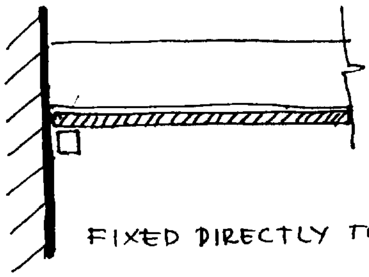
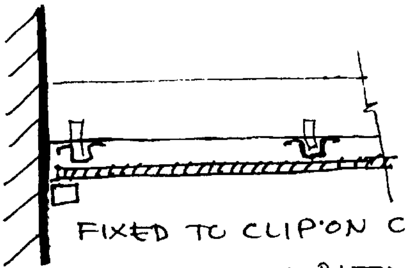
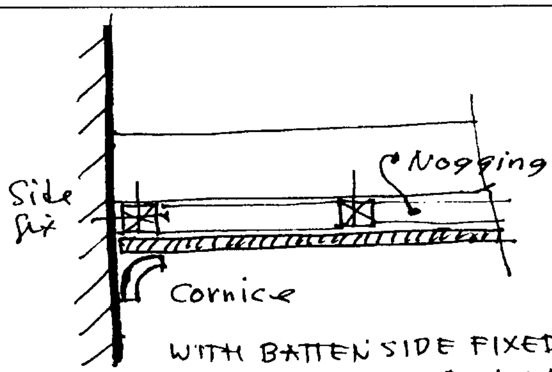
A suggested solution with concrete framed walls, brick infill and concrete and steel beams.







CEILING SHEETING AS DIAPHRAGMS

	Strength per m² kN/m²	Strength 10.0m length kN/m²
 SUSPENDED CEILING	ZERO	0
 FIXED TO BATTENS	0.5 – 1.7	5 – 17
 FIXED DIRECTLY TO JOISTS	0.7 – 1.5	7 – 15
 FIXED TO CLIP'ON CHANNELS WITH CHANNEL BATTEN SCREWED	0.1 – 0.2 0.6 – 1.0	1 – 2 6 – 10
 WITH BATTEN SIDE FIXED AND NOGGING TO JOINTS WITH CORNICE GLUED	1.8 – 2.9	18 – 29

9.6.3 *Ceiling Diaphragms*

We are mostly familiar with the solidity and stiffness of the concrete floors and brick walls in our buildings.

However, we tend to accept much lighter constructions in our ceilings and roofs with thin metal or fibre cement or tile roof cladding and ceilings are either omitted or are of the suspended drop-in panel type or of other light materials.

University tests of the Cyclone Testing Station in Townsville, Australia, have revitalised interest in the contribution that properly constructed ceilings can make to the integrity of the building by providing in the ceiling plane, significant resistance to the forces tending to bend the external walls.

Most ceilings, erected without consideration of the fact that the construction and it's fixings are so important, can expect the ceiling to have an equivalent design strength of from zero to 0.8 kN/m.

With the better fixing methods, the design load can be increased up to 1.5 to 2.9 kN/m with better placement of sheet and more nails, holding the ceiling sheets to the ceiling framework. It justifies the cost of the re-introduction of ceiling joists and their supports in the developed countries.

Some examples are as follows:

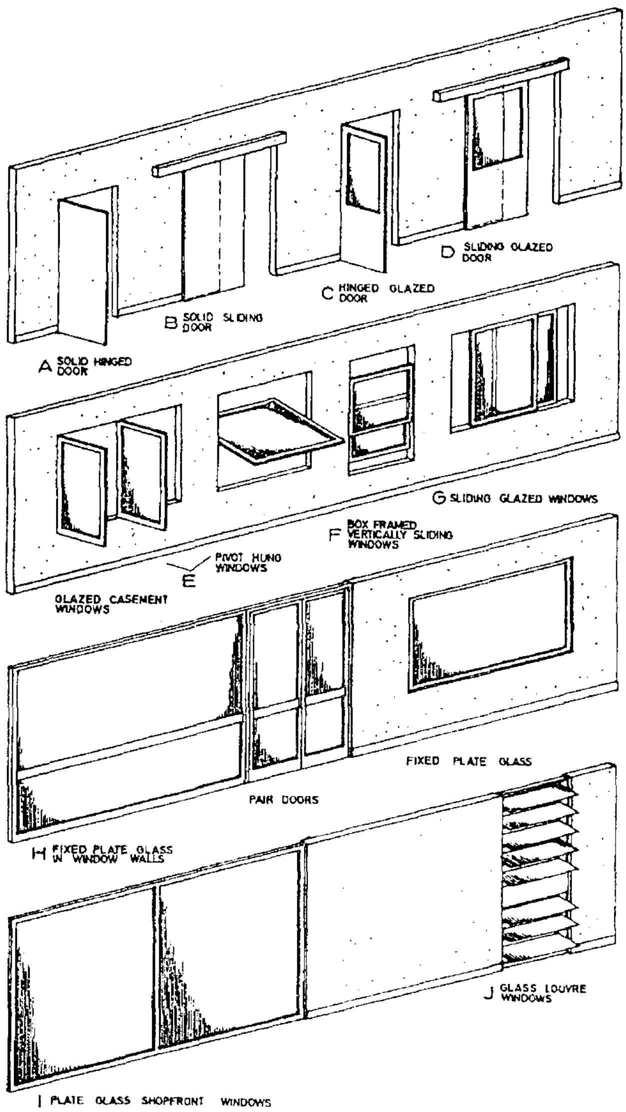
1. Plasterboard on clip on metal furring channels with fixings at 300 cc to perimeter and field.
2. Ditto but with furring channels screwed to joist, a big improvement.
3. Ditto but with pine timber battens.
4. Fibre cement sheeting fixed directly to ceiling joists.
5. Ditto but fixed to battens.
6. Ditto fixed, but with edge batten also fixed to wall to add to strength.
7. Hardboard sheeting with perimeter fixings at 100 cc, field fixings at 300 cc fixed to battens with cross nogging between battens at end joints.

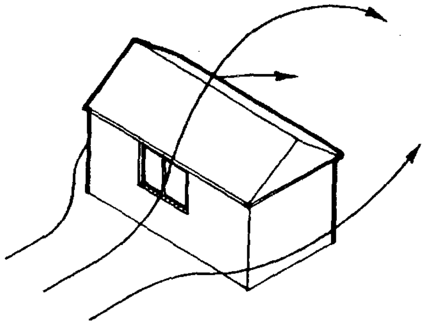
9.7 DOORS & WINDOWS

The installation of doors and window openings requires attention to the following:

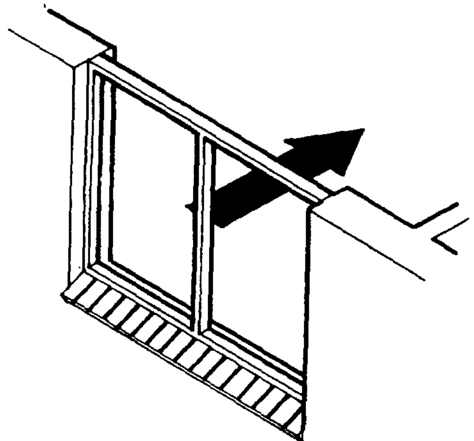
- Design of glass, frame and fixing by experienced personnel.
- Thickness and size of glass.
- Fixing of frame to wall, including size and spacing of fixings.
- Adequate supervision.

The illustrations show a range of doors and windows, together with diagrams of wind pressures and suction forces.



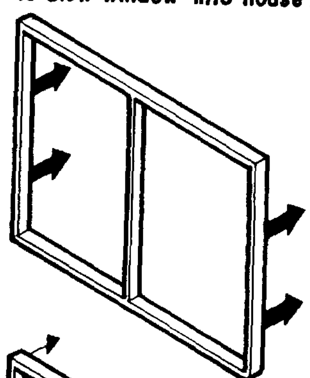


Wind flow with window facing wind.

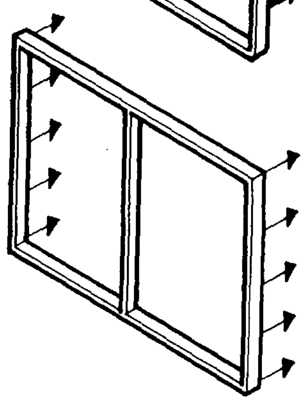


Consequent wind pressure attempts to blow window into house.

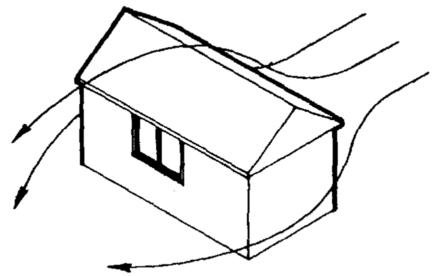
Forces on frame fixings will be inwards.



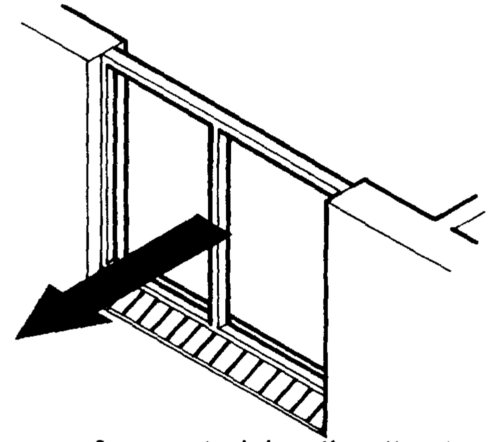
The forces will be smaller the more fixings there are.



FORCES ON WINDOWS
(Facing wind)

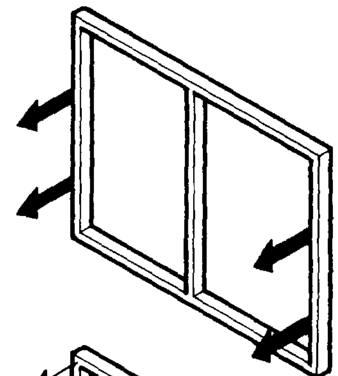


Wind flow with window away from wind.

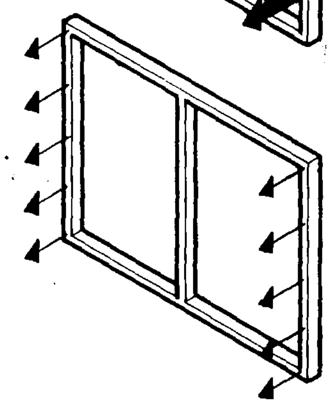


Consequent wind suction attempts to suck window out of house.

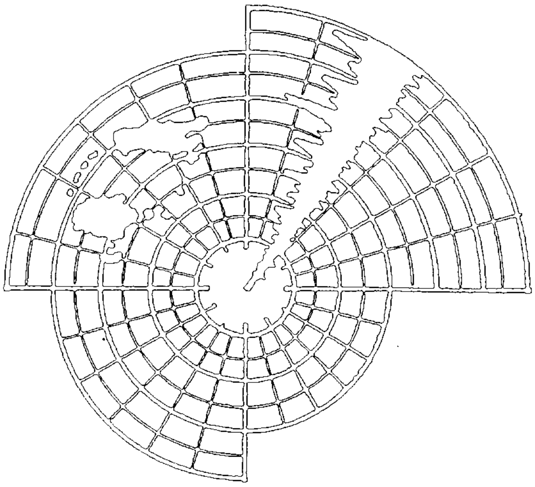
Forces on frame fixings will be outwards.



The forces will be smaller the more fixings there are.



