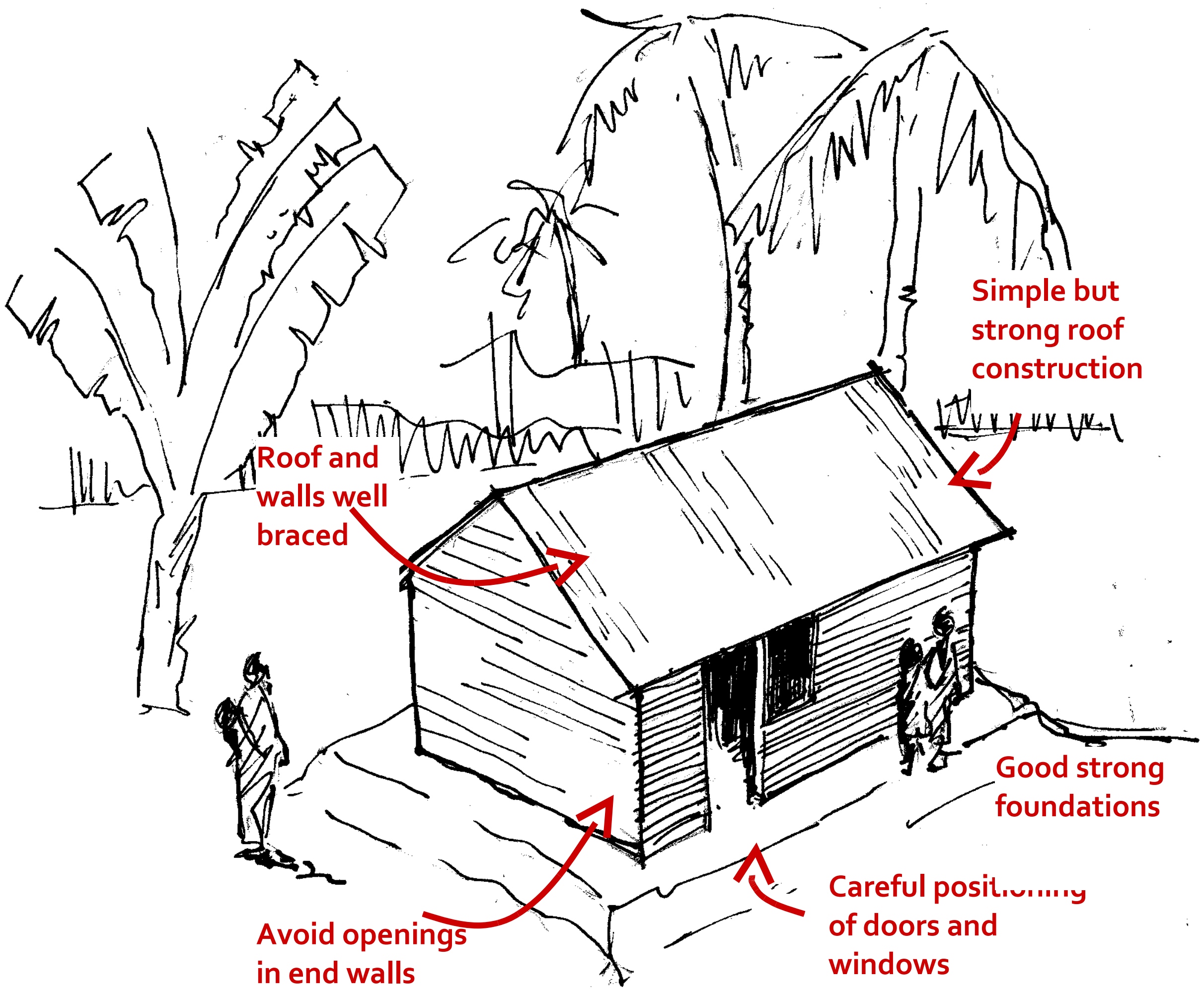


All elements well
connected together

CONTENTS

INTRODUCTION

The purpose of this document – what it is and what it is not.

The ambition behind this document is to increase quality of design, engineering and construction in the houses of poor families living in hazard prone parts of the world. It is intended for **post-disaster reconstruction** of both temporary and permanent dwellings. However it is hoped that it will be equally valuable for **preparedness and the reduction of disaster risk**.

Primarily it is a **teaching manual**. It is accompanied by a series of powerpoint presentations that follow the text, reproducing the illustrations but also augmenting them with photographs of good and bad examples. Physical models also accompany the text.

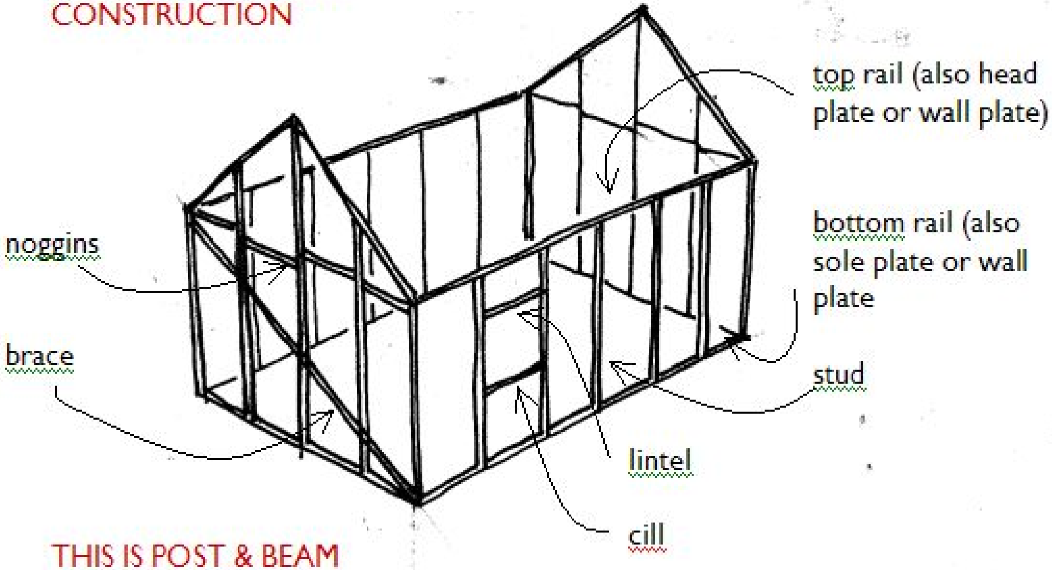
Every effort has been made to use non-technical language that can be understood by all. But it should also be useful to people with varying technical ability. So in some instances extra detail has been included "for the more technically minded". This should not detract from the basic principles that can be understood by everyone, but will allow some people to dig a little bit deeper.

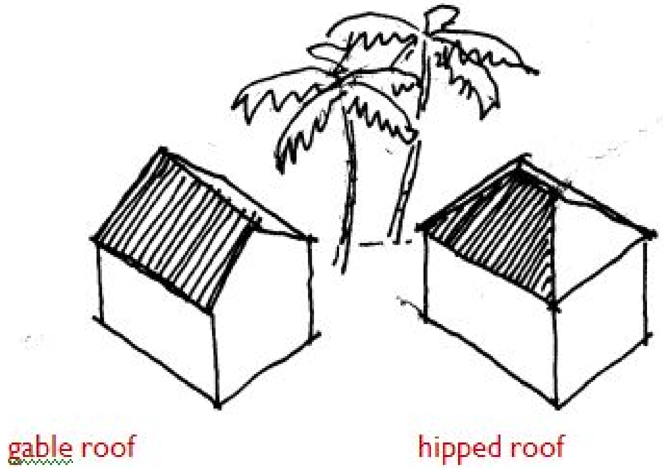
Here are some things that this manual does **not** set out to do:

1. It is not intended to substitute for the use of a properly qualified structural engineer; all designs, particularly if being built in large quantities in areas of hazard risk, should be overseen by an engineer.
2. There are many important issues that are not discussed: cultural and climatic influences; the variety of ways in which a shelter programme can be delivered; the participation of the community in decision making; and many others. There are a number of other publications that cover these areas.
3. It is by no means exhaustive: it only intends to cover some of the important principles as a guide to improving quality.
4. It is not a step-by-step guide to building a shelter. Every situation is unique and there are no "off the shelf" solutions. The principles outlined here will be useful, but the solution has to emerge from the specifics of each circumstance.
5. It does not cover all construction types. Emphasis is on timber construction, but the basic principles hold good for all building.