FORCES ON WINDOWS
(In lee of wind)



10 CASE STUDIES – REHABILITATION

CONTENTS

10.1 OVERVIEW OF REHABILITATION CASE STUDIES

This section includes case studies on:

i. **Case Study 1** • A Joint Venture Reconstruction Programme in Tonga

Showing how small nations can initiate, absorb research results and implement state of the art technology.

ii. **Case Study 2** • Restoration of Historic Buildings

Showing how a large historic Federation building can be upgraded and rehabilitated with minimal interference to the architectural fabric.

iii. **Case Study 3** • Rehabilitation of Damaged Motel Buildings

After loss of roof and some walls and loss of interiors and exposure to deterioration for some years the building was able to be saved and rehabilitated to a first class, cyclone secure position.

iv. **Case Study 4** • Upgrade of Holiday Units

A timber framed complex of holiday units which was sub-standard in structure was able to be upgraded to enable it to survive cyclone winds.

v. **Case Study 5** • Two Level School and Facilities

A two level timber classroom block with suspect structural capacity was made secure with minimal cost and survives 24 years later. A toilet block shows how to ventilate the walls to reduce the effects of wind forces and models good quality tie-down techniques.

10.1.1 Case Study 1

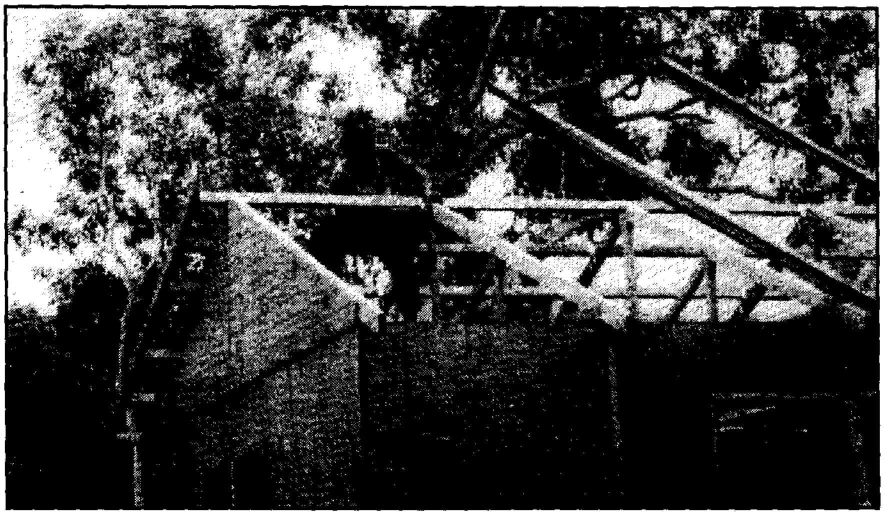
- *Joint Venture Community Reconstruction – Tonga*

It could be said that Tonga led the world in 1982–84 with investigation, identification, research, full scale testing, adoption of recommendations and implementation of new design techniques for cyclones.

During March 1982 cyclone "Isaac" (43 m/s) hit the islands of the kingdom of Tonga causing much damage. The Government was committed to a reconstruction programme of 2,000 houses in a two year period.

After the cyclone and damage assessment review, the Government identified some weakness in the designs for the new houses and it was decided to make available a house for full scale testing (refer Eaton & Reardon 1985).

- A unique joint venture developed.
- The Tongan Government provided the house.
- The Commission of the European Community financed the cost of the house materials.
- The New Zealand Government funded the cost of a travel for a Tongan official to visit Australia to erect the house at the test site at James Cook University of North Queensland, Townsville, Australia, to Tongan standards.
- The Australian Government funded part of the testing in conjunction with the Cyclone Structural Testing Station (CSTS) at the University.
- The British High Commission to Tonga provided the liaison.
- The British Building Research Establishment (BRE) acted jointly with the Testing Station in regards to recommendations and testing.



After the full scale testing, simple but effective solutions with roof batten location and more secure fixing methods were identified that would enable the house to be modified to resist maximum cyclone winds of over 60 m/s.

These recommendations were quickly adopted by the Government and implemented in the houses already under construction in Tonga.

The houses contained 2.4 x 1.2 ply sheeted wall panels, pre-cut and assembled in a factory, together with the pre-fabricated roof trusses, creating a mini-industry for a training and assembly program, and providing employment.

The whole project of initiation, testing and action in implementing the results into the 2,000 homes was completed in the existing housing development programme of a little over two years.

It was a fine example which created employment, initiated quality controlled mass production of wall and roof panels and trusses also used in school construction; the whole of which educated the construction industry which lifted its level of expertise.

10.1.2 ***Case Study 2***

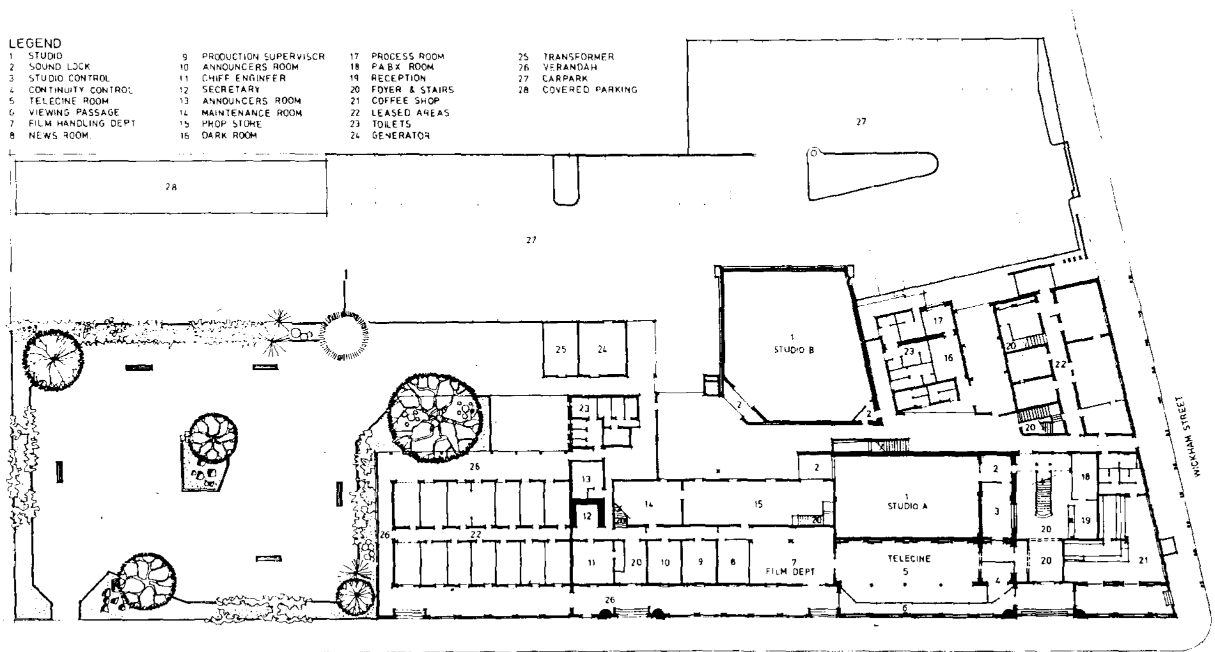
- *Television Studios & Offices*

This Queen's Hotel building in Townsville, Australia, erected between 1896 & 1920, which was, in 1976 recycled to a Television Studio Complex, suffered in a 1971 cyclone (as it did also in 1903).

The historic building showed weakness in the roof truss framing, the holding down mechanism to the top bearing plates, in the stability of some of the brick walls to the top floor and in transfer of loads down to first floor level where adequate dead weight was available to counteract the uplift wind forces.

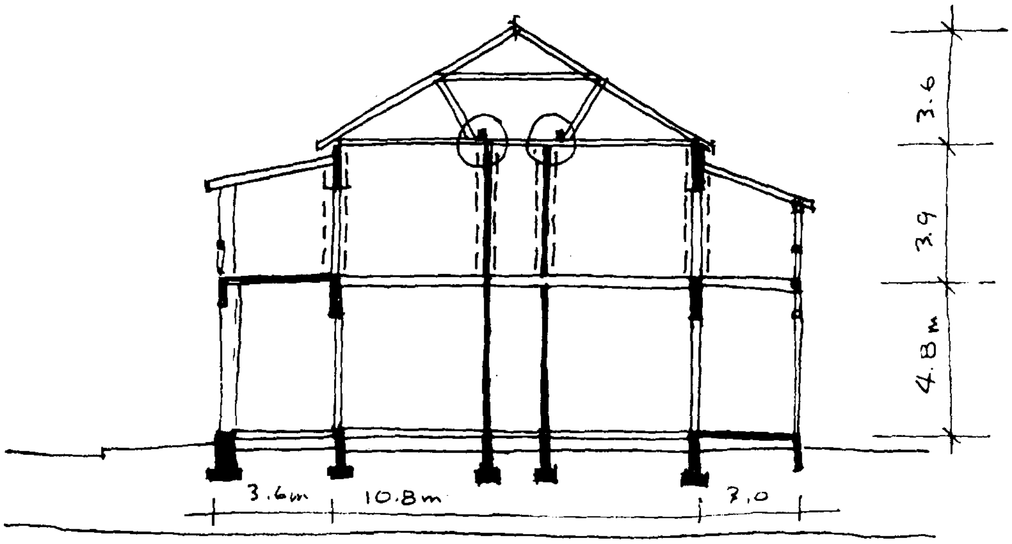
Actions taken by the architects included:

- installation of steel stiffening to the existing traditional roof trusses;
- metal strap connections from roof battens to trusses;
- new roof sheeting, installed in stages;
- special tie down details to first floor brick walls;
- the whole of the work done without interrupting the operation of the Station.



GROUND FLOOR PLAN
TELEVISION AND RADIO CENTRE 1978

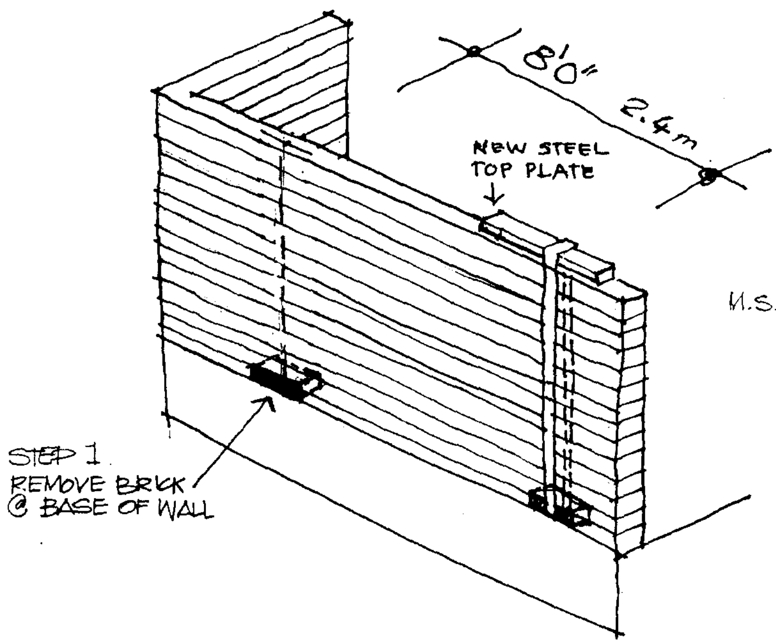
DRAWINGS PREPARED BY MACKS AND ROBINSON, MAY 1978

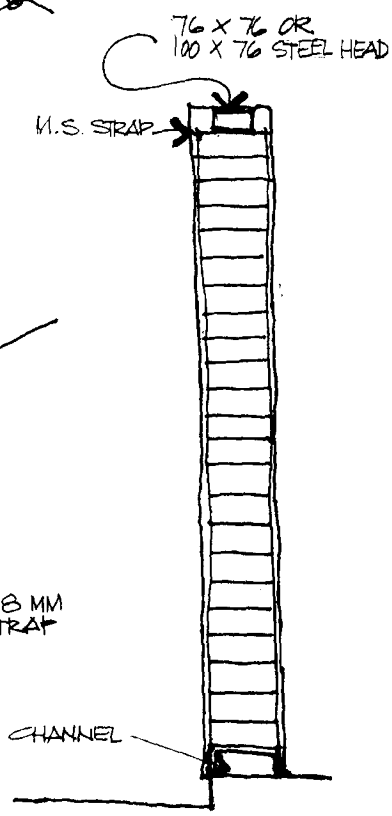


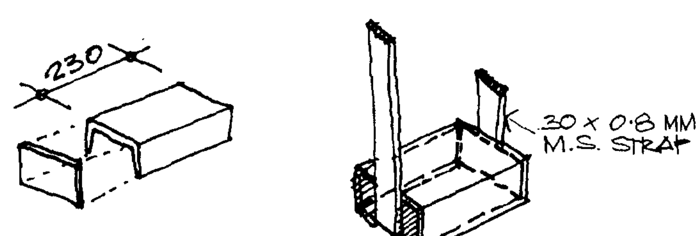
SECTION

LOCATIONS OF TIE DOWN POSTS OR STRAPS ----

POSITIONS OF NEW TOP PLATES (STEEL)







CHANNEL & END PLATE

SECTION

STEP 1 - REMOVE BRICK
STEP 2 - INSERT CHANNEL SECTION
STEP 3 - WELD ON HOLDING DOWN STRAPS.