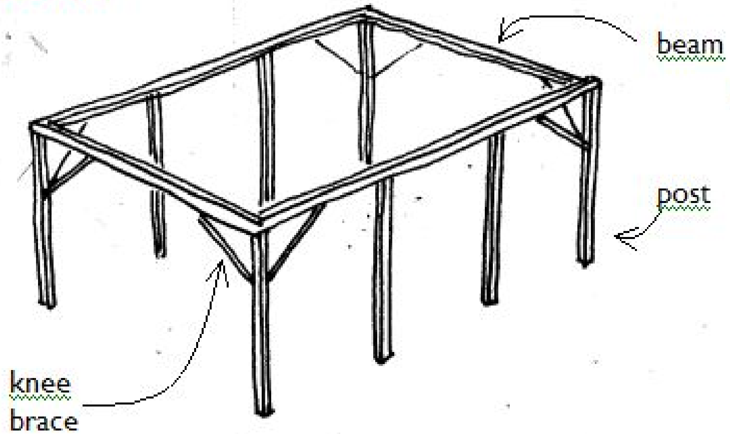
Glossary of terms

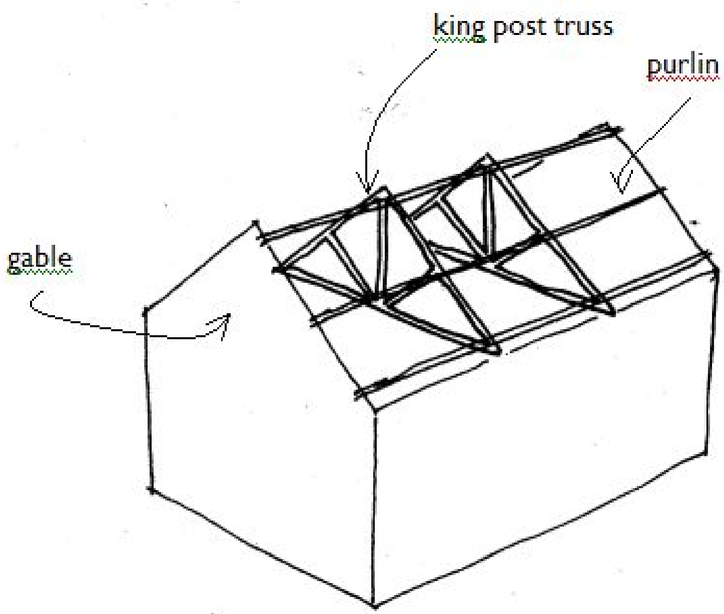
THIS IS TIMBER PANEL CONSTRUCTION





THIS IS POST & BEAM CONSTRUCTION





TERM	EXPLANATION
Brace	A building is braced when it has diagonal members to prevent it “racking”, This explained on page 11.
Centres	The spacing between studs or columns or rafters etc. Normally measured from “centre to centre”
Cladding	The final covering to the walls: boards, plywood, plastic sheeting, sometimes even corrugated steel sheet.
Compression	The action of pushing. See page 9
Leeward	The downwind side. The side of the building that is not exposed to the direction of the wind. It will be experiencing a negative or suction force.
Load	A building is subject to different loads or forces. This can be due to gravity (the weight of the building and its occupants and furniture) or wind, earthquakes, flood waters. Most loads are *static*, but some loads are *dynamic* – for instance the buffeting of wind or the sudden shaking of an earthquake. See page 8.
Noggin	A short horizontal piece of timber that connects and stiffens the studs
Plate	A term often used for the top and bottom horizontal rails of a timber wall panel. You will hear the terms sole-, wall-, head- or top-plate.
Span	The span is the measurement of the unsupported distance between the two ends of a beam, or other structural member; as in, for example, the span of a bridge or an aeroplanes wing span.
Strain and stress	These terms have specific engineering meaning. For the technically minded: strain = the change in length /original length; and stress = applied load / cross-sectional area
Tension	The action of pulling. See page 9
Windward	The upwind side. The side experiencing the direct positive force of the wind.

A FEW KEYS MESSAGES

1. A family's home should be **safe**. At the very least, we should be striving for significant improvements in construction quality that lead towards a culture of safety. Of utmost importance is safeguarding people's lives. One aspect of this must be safe and durable construction that decreases long-term vulnerability. Even a temporary or transitional shelter (that often last much longer than anticipated) must be built safely.

2. It is often said that a building needs **"a good hat and a good pair of boots".** In other words, the roof and the foundations are very important elements of the design.

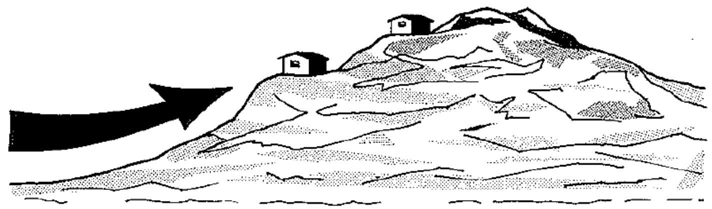
3. All designs must be checked by a **suitably qualified structural engineer**. This should be much more than just a checking exercise and ideally the engineer will be involved from the outset in pro-actively improving the design and construction. Nothing in this manual should be "copied".