IF WALL IS 9'0" HT. (2.7M)
AND IF STRAPS ARE FITTED @ 8'0" CNTS. (2.4M)
AREA BRICKWORK 72 SF. - 16 SF = 56 x 90 # = 5040 #
ALTERNATE USE 76 x 76 RHS IN LIEU OF STRAP.

NOTE
STRAP CAN BE CONCEALED BEHIND ARCHITRAVES IF INSTALLED BESIDE DOORWAYS IN HERITAGE BUILDINGS

10.1.3 *Case Study 3*

Motor Hotel (Motel) Building

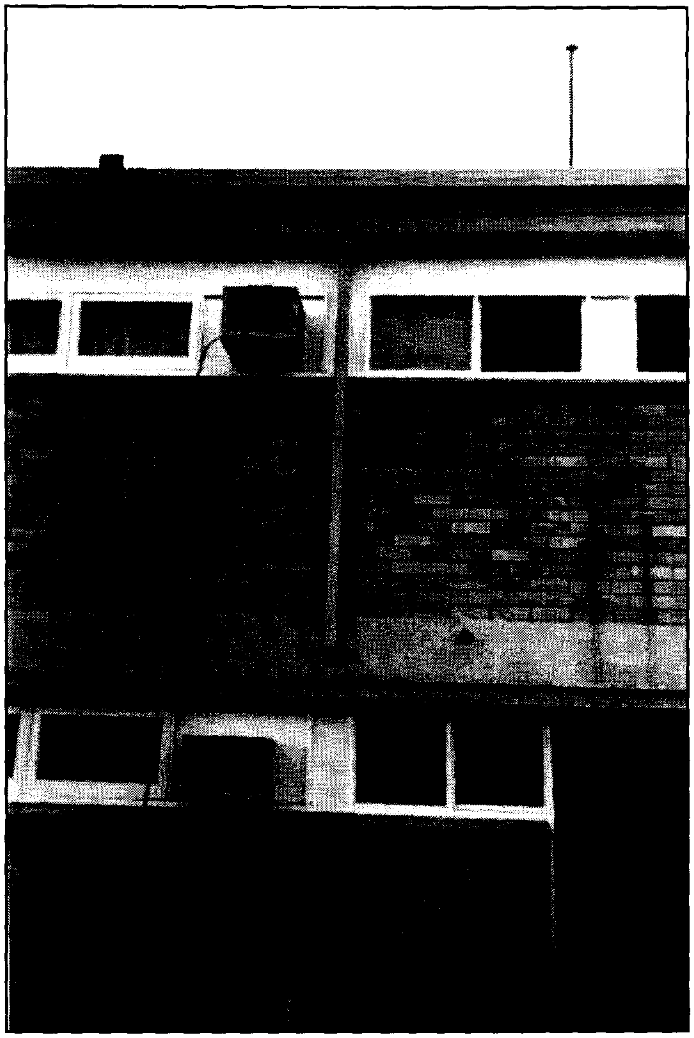
The motel building illustrated lost its roof in a cyclone due to very poor connections from walls to roof.

The connections were so weak that the roof blew off cleanly early in the cyclone leaving little damage to the walls and structures which, with lesser loads to contend with, mostly survived.

When the owners decided to reconstruct, after some years exposed to the weather, the architects decided to retain the existing unreinforced brick walls on the upper levels.

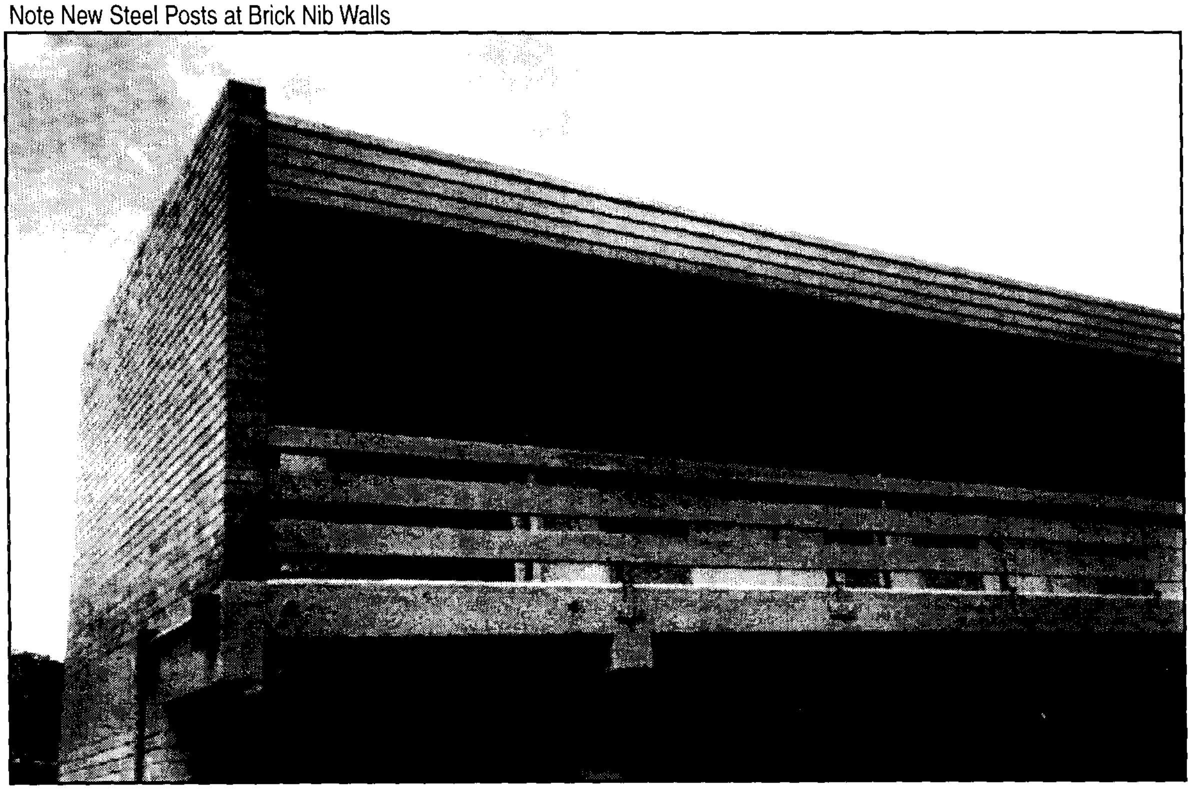
They imposed at each end a steel post fixed to the concrete floor, bolted at regular centres to the existing brick walls and connected to a timber and steel framing structure in the roof which collected and transferred the wind forces to the new columns.

The illustrations show the steel posts at the front, on the face of the brick wall, and the post on the rear, in the line of the dividing brick wall, the posts were anchored to the first floor slab and beams.



New Steel Post
Fixed to Concrete Beams and to New Top Plate in New Roof Structure

View of Motel
Note New Steel Posts at Brick Nib Walls



10.1.4 Case Study 4

- *Holiday Units, Magnetic Island*

This set of holiday units, illustrated, is located on Magnetic Island, NE Australia, 10 km off the coast at Townsville which was hit in December 1971 by Cyclone Althea with winds of 55 to 60 m/s. The building was partially damaged in the cyclone but was saved from demolition by the upgrading systems, initiated by the architects, to provide anchorage and continuity to complement the existing adequate bracing in the walls.

The roof system consisted of a rafter spanning from ridge to top plate to eaves.

The roof sheeting was adequately fixed by screws and the battens were securely fixed to the rafters.

However, the rafters needed better fixing to the top plate.

The top plate was too small to support uplift forces.

There was inadequate tie down from top plate to the floor framing where the weight of the building could be utilised to resist the uplift forces.

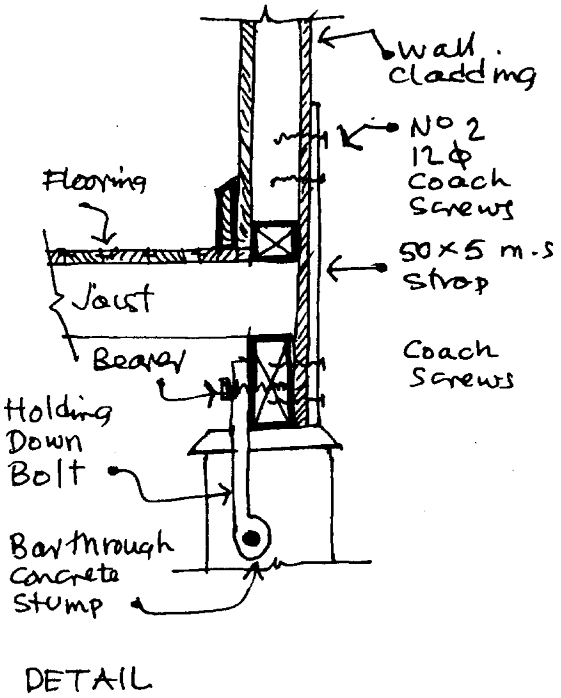
The existing external wall cladding was fibre cement sheets fixed vertically with joints covered by a 50 x 5 fibre cement cover strip.

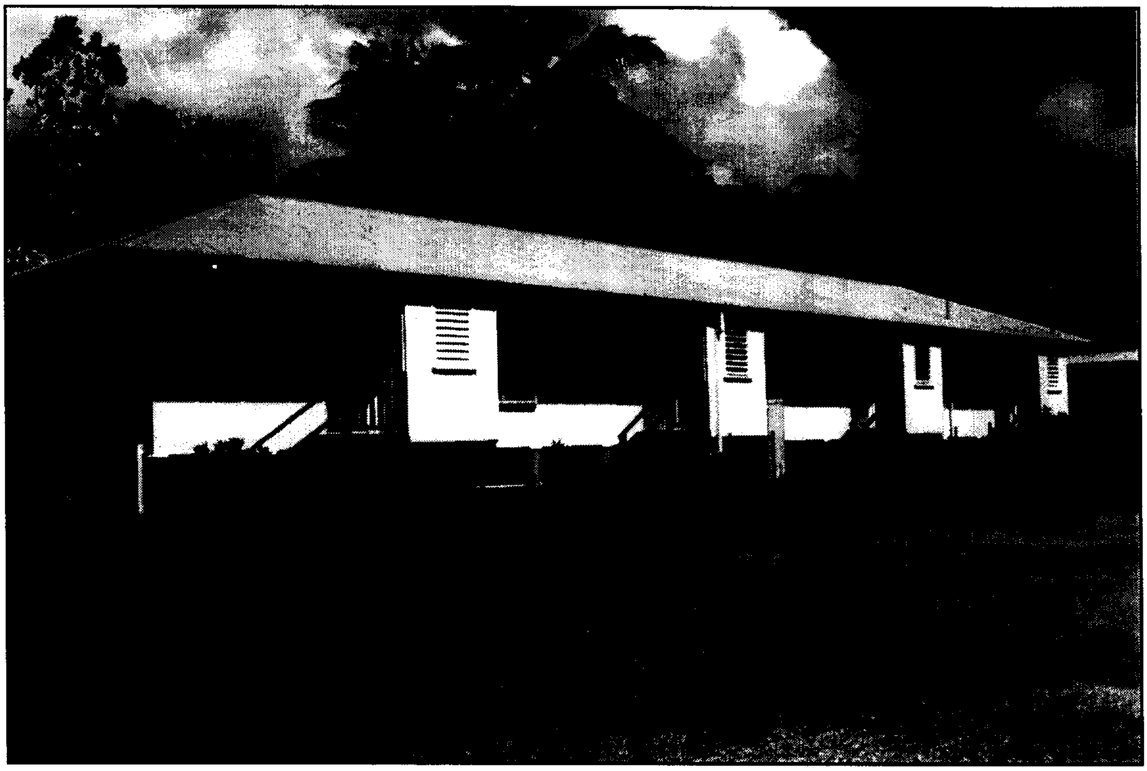
Evaluations were carried out and a decision made to rehabilitate the building.