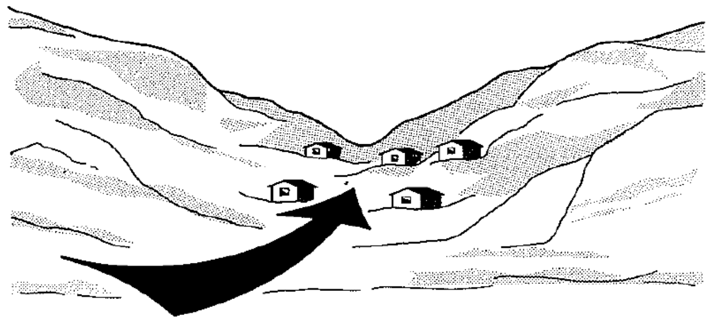
4. There are many **principles** in this manual; however they are not **rules**. There may be a good reason why a principle can be altered, adapted or even ignored. As an example: it is a good principle to avoid having windows and doors in the shorter side of a building; however there may be very valid cultural reasons for over-riding this principle. The project manager – because he or she is aware of the principle – can now ask relevant questions and ensure that the engineer has made appropriate allowances in the design.

5. **Alarm bells**. Engineering and construction cannot be taught from a manual in a short space of time. The intention here is to de-mystify some the basic principles of good building practice in a way that a non-technical person can understand. Alarm bells will ring in the heads of the project manager, the builder, the family – anyone with an interest in the project – when they see something that appears to contradict good building practice. This manual should give you the confidence to ask the right questions.

SOME SIMPLE DESIGN PRINCIPLES – a summary

1. Choose a **sensible site** – although circumstance may dictate that there is no choice at all! Beware of excessive earth-works and in particular "cut and fill". For some hazards – flooding and *tsunamis* for example – the choice of sites may be the most important factor.





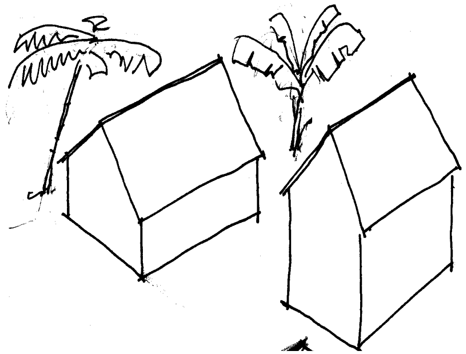
Hills and open-ended valleys increase windspeeds
Drawings from "Cyclone resistant housing – BRE"

2. **Simplicity** nearly always makes sense. This is true in terms of good design and cost. Simple is also good for achieving a stable and durable structure.
Beware of asymmetrical buildings with odd shapes – always ask why they are necessary, what function do they serve. Kitchen and bathroom extensions, porches and verandas may well be an entirely appropriate design solution, but they should be incorporated in a way that is simple and sensible.

3. **Low and wide is good; tall and skinny bad**. Common sense tells us that a tall building will be less stable than one that is low and covers more ground area. This can be simply demonstrated by blowing on appropriately shaped wooden boxes. A square plan is the most stable (or, indeed, a circular plan; but we don't often see circular buildings). In reality most houses have rectangular plans with one side longer than the other. One structural reason for this is that it is difficult and expensive to span long distances – so it cheaper to put a roof onto a rectangular building than a similar sized square one. Beware also of long walls with no cross walls.

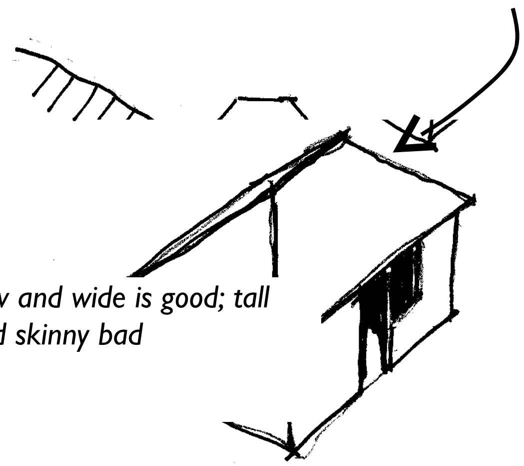
4. **Every element** of the building must be properly designed and considered. For instance, well-braced walls alone are not sufficient to guarantee a robust building; the foundations and the roof and how everything is connected together are just as important. A building is only as strong as its weakest component.

5. Nearly always buildings will be **extended and altered**. The initial design – both the spatial design and the



Low and wide is good; tall and skinny bad

Cut & fill



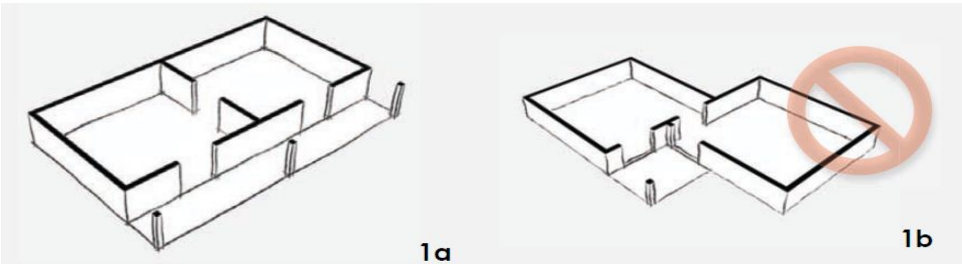
structural design – must take this into account. Can internal walls be removed without affecting the structural strength? Can new doors and windows be made?