A new larger top plate was surface mounted on the face of the exposed studs at the junction with the roof and connected to rafters with metal framing anchors.

The new wall top plate was coach screwed to each stud with two 12 mm coach screws, the studs were spaced at 450 cc, thus activating the timber studs to act as "holding down" posts.

The base of the studs were connected to the floor bearer by a mild steel strap (replacing part of the fibre cement cover mould).



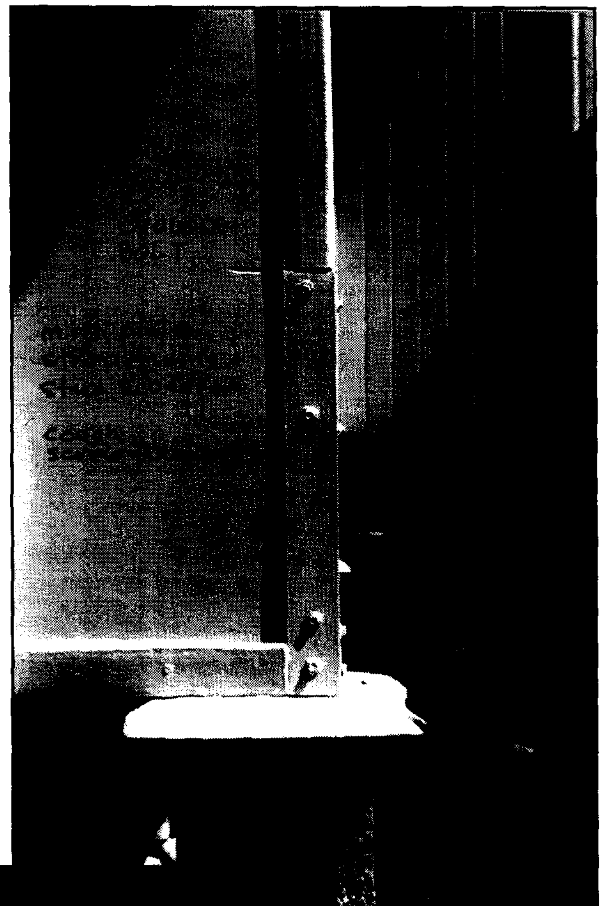


The 500 mm long, 50 x 5 MS. strap was extended from the bearer to 300 above floor level with two 12 mm Ø coach screws to both the bearer and to the stud.

Thus, the roof loads were transferred to the new top plate. The top plate transferred the loads to the studs. The studs transmitted the loads down to floor bearer which in turn supported the floor joists and in effect the whole building.

Rehabilitation Hold Down Method – Holiday Units, Magnetic Island

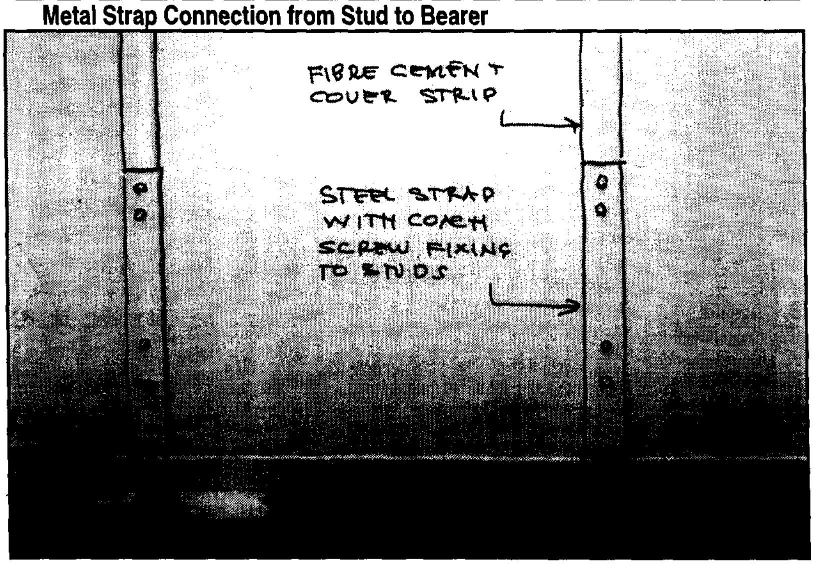
Fix new wall plate, Coach screw to studs, connect rafter to new plate with metal connectors



Fixing of Stud to Joist or Bearer by Metal Straps

Use existing timber studs as 'Hold Down' Mechanism

Metal Strap Connection from Stud to Bearer



10.1.5 ***Case Study 5***

(a) *Two Level Timber School*

This two level timber school, the Marian School, was affected by a 1971 cyclone and was able to be repaired.

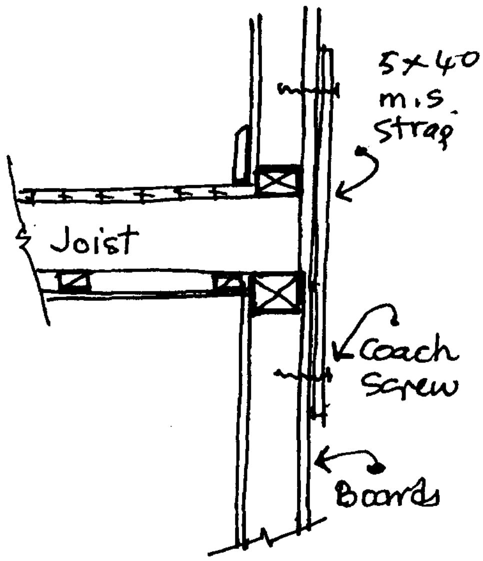
The construction consisted of bottom plate, studs to ground floor ceiling, bearer plate, upper floor joists, floor plate, studs to roof level, top plate and rafters bearing on to top plate.

This was defined as a "discontinuous" construction system.

The stability of the upper floor timber structure, sitting on a disconnected system of plates and joists at ground floor ceiling level, was in question when cyclone overturning forces were considered.

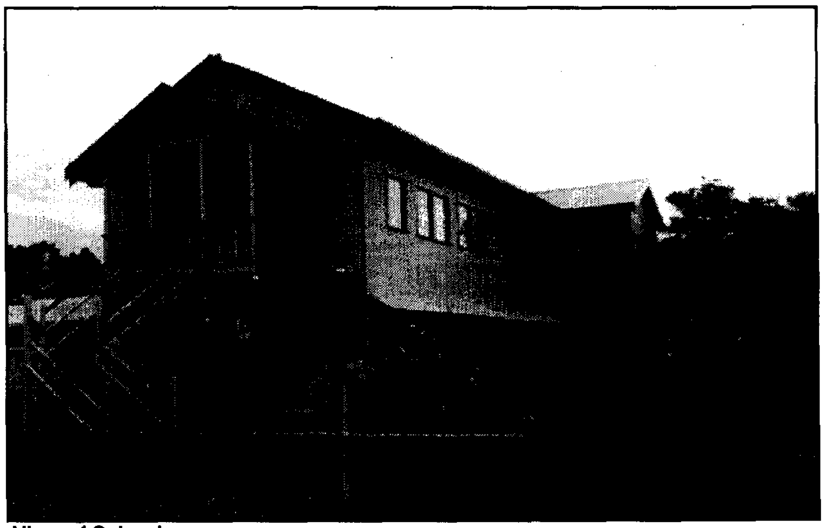
A decision was taken to provide continuity of fixing from the first floor studs to the ground floor studs without removing the external cladding.

A series of mild steel straps were used to connect the studs adjacent to windows on the upper floor to the studs on the lower floor. Surface mounted straps were used with Ø 20mm coach screws.



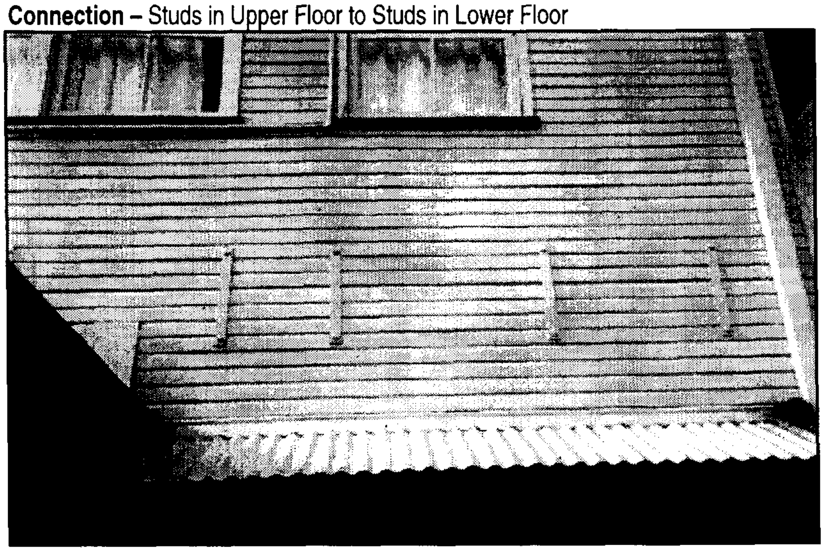
DETAIL

Providing Continuity from Roof to Foundation



View of School

Connection – Studs in Upper Floor to Studs in Lower Floor



(b) *School Toilet Block Structure – The Marian School*

This detail of design and construction of a small toilet block at a school illustrates a number of details.

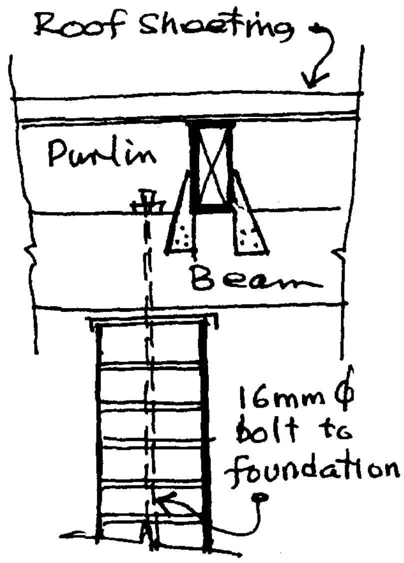
1. The space between the top of the wall and the roof is open. This avoids the application of internal pressure when calculating wind forces, saving over 35% of the wind loads applicable if the structure were closed.

   The ventilation is also useful in this building.

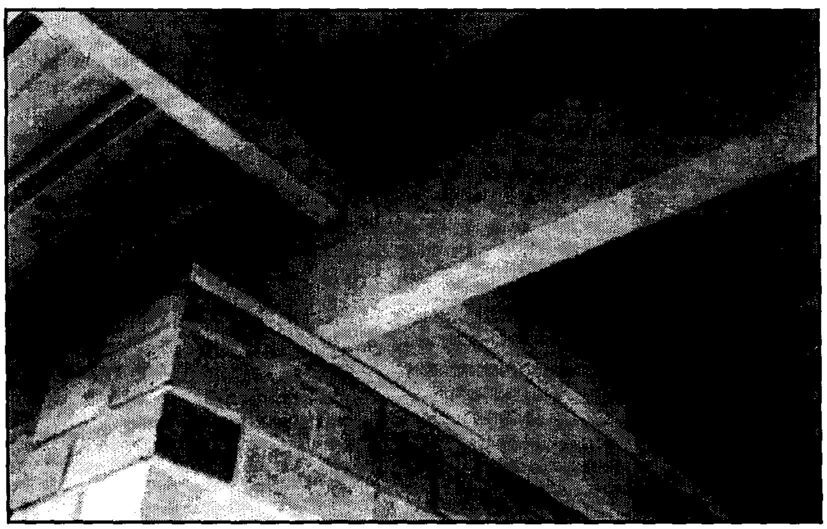
2. The purlins are shown connected to the supporting beams by metal framing anchors.