6. **Doors and windows** should generally be away from **corners**. The photograph is an example of bad practice. When a strong gust of wind hits the long side of a building, it is the short sides that have to be strong enough to take the load. The short sides, therefore, have to be relatively stronger. So it is good practice to avoid windows and doors in the **short side**.

windows and doors best in long side

7. **Escape** from a building is important (particularly earthquakes and fire). Consider more than one wide door opening outwards (easier to push than pull).

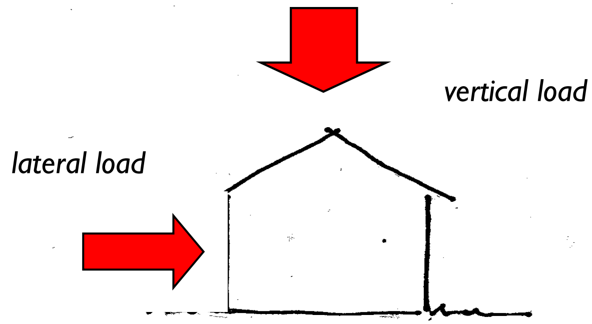
8. **Even transitional shelters should be built safely** – and a safe building is also likely to be a durable building. We all know that transitional shelters can last much longer than originally intended, and even when a new permanent house has been built, the transitional shelter can become a kitchen, an extra bedroom or a store. There has to be, of course, a debate about the appropriate level of safety – or the appropriate engineering design standard. "Earthquake-proof" may not be a realistic expectation, but remember that improving the strength and safety of a building need not be expensive. Always ascertain to what standard the building has been designed – ask to see the calculations and obtain an independent second opinion.



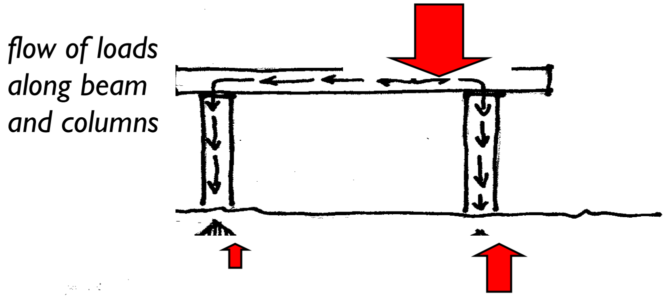
Simple but functional design *A more complex design*

This is an example of bad practice

SOME SIMPLE ENGINEERING PRINCIPLES



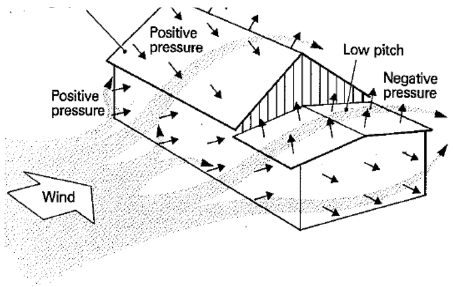
Houses are made of **elements** or **members** (posts, beams, sticks, bricks, roofing sheets etc) and **connections** that hold the elements together. The manner in which the elements are connected to form a whole constitutes the **structure** of the building. In order to have an understanding of how a simple building like a house can withstand the forces of a cyclone or an earthquake, it is useful to have some knowledge of simple engineering principles.



Load

All buildings are subject to loads. Most obviously, a building must be able to support its own weight, the weight of the people in it, and their furniture and belongings. Perhaps less obviously a structure may also have to support a heavy snow load on the roof. These loads act **vertically**. However, the loads applied by wind or an earthquake can come from different directions; so when designing a building both **vertical** and **lateral** loads have to be considered.

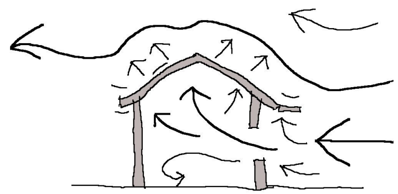
Most loads are either a permanent feature of the building (its weight for example) or build up slowly (snow on a roof for example). These are called **static** loads. The sudden blow or buffet of a gust of wind or the shaking of an earthquake will cause **dynamic** loads. An illustration best explains this: if you place a heavy brick on a china plate the plate will support the brick quite happily; if you drop it from a short distance, the plate will surely smash. The dynamic load is much, much more than the static load. **The sudden and dangerous collapse of buildings is often due to dynamic load.**



Wind forces on walls and roofs are affected by direction of wind and shape of buildings

Diagram from *Cyclone resistant housing – BRE*

All loads have to be safely transmitted to the ground. It is simplest to think of this as though the load were a liquid flowing along beams and down columns, much as water would flow in pipes.



The direction in which a load is acting is not always immediately obvious. One side of a roof, for example, will be experiencing the full force of a storm trying to blow the roof in; the other side of the roof will be experiencing a suction force (or up-lift) trying to suck the roof off.[1] In fact, the negative or suction force on the leeward face of a rectangular building is almost half the direct or positive force.

[1] Note that wind load is proportional to the square of the wind speed. So for double the wind speed, the load increase by a factor of four – see appendix .

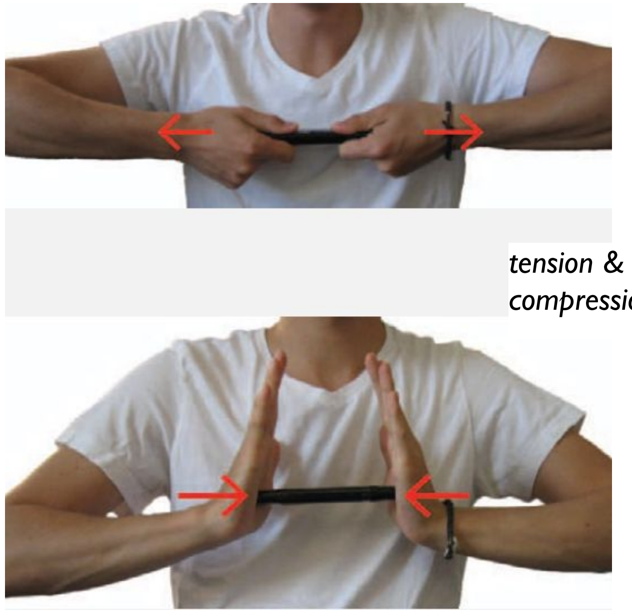
Tension and compression

The effect of loads on buildings results in **two actions only**: pushing or pulling, compression or tension. A column is in compression: it is being squashed by the weight it is carrying. A steel cable supporting a bridge is in tension and tends to stretch. Some building elements, a brick or stone wall for example, are strong in compression and weak in tension. Some materials, steel cables being the clearest example, are only strong in tension.

Fortunately, some of the commonest building materials, timber and steel in particular, are strong in both tension and compression. Concrete, when it is un-reinforced, is weak in tension but when it is reinforced with steel which is excellent in tension it becomes a composite material that is strong both in tension and compression.

It is very useful to be able to analyse a structure and determine which elements are in compression, and which in tension. But remember that with the unpredictable nature of wind and earthquake loads, some structural elements can be in tension one moment and in compression the next.

It is this last point that makes the **connections** in a building so important; a joint has to be able to resist pulling apart.



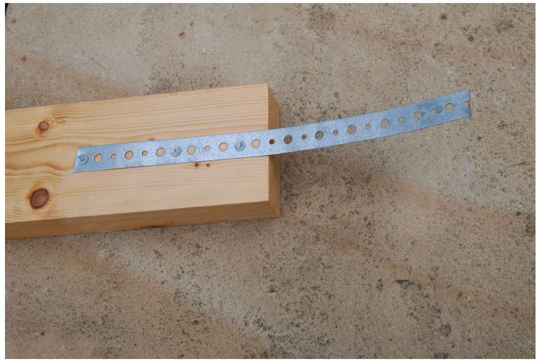
tension & compression

Bending, buckling and shear

Engineers will discuss the effect of bending, buckling and shear. These are important concepts to understand, however, they can all be resolved into the two actions of push and pull: compression and tension.

For a non-technically minded lay-person, it is simplest to think of these concepts as being akin to their normal English usage. In other words a beam bends, a column buckles and a beam or a connection might "shear off" or tear.

The diagram (p10) shows a beam **bending**: when it breaks it is said to have failed in "bending". It can be seen that the top of the beam is in compression, while the bottom edge is stretching or in tension. It fails by crumpling along the top edge, or pulling apart along the bottom. A vertical member can also be in bending.