3. The beams are connected to the foundations by 16 mm Ø steel bolts extending through the centre of the 230 thick brick wall.

4. The brick walls provide mass and bracing to the building.

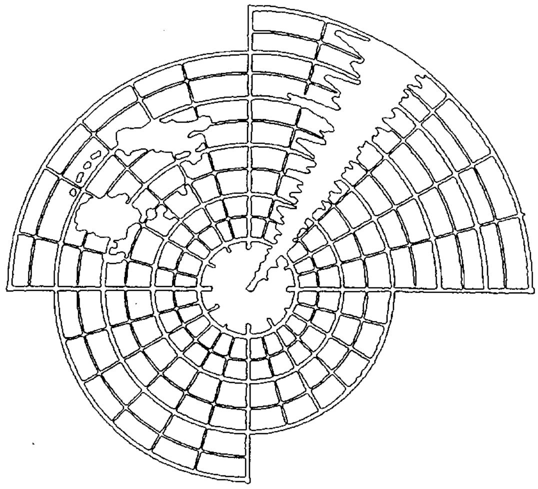


DETAIL



Beam Held Down by Bolt Through Brickwork to Foundation
Purlins connected to Beam by Metal Framing Anchors

Ventilation above window reduces pressure internally
Purlins connected by Metal Framing Anchors to Beams

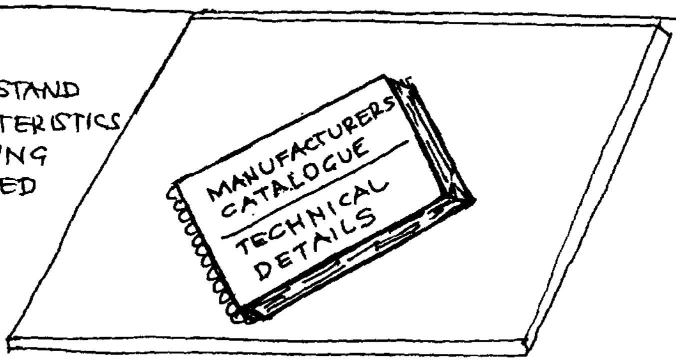


11 RESPONSIBILITIES & CONCLUSIONS

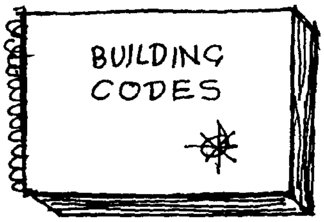
CONTENTS

DESIGNER'S RESPONSIBILITIES

- DESIGNER TO UNDERSTAND PERFORMANCE CHARACTERISTICS OF ALL OF THE BUILDING MATERIALS SPECIFIED

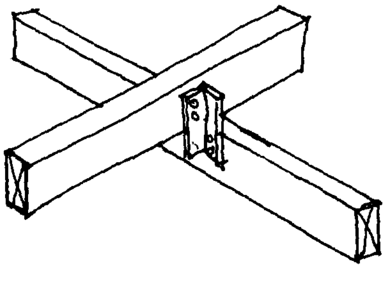


- DESIGNER TO UNDERSTAND LOCAL AND NATIONAL BUILDING CODES



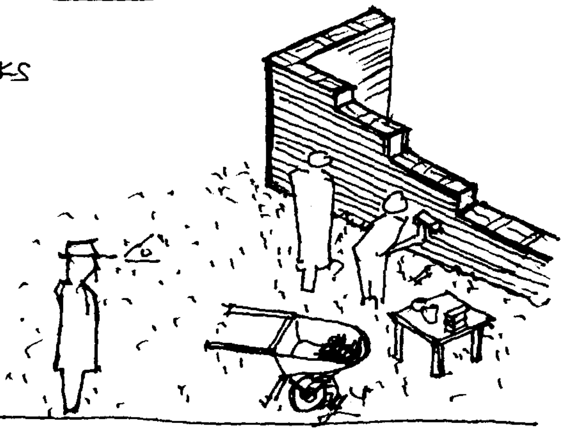
- DESIGNER TO DETAIL AND SPECIFY THE FIXING DETAILS AND WORKMANSHIP

  MAINTAIN EXPERIENCE IN CONSTRUCTION DETAILS



- DESIGNER TO INSPECT THE WORKS FROM TIME TO TIME

  SUB-CONTRACT SPECIALISTS AND CONTRACTORS TO SUPERVISE THE INSTALLATION



There are many sections of a society that bear responsibilities for the mitigation of the effects of disasters, of which cyclones are one of the most damaging.

A typical scenario of concern encompasses the following:

- Relief.
- Rehabilitation.
- Reconstruction.
- Research & Testing.
- Mitigation.
- Preparedness.

We are, in the design and construction industry, concerned with a number of these situations.

However, as stated in the Introduction, the Governments of individual countries are primarily responsible for mitigation against disaster events and the establishment of criteria and standards in their own country.

International co-operation and co-ordination can assist in establishing correct standards and should be supported by all governments and research establishments.

Technical data banks should be established at selected epi-centres in the disaster regions so that expert local advice can be obtained from people familiar with the region.

11.1 UNESCO CONTRIBUTION

UNESCO has been playing its part in assessing regions at risk in the Pacific and Indian Oceans and in the Caribbean and has sponsored Sub-Regional and National Training Courses for member states in these regions.

The publication no. 4 in this series, "School Buildings and Natural Disasters" in 1982 by D J Vickery, identified the overall problems, diagnosed the risk recognition and response and identified programme areas.

Subsequent UNESCO missions outlined above have been addressing the problems of education of professional and technical personnel to create an international cartel of experienced advisers in the field of disasters and in particular in the mitigation of the effects of cyclones.

The UNESCO mission to Bangladesh in April 1990 established wind code loading tables which estimated maximum wind speeds of 146 mph; and set out criteria for this speed. Workshops were held in the four major centres to pass on the information and experience and to learn of the local response.

In 1991, 12 months later, the highest wind speed in the recorded history of the country gusted at speeds up to 145 mph (65 m/s).

This should confirm the validity of the criteria already offered.

Some general overview should be maintained, as is presently done by UNESCO, to ensure that cyclone disaster events are properly examined and evaluated so that overlap is avoided, wherever possible, on major research projects.

11.2 RESEARCH, DISSEMINATION & EDUCATION

The following statements, initially made in the Introduction, are repeated hereafter to reinforce the need for consideration of these important matters.

Support of independent research and evaluation by experienced teams, whether government agencies, academic institutions, private committees or commercial ventures should be sponsored.

Another prime need is for collation and dissemination of research done to date. A great deal of research is lost once it is complete due to lack of publication. The cost of reproducing research and technical data is a hurdle to be crossed. Perhaps support from manufacturers or from the re-insurance industry and governments could assist in this regard, providing a suitable co-ordination body or council is set up to provide control.

The major problem is to instil into the education courses for both professional and technical students the input needed to make these future leaders aware of the wind problems and its effect on construction details.

Unfortunately, too often schools do not upgrade their course material on a regular basis and the time lag in imparting new techniques is too slow.

With the growing demand in the nations for better buildings, the need to update educational material is vital.

In any case, architects, engineers and their clients have a need to re-examine the security and integrity of constructions in regard to resistance in high wind damage areas.

The rapid growth of population in many countries has identified the need to provide greater protection now that a larger community is at risk. The reliance on a limited number of experienced professionals and contractors is no longer satisfactory.

11.3 THE EASY SOLUTIONS

As soon as a cyclone strikes a community and the subsequent damage reports are published we are faced with a litany of what we should not do in future development. Some of the easy solutions are offered:

Avoid roof overhangs:
Lose your shade

Avoid flat roofs:
Pitch all roofs at 30°

Avoid large windows:
Sweat all summer

Avoid wave surges:
Build in the hills

Avoid exposed sites:
Don't build in the hills

Don't use aluminium or fibre cement:
Build everything in concrete

Don't use nails or glue:
Bolt everything to the floor

Don't build near the sea:
Live on a farm

Don't build near trees:
Cut them down

Don't have fancy roof shapes:
Live in a box.

Avoid Cyclones:
Live in a cave and design for rock slides!

And so it goes on...

Obviously, these suggestions are impractical. But, well considered solutions must be developed to all of the problems confronting us so that the future population has an economical choice of solutions to allow the flexibility that is so necessary to maintain some individuality and comfort.

The results must be practical, economical and attractive additions to our environment.

After a disaster of significant magnitude, governments are catalysed into initiating research.

But, advantage must also be taken of the practical experience that is available and mix some of these practical people with the theorists while the theories are being developed in order to try and halve the time lag from conception through acceptance to use.

11.4 PEOPLE INVOLVED

The dissemination of material from the theorists mentioned above should pass on to and between the following diverse groups who should be involved in some occasional, at least, interaction at conferences and workshops.

- Professionals and technicians.
- Industry and manufacturers.
- Trade and contracting personnel.
- Local government departments and inspectors.
- Financiers of all colours.
- Insurers and government advisers.
- Developers.
- Occupants and the public at large.
- Media.
- Schools of education at both trade and tertiary level throughout the nation.

A great amount of design is carried out by individuals who are not aware of the implications involved in the design solution.

Government officials need to understand some of these considerations when a brief is formulated for a particular building project, especially where disaster prevention and post disaster functions may be needed to be served by the building.

Properly trained designers are often involved in only a minor percentage of the building stock in any country. The importance of the design stage should therefore not be underestimated nor the value of communication between the Construction Authority and the design team or between the design team and the end users of the building. Each should understand the problems of implementation, bureaucracy, current practice, codes and regulations and the need for clear and concise documentation and presentation.

Design solutions should be presented in a manner that is easily understood by the Construction Authority and the user. They should indicate which solutions the design is solving and also those matters that the design has not attempted to resolve. Awareness is a key factor in this stage.

The selection of the design team is therefore a most important decision which is often taken too lightly. The design team should be aware of current practice, traditional techniques and should also possess an administrative ability and the skill to relate the cost of the design to achievable budgets and the economy of the region where the building is to be erected.

Buildings subject to a post disaster function such as schools which should be available for shelter and service should be nominated prior to design stages by the construction authority and designed for higher loads to give these buildings a greater chance of survival to enable them to secure a post disaster function.

11.5 TRADITIONAL TECHNIQUES

There are many traditional techniques of building construction used around the world.

A lot of these have been developed in disaster-prone regions, most of which up until recent decades have small underdeveloped populations and little cross communication between each other. However, it is surprising how similar most of these traditional methods are to each other. There is a need for a study to be made to locate the details used in different regions and to study their similarity and their development in solving the problems of construction in disaster areas.

There are regions with common development techniques and others where there is a marked difference in construction techniques between developed and underdeveloped areas.

These lesser developed areas are not necessarily lacking in expertise in survival construction.

Adequate study may show unique solutions already resolved and proven which may save the cost of duplication of theory and development in these areas and assist in productivity allowing research to concentrate on unresolved problems.

Research alone, tends to isolate the elements and often fosters complex technical solutions. There is little published on how to integrate the elements into a simple practical and economic solution.

There are many papers on "How the wind blows", but very few on "How many nails to use".

The paper attempts to offer some practical solutions to the problem of disaster resistant design and construction by identifying "where" problem areas exist and to indicate "how" these problem areas can be resolved.

11.6 SUMMARY

Most of the population consider Architecture as providing suitable aesthetic and spatial solutions to a building design problem.

Architecture in disaster areas demand that this solution be consistent with a satisfactory structure.

Unfortunately, whilst architects study structure during training, some promptly forget or underestimate this discipline and delegate the responsibility. Likewise, many engineers look only to steel and concrete to solve problems and often have a less than intimate experience in timber design. Builders often care more about deflection and maintenance problems than extreme events. Some owners prefer to carry insurance against damage and build a cheaper structure rather than building stronger buildings.

These positions should be reversed. The professional should co-ordinate their knowledge to achieve some unity in their approaches to design for disasters. Professionals and builders should meet more often together to resolve the conflicts that occur between design and construction, so that each side understands the other's problems.

Owners and insurers need to be more aware of the real costs of failure so that briefing and legislation take due account of this future cost.

Researchers should intermingle more with the people involved in the construction of buildings. Experienced practitioners should be more involved in the research carried out. They should also be involved in the framing of codes and regulations.

Funding where necessary should be made available to promote this mixture of research and practise.

The insurance industry needs to look very seriously at their involvement in the research and implementation of the results.

Education is still a vital area of concern to both technical personnel and the public at large.

Dissemination of information follows as a natural flow on from research and education.

The time lag between research and implementation must be shortened.

Policing of implementation needs upgrading by inspectors, financiers, insurers and government.

Publication to be economical and available to the full range of involved personnel.

There are many papers on how the disaster occurs.

There are too few papers on how to put the elements together.

11.7 DESIGN GUIDELINES CHECKLIST

The checklists set out in this paper relate to those matters to which the designer should give consideration where the building is in a disaster region.

Whilst the list of considerations is detailed, it is important to understand that most designers already pay attention to many of these factors from an aesthetic point of view.

The purpose of this set of guidelines is to make the designer aware of the factors to be considered when the building is in a disaster area. Resolution of most of these items does not involve a lot of time when the designer has a basic knowledge of the problems associated with disaster building construction techniques.

However, some of the matters to be checked do need some education and awareness of what the problem areas are, where to look for solutions, and of how to resolve these problems into aesthetic, economical design solutions related to the scale of the project, its budget and to the environment of the region.

The checklist points to a need to introduce an awareness programme into the curriculum for education of architects, engineers and building construction operatives.

National Code and Regulation Authorities need to understand the importance of not only production of Manuals of Construction but also the more important point of adequate policing of these matters. All major elements of the building have, and should have, a part to play in providing security for the occupants.

It is vital, in protecting our built environment, to adopt a policy of knowing the performance of all materials and of using the load sharing abilities of each of these materials when properly fixed.

Universal adoption of these principles can only result in improved design and greater respect for the design team.

11.7.1 Practical Solutions

In the development of a Disaster Resistant design theory, the designer must of course continue to service the desirable aesthetic and comfort motives in order to provide a satisfactory design solution.

However, he must also provide himself with a list of security items to avoid the consequences of improper detailing and inadequate construction.

The following is a set of "Disaster Resistant design" guidelines for use by a designer in the course of designing disaster resistant buildings. Before commencing the drafting of working drawings, reference should be made back to these guidelines to confirm all considerations have been taken into account.

11.7.2 Site Selection

- ❑ Identify site, location, proximity to sea.
- ❑ Study future developments, viz. growth patterns.
- ❑ Establish terrain category in relation to known disasters.
- ❑ Is this likely to change in the life of the building?
- ❑ Establish flood heights and possible surge levels.
- ❑ Is site a flood plain?
- ❑ Is evacuation possible immediately prior to disaster?
- ❑ Study neighbours' proximity to proposed building construction.
- ❑ Study extent and size and rate of growth of trees in immediate vicinity.
- ❑ Advice of possible effects of damage by debris from both trees and neighbours' properties.
- ❑ Where near rivers and open spaces, estimate effects of micro-turbulence and effects of wind and flood patterns.

11.7.3 Landscaping

- ❑ Study topography in immediate vicinity.
- ❑ Can advantage be taken of mounds, etc. to give protection or reduction in a disaster situation?
- ❑ Can trees be planted that are more resistant to fracture and collapse?
- ❑ Can tree foliage be easily pruned to reduce effects of debris?
- ❑ Well located screen walls can break-up flow patterns and act as debris barriers.

11.7.4 Floor Levels

- ❑ Study topography and drainage in storm rains to determine flood-free floor levels.
- ❑ Evaluate implications of number of flood levels needed; one, two or more depending on intensity.
- ❑ Rises in height introduce higher loads from winds and earthquakes.

11.7.5 Shape

- ❑ Consider shapes to be adopted.
- ❑ Can roof profile be designed to transfer loads more evenly over whole roof?
- ❑ Advise where roof projections and shapes cause local turbulence - e.g. chimneys, vent pipes, sharp direction changes, out-riggings, etc., where these are dangerous if they collapse during floods, windstorms and earthquakes.

11.7.6 Structure

- ❑ Design for structural integrity.
- ❑ Consider a structural grid system of posts and beams to provide stiffness.
- ❑ Keep structural systems simple.
- ❑ Consider extent of vertical supports internally and in large open areas.
- ❑ Examine large spans and cantilevers.
- ❑ Make decisions on purlin / rafter spacings in roof framing.
- ❑ Closer spacings provide a stronger roof structure.

11.7.7 Codes

- ❑ Designers should maintain a continuing subscription to relevant code supplies and other trade publications.
- ❑ Office libraries should be kept up to date with current codes.
- ❑ It is not satisfactory to expect builders and tradesmen to build to a list of codes specified if the specifier does not have the code, has not read it and does not fully understand it.
- ❑ Note performance of code requirements so that better alternative solutions may be fed back to the code authorities.

11.7.8 Windows and Doors

- ❑ Check size and loads to be carried.
- ❑ Design frames and their connections to walls.
- ❑ Should shutters be used?
- ❑ Resolve conflict of wider windows for views and light and smaller windows for safety.

11.7.9 General Planning

- ❑ Consider alternative and innovative design solutions.
- ❑ Check interior half-height walls and their stiffness.
- ❑ Good interior cross ventilation can be an advantage.
- ❑ Stiffen structure around most secure rooms.
- ❑ Disposition and planning of internal spaces should fit into the structural system or vice versa.

11.7.10 Costs and Estimates

- ❑ Evaluate costs of alternative solutions.
- ❑ Know the real costs of the individual elements.

11.7.11 Selection of Finishes

- ❑ Are wall and ceiling linings suspect when wet?
- ❑ Are external walls debris resistant and water resistant?
- ❑ Is there adequate bracing in wall planes, ceiling and roof planes and in internal partitions?
- ❑ Select type of wall cladding materials, bricks, blocks or sheeting.
- ❑ Check higher pressure areas at walls and roofs near corners and profile changes.
- ❑ Check type of sheeting, thickness and fixing.
- ❑ Check that manufacturers instructions are adequate for the disaster area in which the building is constructed.

11.7.12 Details

- ❑ Check weak joints such as half-height wall with windows above where joint of vertical cantilevered wall and window needs stiffness to resist breaking or overturning (wind, flood, earthquake).
- ❑ Check flashings to roofs and ensure adequate fixings are provided.
- ❑ Parapets should be reinforced.
- ❑ Tying-down of roof members should extend down into foundations.
- ❑ There are technical details available to fix windows into frames but the actual fixings are seldom made correctly.
- ❑ Details of fixings of structure and claddings at edges and corners is very important.

11.7.13 Claddings

- ❑ When selecting claddings for walls and roofs examine thickness of material for the proposed use.
- ❑ Examine manufacturer's instructions and verify that they are suitable for the job.
- ❑ Check method of fixing of all materials.
- ❑ Check type and number of fixings used: nails, screws, glue, bolts, etc.
- ❑ Verify that the material selected is suitable for the job.
- ❑ Does the material have any debris resistance?
- ❑ What happens to the material when it breaks?
- ❑ Does the material add stiffness to the frame?
- ❑ Does the material still have strength after breaking?

11.8 INSPECTOR'S CHECKLISTS FOR SCHOOLS

It is recommended that checklists be prepared for various stages of school inspections, design, documentation and construction inspections.

The lists presented here are not conclusive but suggest topics that could be listed, developed or reviewed depending on the needs of the country nationally or regionally.

A Regional check list for cyclone damage could be prepared.

It is suggested that each region prepare a single page sheet for each school showing:

- Rough site plan and location.
- Number of classrooms and students (approximately).
- Notes on areas prone to disaster attack.
- Space for brief damage report.

Regions could subsequently provide overall reports to zone Headquarters.

Check lists could be under the following headings:

11.8.1 For Annual Inspection of Schools

- ❑ For design of schools generally.
- ❑ For quality of equipment.
- ❑ For standards of cleanliness.
- ❑ For maintenance requirements.
- ❑ For upgrading to meet current standards.
- ❑ For light, ventilation, acoustics and orientation.
- ❑ For site planning, landscaping and fencing.

11.8.2 For Documentation of Basic Plans

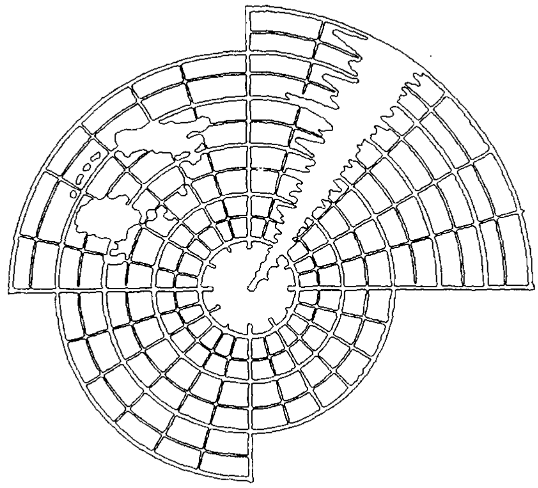
- ❑ Draw all construction details needed.
- ❑ Develop typical details.
- ❑ Prepare site and landscaping plan.
- ❑ Prepare standard specification clauses.

11.8.3 For Construction Details

- ❑ Ridge of roof to roof cladding.
- ❑ Barge of roof at gable.
- ❑ Fixing of roof cladding to purlins.
- ❑ Avoid small battens where possible.
- ❑ Reduce spacing of purlins.
- ❑ Space purlins to suit cladding loads.
- ❑ Purlin to truss connection.
- ❑ Truss to ring beam.
- ❑ Ring beam to foundation.
- ❑ Door and window joints detail and fixing.
- ❑ Verandah roof and supports.
- ❑ Bracing in roof plane.
- ❑ Bracing between trusses.
- ❑ Roof tiles to roof batten.
- ❑ Connections of bamboo members.
- ❑ Alternate gable wall details.
- ❑ "J" hooks or bolt fixings to steel trusses, including more direct and positive fixing.
- ❑ Connection of brick walls to concrete column.
- ❑ Bracing or buttress to walls as required.
- ❑ Fixing spacings to C.I. roofs.
- ❑ Type and size of washers.
- ❑ Specify cover of concrete to reinforcement.
- ❑ Specify proper vibration given to concrete.
- ❑ Use innovative materials for low cost schools.

11.8.4 For Contract Administration

- ❑ Check quality of materials, e.g. sand, cement, timber, etc...
- ❑ Check standard of workmanship.
- ❑ Is brickwork connected to concrete columns.
- ❑ Is roof structure tied down in a continuous manner to the foundations.
- ❑ Check all connections, especially roof sheeting to purlins, purlins to rafters or trusses, truss or rafter connection to ring beam.
- ❑ Ensure that roof bracing is installed.
- ❑ Check ridge and barge fixings.
- ❑ Check cover of reinforcement in concrete is as specified.
- ❑ Ensure concrete is properly vibrated during placing.



BIBLIOGRAPHY

ADLER, B W (1982): "Rehabilitation Project – Space Planning – Asian Development Bank, Manila", Tonga Education and Health Facilities.

ADLER, B W (1982): **Tonga – Education and Health Facilities – Rehabilitation Project – Space Planning Project**, [Fact Finding Mission 1–12 November 1982], [Unpublished].

ALAM, Md A (1990): **Low Cost Rural Primary School in Bangladesh**, [Unpublished], Facilities Department, Ministry of Education, Government of Bangladesh, Shikkha Bhaban, Dhaka.

ALMEIDA, R; LINDEN B (1984): **Évaluation des dégats causés aux éstablissements éducatifs par le cyclone « Kamisy »**, [République Démocratique de Madagascar] [Conception et réalisation d'infrastructures et d'espaces éducatiffs], France, UNESCO.