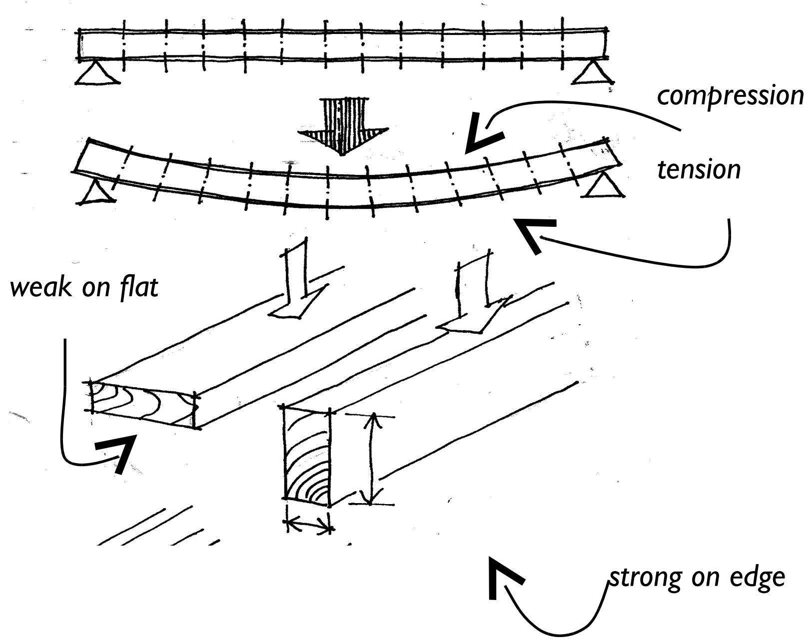


Shear – by pulling on this hurricane strap, either the strap will break in tension or the nails will tear apart in shear. In fact, the strap will break before the nails - they are very strong in shear

Buckling is a phenomenon associated with **compression**. If a thin wooden ruler is pressed together end-to-end, then after a certain force it will suddenly bend outwards. Very quickly it will break. This is known as axial buckling and is mostly an issue with columns that are too slender (low cross sectional area : height ratio). However it can also be important in horizontal members. An example of this is the bottom element of a roof truss, called a tie. Instinctively we think of this being in tension due to the weight of the roof. However in a strong wind there can be considerable up-lift and the tie can fail in buckling. To avoid buckling the column or tie can be braced along its length.

Shear is perhaps the most difficult concept to grasp. The diagram on p9 shows a metal strap nailed to a piece of wood (a hurricane strap). This is extremely strong because the nail cannot be torn in two – the nail is said to be **strong in shear.**

The final point to mention here is the importance of adequate **bearing.** If a heavy beam is not bearing sufficiently on a wall or column, then there will be localised **crushing** that can result in failure.



Depth is king

We all know that a wooden ruler is bendy in one direction and very strong and stiff in the other. This illustrates how the **depth** of the ruler gives it strength. A beam is stronger if placed on edge, rather than flat. Surprisingly, this simple principle is often ignored.

The **width** of a timber beam is often 50mm – anything less than this tends to split when a board or batten is nailed to it – but the depth will vary depending on the distance that the beam has to span and the load it has to carry. Although many experienced builders will have an intuitive feel for the correct depth of a beam, the actual dimensions should be specified by an engineer.

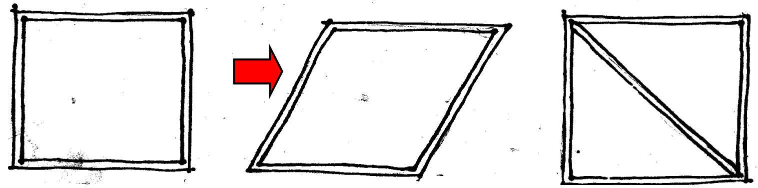
For the more technically minded it is worth noting that the strength of a beam is proportional to its width, but proportional to the square of its depth (strength $\propto$ width; strength $\propto$ depth^2). In other words by doubling the width of a floor joist (as an example) or by doubling the total number of joists, then the strength is doubled. By doubling the depth, the strength increases fourfold (see diagram in the powerpoint slide for further illustration) and so increasing the depth of a beam is always the most efficient use of

Example of floor joists laid the wrong way round materials. The difficulty arises as deep sections of timber are often hard to obtain and expensive.

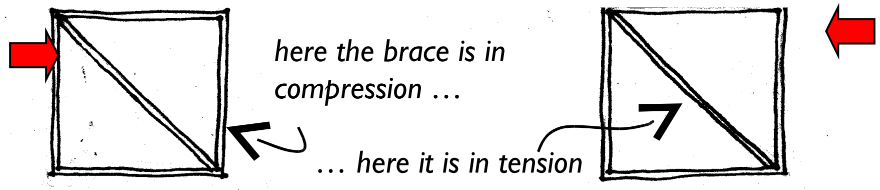
Triangles – the importance of bracing

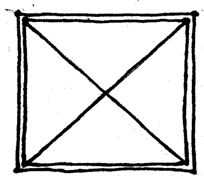
The simple model illustrated (p13) is an easy way to understand the concept of triangulation and bracing. The triangle is the **only** simple and inherently rigid shape. The design of adequate bracing should be done by a structural engineer. Nonetheless, it is important to understand that all walls, ceilings and roofs should be adequately braced. This is also referred to as **racking strength**. This can be achieved in a number of ways.