AUSTRALIAN DEVELOPMENT ASSISTANCE BUREAU (ADAB) & STANDARDS ASSOCIATION OF AUSTRALIA (SAA) (1975–80): **Cyclone Construction Details.**

AYNSLEY, Prof. R M (Ed.) (1993) 2nd Edn: **Proceedings – Tropical Architecture Workshop**, [Tropical Architecture Workshop, 27-30 September 1993], Townsville, Australia, Australian Institute of Tropical Architecture, James Cook University of North Queensland.

AYNSLEY, R M (n.d.): "Wind Effects", **Handbook of Architectural Technology**, COWAN, H J (Ed.).

AYNSLEY, R M; MELBOURNE W; VICKERY, B J (1977): "Architectural Aerodynamics", [Architectural Science Series], Sydney.

BEATH, J; CLARK, G; GAMBLE, J; HUMPHRY, L; LINDSAY, D; SNEATH, N (1976): **Structural Design – Cyclone Resistant Dwellings – Part A: Design**, [Second Printing], Department of Construction, Australia.

BEATH, J; CLARK, G; GAMBLE, J; HUMPHRY, L; LINDSAY, D; SNEATH, N (1976): **Structural Design – Cyclone Resistant Dwellings – Part B: Construction**, [Second Printing], Department of Construction, Australia.

BEYNON, J (1982): **Report on Cyclone Isaac – Damage at Tonga**, UNESCO Principal Regional Office for Asia and the Pacific.

BEYNON, J (1986): "General Principals of Good School Building Design which have relevance to Schools in Cyclone Affected Areas", [John Beynon, Principal Architect, UNESCO Bangkok], Paper delivered at UNESCO Regional Office for Education in Asia and the Pacific, Training course on Educational Buildings in Cyclone Affected Areas, Manila and Los Baños, Laguna, Philippines, 3 October 1986 (drawn 8 April 1986).

BEYNON, J (1988): **Assistance to Bangladesh following the 1988 Flood**, [Unpublished], Paris, France, UNESCO.

BEYNON, MACKS, NGUYEN ET AL, UNESCO PROAP (1987): **Construction Design and Reinforce the School Buildings in the Storm Wind Zone**, [the programme co-operated between the Ministry of Education of the Socialist Republic of Vietnam and UNESCO organisation of the Asia and Pacific Region.

BRITISH STANDARDS INSTITUTION (1972): **Code of Basic Data for the Design of Buildings, Chapter V. Loading, Part 2. Wind Loads**, [CP3: Chapter V: Part 2], London, British Standards Institution.

BUILDING OWNERS & MANAGERS ASSOCIATION OF AUSTRALIA LTD, (WA DIVISION) (1993): **Building Maintenance Manual**, Perth, Australia, Building Owners & Managers Association of Australia Ltd, Western Australian Division.

BUILDING RESEARCH ESTABLISHMENT; BALL, D (1974): **Funafuti Physical Development Plan**, [Final Report to His Excellency the Governor].

BUREAU OF ELEMENTARY EDUCATION, BUREAU OF SECONDARY EDUCATION, MANILA (1990): **Maintenance of School Facilities – A Practical Guide for School Administrators**, Manila, Bureau of Elementary Education, Bureau of Secondary Education.

CALDARONE, M; BEYNON J (1988): **Educational Building Design, a. Costs, b. Typhoon affected areas, c. Earthquake affected areas**, [National training course for school construction specialists], Nanjing, China, UNESCO Principal Regional Office for Asia and the Pacific.

CALDARONE, M; BEYNON, J (1989): **School Building Maintenance Planning, A Preliminary View of Current Knowledge**, [Educational Facilities Development Service], Bangkok, UNESCO Principal Regional Office for Asia and the Pacific

CAMPBELL, J R (1951): **Dealing with Disaster – Hurricane Response in Fiji**, [Government of Fiji, Suva – Pacific Islands Development Program East-West Center, Honolulu], Library of Congress Cataloguing in Publication Data.

CENTRE FOR DISASTER STUDIES (1995): **Proceedings – Design for Tropical Cyclones** [Workshop – 02–04 May 1995], [Unpublished], Townsville, Australia, Centre for Disaster Studies and James Cook University of North Queensland.

CHARANYANOND, K (1991): **Multi-Purpose Buildings for Disaster Situations for Thailand**, Department of General Education and UNESCO.

CHINA BUILDING TECHNOLOGY DEVELOPMENT CENTRE (CBTDC) (1991): [Series No. 91YJ32, June 1991, Issue 39] [Construction Detail Handbook].

CLARKE, A G; SWANE, R A; SCHNEIDER, L M; SHAW P J R (1979): **Technical Assistance to Sri Lanka on Cyclone Resistant Construction – Volume 1 – Parts 1–4**, [Project Summary, Roofing Materials and Fixings, Building Materials – Masonry Technology, Meteorological Instrumentation], Australia, Commonwealth of Australia, Department of Housing and Construction for Australian Development Assistance Bureau.

CSR LIMITED, GYPSUM PRODUCTS GROUP (1982): **Gyprock Structural Wall Bracing System** [Design Manual].

CYCLONE BUILDING RESEARCH COMMITTEE (1980) 4th Edn: **Papers of Cyclone Building Construction Seminar**, Townsville / Cairns / Darwin, The Cyclone Building Research Committee.

CYCLONE BUILDING RESEARCH COMMITTEE; MACKS, K J; LLOYD, D H; CLAYTON, R V; BLOXHAM A F; (1973) 3rd Edn: **Cyclone Construction Seminar**, Townsville / Cairns / Mackay, The Cyclone Building Research Committee.

CYCLONE TESTING STATION (November 1981): **Investigation of Diaphragm Action of Ceilings, Progress Report 1**, [Technical Report No. 10] Townsville, Australia.

CYCLONE TESTING STATION (December 1982): **Investigation of Diaphragm Action of Ceilings, Progress Report 2** [Technical Report No. 15] Townsville, Australia.

CYCLONE TESTING STATION (December 1983): **Investigation of Diaphragm Action of Ceilings, Progress Report 3** [Technical Report No. 20] Townsville, Australia.

DARWIN RECONSTRUCTION COMMISSION (1977): **Darwin Area: Deemed to Comply Standards**, [Unpublished binder of details], Darwin, Australia.

DARWIN RECONSTRUCTION STUDY GROUP (1975): **Tracy – Phase One.....Impact on Design, Building, Planning, Landscape**, [Preliminary Report], Darwin, Department of Housing and Construction.

DEPARTMENT OF HOME BUILDING COMMUNITY (1982): **Building Structure**, [Construction Details of National Standards], Vietnam, Department of Home Building Community.

DEPARTMENT OF HOUSING AND CONSTRUCTION AUSTRALIA (1975): "Darwin Reconstruction Study – Phase 1 – Impact on Buildings, etc." [After Cyclone Tracy].

DUPON, J F (c. 1988): "The Effects of the Cyclones of 1983 on the Atolls of the Tuamotu Archipelago (French Polynesia)", **Natural and Man-Made Hazards**, D Reidel Publishing Company.

EATON, Dr K J (1981): **Overseas Building Notes – Buildings and Tropical Windstorms**, Building Research Establishment, England.

EATON, K; REARDON, G (1985): **Cyclone Housing in Tonga**, Building Research Establishment, Department of the Environment, Cyclone Testing Station.

FACILITIES DEPARTMENT, MINISTRY OF EDUCATION, BANGLADESH (n.d.), **3 Classroom Government Primary School.**

GOVERNMENT OF THE PEOPLE'S REPUBLIC OF BANGLADESH (1991): **Integrated Protection Plan Proposal for Lives and Properties Exposed to Risk of Cyclone and Storm Surge in Coastal Areas of Bangladesh**, Bangladesh, Local Government Engineering Bureau (Local Government Division), Ministry of L.G.R.D & Co-operatives, Government of The People's Republic of Bangladesh.

GOVERNMENT OF THE PEOPLE'S REPUBLIC OF BANGLADESH (1991): **Preliminary Report of the Inter-Ministerial Task Force on the Construction of Multi-purpose Cyclone Shelters in the Coastal Areas of Bangladesh**, Bangladesh, Government of the People's Republic of Bangladesh, Physical Infrastructure Division, Planning Commission.

HAMNETT, M P; FRANCO, A B (1982): **Regional Overview of Disaster Preparedness and Disaster Experience in the South Pacific**, [Pacific Islands Development Program].

HOLMES, J D; MELBOURNE W H; WALKER, G R (1990): **A Commentary on the Australian Standard for Wind Loads**, Australia, Australian Wind Engineering Society.

JAMES COOK CYCLONE STRUCTURAL TESTING STATION (1988): **10 Year Report**, Townsville, Department of Civil & Systems Engineering, James Cook University of North Queensland.

JAMES COOK UNIVERSITY OF NORTH QUEENSLAND, Macks K J; (1972): **Design for Cladding – Design for Tropical Cyclones, Vacation School**, Townsville, Australia, Department of Engineering, James Cook University of North Queensland.

JAMES COOK UNIVERSITY OF NORTH QUEENSLAND, Trollope Prof. D H (Ed.) (1978): **Design for Tropical Cyclones – Volume 1** [A Vacation School held at James Cook University by Department of Civil & Systems Engineering], Townsville, Australia, James Cook University of North Queensland and The James Cook Cyclone Structural Testing Station.

JAMES HARDIE & COY PTY LTD (1983): **Design Manual Structural Wall Bracing on High Wind and Cyclone Areas.**

JONES, D S (c. 1970): **Tourist and Domestic Structures for Cyclonic Areas. Some Lessons from Cyclone Ada.**, [Unpublished] Australia, Queensland Timber Board.

KAVA, P (n.d.): **The Impact of High Winds on Houses in Tonga**, [Unpublished Thesis], Thesis for Unitech, Lae, Papua New Guinea.

LAPISH, E B; LYNCH, A J (n.d.): **Strengthening Village Fales for Strong Winds**, [Unpublished], for The Public Works Department Government of Western Samoa in conjunction with The Ministry of External Relations and Trade Government of New Zealand.

LEWIS, J (c. 1991): **Caribbean Sub-Region – The development of school design and hazard resistance, construction training and curriculum infusion – Participation Programme Request No 5168 –**

St Christopher & Nevis, [Unpublished Report], UNESCO Educational Architecture Unit.

LYNCH, A J (1991): **An Introduction to The Mitigating of Cyclone Hazard in Low-Rise Buildings. Case Study; The Islands of the Southwest Pacific**, [Unpublished Thesis], Thesis for University of Auckland, New Zealand.

MACKS AND ROBINSON PTY LTD (1979): **DRAFT Details for Standards Association of Australia (SAA) Committee BD/57 – Construction Details for Houses in High Wind Areas**, [drawn by Macks and Robinson Pty Ltd Architects for The Cyclone Building Research Committee], Townsville, Australia, Macks and Robinson Pty Ltd.

MACKS, K J (1966): **Building Construction for Engineering University Students – Building and Trade Works**, [Lectures 1–14], [Unpublished].

MACKS, K J (1972): "Design of Claddings", [Vacation School], James Cook University of North Queensland.

MACKS, K J (1973): "Paper 2 – Claddings" & "Paper 6 – Linings, Doors and Windows", Cyclone Building Research Committee, Townsville.

MACKS, K J (1975/1984): **Interpretation of ASA Code 1170 – Part 2 – Wind Loadings**, Townsville, Australia.

MACKS, K J (1978): "Architectural Design Philosophy", [paper to James Cook University Vacation School], Townsville, Australia, James Cook University of North Queensland and Cyclone Structural Testing Station.

MACKS, K J (1979): "Co-operation in the Building Industry", Australian Institute of Building Surveyors.

MACKS, K J (1980): **Roof and Wall Claddings**, Townsville, Cyclone Building Research Committee.

MACKS, K J (1985): **Design Construction and Maintenance of School Buildings in Cyclone Affected Areas, Volumes 1 & 2**, [UNESCO Training School], Fiji, UNESCO.

MACKS, K J (1986): **UNESCO Training School – Manila – Educational Buildings in Cyclone Regions** [Volume 1] [Sub-Regional Training Course] [Unpublished], UNESCO.

MACKS, K J (1986): **UNESCO Training School – Manila – Educational Buildings in Cyclone Regions** [Volume 2] [Sub-Regional Training Course] [Unpublished], UNESCO.

MACKS, K J (1987): "Planning for Cyclones – Paper 8", **Science and Life in the Tropics**, [Section C-11 Architecture and Planning], *[Unpublished]*, [Portfolio of Papers Presented, Townsville, 24-28 August 1987 - ANZAAS Congress], Townsville, Australia.

MACKS, K J (1992): **Disaster Management Workshop – Rehabilitation Assistance to Anhui Province, following Flood Disaster**, [Workshop Report – April 1992], UNDP / UNESCO PROJECT IN CONJUNCTION WITH CICETE / MOFERT.

MACKS, K J (1994): **Cyclone Preparedness Workshop**, [Collection of papers presented at 14th General Assembly & Conference, Mauritius] [Commonwealth Association of Architects], [Unpublished] Townsville, Australia, Macks and Robinson Pty Ltd.

MACKS, K J (1995): "Windloads on Low Rise Buildings" presented at Tropical Architecture Workshop, University of the South Pacific, Suva, Fiji, [Unpublished], Suva, Fiji, Australian Institute of Tropical Architecture & Fiji Association of Architects.

MACKS, K J (c. 1975): "Fixings – Loading Resistances" [Calculated by K J Macks using Australian Standard CA65 – 1972 SAA Timber Engineering Code (superseded)].

MACKS, K J; FACILITIES DEPARTMENT, MINISTRY OF EDUCATION, BANGLADESH; EDUCATIONAL FACILITIES SERVICE, UNESCO, BANGKOK (1990): **Cyclone Resistant School Buildings for Bangladesh: Report on Country Training**, Bangkok, UNESCO / PROAP.

MACKS, K J; MURRAY F J; WITTENOOM, R A: (1979): **Technical Assistance to Sri Lanka on Cyclone Resistant Construction – Volume 2 – Part 5**, [Improvement of Building Methods for Cyclone Resistance], Australia, Commonwealth of Australia, Department of Housing and Construction for Australian Development Assistance Bureau.

MACKS, K J; UNESCO BUREAU FOR OPERATIONAL ACTIVITIES (1991): **Primary School Construction Project – Project Preparation Report**, [The People's Republic of Bangladesh] [The Opec Fund for International Development] [UNESCO Bureau for Operational Activities].

MERA, R V (1990): **Report on Mission to Dominica (15 to 21 February 1990)**, [Unpublished], (Ref: ER02321].

MINISTRY OF LOCAL GOVERNMENT, HOUSING AND CONSTRUCTION, SRI LANKA (1979): **Cyclone Preparedness and Reconstruction: An Overview Report**, [United Nations Development Programme] [Office of Project Execution] Washington DC, PADCO, INC.

MINISTRY OF PUBLIC WORKS AND HIGHWAYS, MANILA (c. 1986): **Three Classroom School Building (E.S.F.)**, [Unpublished], Architectural Division, Bureau of Design, Ministry of Public Works and Highways, Manila.

MINISTRY OF PUBLIC WORKS, REPUBLIC OF THE PHILIPPINES (c. 1986): **Construction and Erection Manual Bagong Lipunam Standard 3 – Classroom Building (Type II)**, [Prepared by Building System Research Division, Prefabricated plant, Bureau of Buildings, Ministry of Public Works, Republic of the Philippines], approved by Castor S Surla IV, Director, Bureau of Buildings.

MÜNCHENER RÜCKVERSICHERUNGSI-GESELLSCHAFT (c. 1975): **Fiji, A Study of the Hurricane Damage in Honduras, 1974**, Münchener Rückversicherungsi-Gesellschaft.

MUNICH REINSURANCE COMPANY (1990): **Windstorm,** Federal Republic of Germany, Munich Reinsurance Company.

NEWBERRY, C W; EATON, K J (1974): **Wind Loading Handbook**, [Building Research Establishment Report], London: Department of the Environment.

PADYA, B M (1976): "Cyclones of the Mauritius Region", Meteorological Office Mauritius.

PAYDA, B M (1989): **Weather and Climate of Mauritius**, [Mahatma Gandhi Institute], Moka, Mauritius, Mahatma Gandhi Institute Press.

PEARSON, R G; KLOOT, N H; BOYD, J D (1962) 2nd Edn, **Timber Engineering Design Handbook**, Australia, The Jacaranda Press in association with Commonwealth Scientific and Industrial Research Organization, Australia.

PENWARDEN, A D; WISE, A F E (1975): **Wind Environment Around Buildings**, [Building Research Establishment Report], London, Department of the Environment Building Research Establishment.

PUBLIC WORKS DEPARTMENT, SUVA, FIJI (1980): **Design Data for Light Timber Framed Construction**, [Unpublished].

REARDON, G (1994): "Hurricane Andrew: Its Effects on Miami" [Unpublished] [Paper submitted to Australasian Structural Engineering Conference – 1994].

SALIM, A; ALI MD A (1988): **Primary School Buildings for Flooded Areas in Bangladesh**, Thailand, UNESCO Principal Regional Office for Asia and the Pacific.

SINNAMON, I T; VAN 'T LOO, G A (1977): **Cyclone Resistant Rural Primary School Construction – a design guide**, [Educational Building Report], Bangkok, Thailand, UNESCO Regional Office for Education in Asia and the Pacific.

SNOWY MOUNTAINS ENGINEERING CORPORATION LIMITED in association with BANGLADESH CONSULTANTS LIMITED (1991): **Cyclone Damage 1991 – Damage Assessment of General Infrastructure**, [Final Report] [Volume 9: Education], The World Bank & Government of The People's Republic of Bangladesh.

SOUTHERN BUILDING (1980): **Bluebook Issue – 1980 – Proposed Changes to the Standard Codes**, Alabama, Southern Building Code Congress International, USA.

SOUTHERN BUILDING (1981): **Bluebook Issue – Mid-year Code Change Hearings, Jackson, Mississippi, July 13-16**, Alabama, Southern Building Code Congress International, USA.

SOUTHERN BUILDING (1981): **SBCCI Goes "Down Under" For U.S./Australia Workshop**, [December 1980/ January 1981], Alabama, Southern Building Code Congress International, USA.

SOUTHERN BUILDING CODE CONGRESS INTERNATIONAL (1990): **Deemed–To–Comply Standard for Single and Multifamily Dwellings in High Wind Regions SSTD 10–90**, Alabama, Southern Building Code Congress International, USA.

STANDARDS ASSOCIATION OF AUSTRALIA (1981): **Construction Details for Houses in High Wind Areas, Draft Australian Standard DR 77109** [Unpublished], North Sydney, Australia, Standards Australia.

STANDARDS ASSOCIATION OF AUSTRALIA (1988): AS 1720.1, **SAA Timber Structures Code – Part 1– Design Methods**, [Australian Standard], North Sydney, Australia, Standards Australia.

STANDARDS ASSOCIATION OF AUSTRALIA (1989): AS 1170.1, **SAA Loading Code – Part 1: Dead and live loads and load combinations**, [Australian Standard], North Sydney, Australia, Standards Australia.

STANDARDS ASSOCIATION OF AUSTRALIA (1989): AS 1170.2, **SAA Loading Code – Part 2: Wind loads**, [Australian Standard], North Sydney, Australia, Standards Australia.

THE WORLD BANK (1990): **Staff Appraisal Report – Bangladesh – General Education Project**, [Population and Human Resources Division, Country Department I, Asia Region].

TIEDEMANN, H (1990): **Newcastle: The Writing on the Wall**, Zurich, Swiss Reinsurance Company.

TIMBER RESEARCH AND DEVELOPMENT ADVISORY COUNCIL OF QUEENSLAND (1990): **TRADAC Timber Framing Manual W50**, Queensland, Australia, Timber Research and Development Advisory Council of Queensland.

TIMBER RESEARCH AND DEVELOPMENT ASSOCIATION (1983): "Details and Load Capacities", **TRADAC W65 Design Manual**, Brisbane, Australia.

TROLLOPE, PROF. D H (Ed.) (1972): **Cyclone Althea – Buildings**, report by James Cook University of North Queensland to Queensland State Government, Australia.

TROLLOPE, PROF. D H (Ed.) (1972): **Cyclone Althea – Wave Surges**, report by James Cook University of North Queensland to Queensland State Government, Australia.

UNESCO & MACKS, K J (1989): **Report on a Mission to Socialist Republic of Vietnam** [Unpublished], UNESCO Principal Regional Office for Asia and the Pacific.

UNESCO (1977): **Design Guide for Secondary Schools in Asia**, Bangkok, Thailand.

UNESCO (1979): [Papers of the mission for calculating consequence of Hurricane David on "Frederick" and possible immediate remedial actions in co-operation with UNESCO], Santo Domingo, Dominican Republic (1 – 19 October 1979) UNESCO, [English Translation].

UNESCO (1980): [Papers of the urgent mission of passing of Hurricane David on "Frederick"], Santo Domingo, Dominican Republic (12 February 1980) [Ref: EF02263] [English Translation], UNESCO.

UNESCO (1982): **Final Report – UNESCO Seminar on School Buildings & Equipment** [Saint Lucia, 23rd – 27th November 1981], Santiago Chile, UNESCO Santiago – Chile.

UNESCO (1982): **Improving the Primary School Environment through Community Efforts**, [Educational Buildings Occasional Paper No 1] [Sri Lanka], Thailand, UNESCO Regional Office for Education in Asia and the Pacific, UNESCO.

UNESCO (1987): **Education Buildings and Natural Disasters – Mexico and Central American Zone, Santos E Ruiz Gomez**, [English Translation], UNESCO.

UNESCO BANGKOK & TONGA CHRONICLE (1982): **Isaac Destroys Tonga Schools**, Thailand, UNESCO Regional Office for Education in Asia and the Pacific.

UNESCO BANGKOK (1981): **Alternative Building Designs for Universal Primary Education in Bangladesh – A Report on an In-Service Training Activity**, Thailand, UNESCO Regional Office for Education in Asia and the Pacific.

UNESCO OFFICE FOR THE PACIFIC STATES (c. 1992): **The Samoan Fale**, [Report printed under UNESCO-AGFUND Regional Project, Development of Educational Facilities in Asia and the Pacific], Thailand, UNESCO Office for the Pacific States and UNESCO Principal Regional Office for Asia and the Pacific.

UNESCO; MACKS, K J (1987): **Typhoon Resistant School Buildings for Viet Nam**, by Department of Educational Buildings, Ministry of Education, Vietnam; Educational Facilities Development Service, UNESCO; and K J Macks.

UNITED C.B.M. LIMITED (n.d.): **Low Cost Housing – Nausori – Fiji**, [Union Manufacturing & Marketing Co. Ltd], [Unpublished document].

VICKERY, D J (1982): **School Buildings and Natural Disasters**, [Series Title: Educational Buildings and Equipment, Book No. 4], [Educational Architecture Unit, UNESCO], Paris: UNESCO.

VIROCHSIRI, X (1977): **Design Guide for Secondary Schools in Asia**, Bangkok, Thailand, UNESCO Regional Office for Education in Asia.

WALKER, ASSOC. PROF. G R (1975): **Cyclone Tracy**, report to Australian Government, Department of Housing and Construction.

WALKER, G R (1985): **DRAFT Report to Underwriters Association of Fiji on Property Damage in Fiji from Cyclones Eric and Nigel and its Implications for Insurance Management – Part 2 – Technical Aspects**, [Unpublished] Australia, James Cook University of North Queensland.

WITTENOOM, R A; MACKS, K J (1979): **Technical Assistance to Sri Lanka on Cyclone Resistant Construction – Volume 3 – Part 6**, [Design of Buildings for High Winds – Sri Lanka, A Proposal for a Design Manual for Adoption in Sri Lanka], Australia, Commonwealth of Australia, Department of Housing and Construction for Australian Development Bureau.