1. The timber bracing in the diagram opposite will be in compression with wind in the direction indicated. If the wind is in the opposite direction then the brace will be in tension and so it is imperative that the **connection** is strong in **tension as well as compression**.
2. The timber brace can be replaced by **cross-bracing** in the form of an X. If these are steel cables or steel straps then they will only act in tension and have to be designed accordingly, and particular attention will have to be paid to the connections.
3. If a wall or roof panel is sheathed in **plywood** then this also has the same effect as triangulating with diagonal braces. The plywood has to be thick enough (normally 9mm if the studs are 600mm apart; it would need to be 12mm for 1000mm apart) and must be nailed according to an engineer's specification. It has the advantage of providing a cladding to the building at the same time as ensuring structural strength, but there is also a danger that if the building is subsequently altered or extended this critical structural element might be unwittingly removed. The kind of plywood or board selected must be suitable for the climate. If the material degrades in hot and humid weather then the fixxings around the edges will quickly become inadequate.
4. Sometimes external boarding is applied diagonally for aesthetic reasons (see photo p12). In fact this also provides considerable extra racking

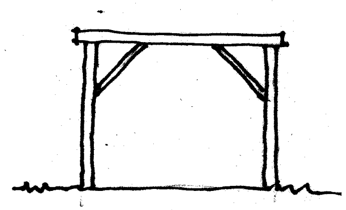


A simple square frame will "rack", the brace forming triangles makes the frame rigid

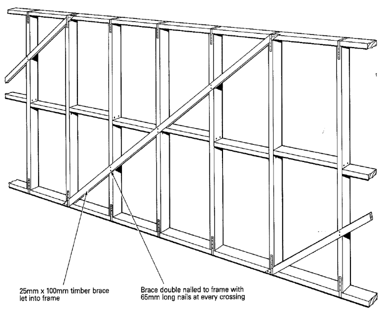


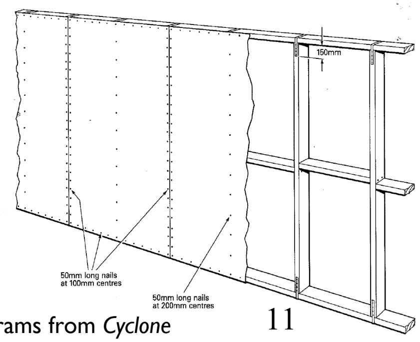


cross bracing



knee bracing





Diagrams from *Cyclone resistant housing – BRE* strength to the building, and should be encouraged. Boards applied horizontally give no appreciable racking strength.

5. A very common form of bracing is **knee-bracing.** Care should be taken as this is often used inappropriately, with insufficient strength and with poor connections. It is often used in **post and beam** construction, but both the posts and the beams must be substantial for the knee-brace to give significant strength to the overall building.

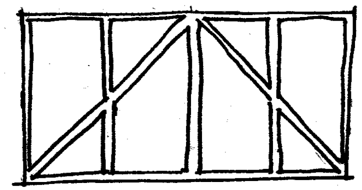
Wherever possible bracing should be **node to node**. A node is a joint or connection. The knee-brace described in 5 above, is not node to node. If the bracing runs from corner to corner then the transfer of load is **axial** (along its length), relying on the straightforward tension and compression of the vertical and horizontal members and not on their strength in bending.

Diagonal boarding gives some racking strength

Building failures – how buildings collapse

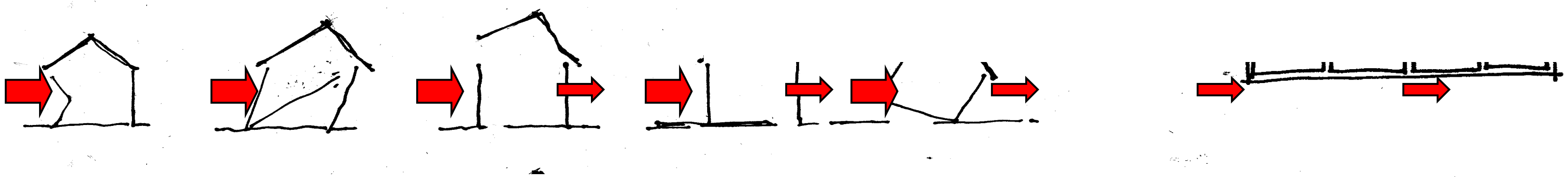
In hazard prone areas of the world, susceptible to high winds and earthquakes, small single-storey buildings can fail in a variety of different ways.

1. Element failure. If a wall or roof is inadequately designed to resist wind or earthquake force it might collapse. Any one element – a beam, a column etc – might fail in **bending, shear** or **buckling**.
2. Racking failure. If the bracing is badly built, not designed properly or omitted then the whole building might collapse.
3. Connection failure. The roof can blow off if it is not properly connected to the walls. Similarly the walls must be firmly connected to the foundations. All joints must be strapped.
4. Sliding. If the structure is not securely attached to the foundations, it can be blown sideways by a strong wind.
5. Overturning. Again, due to inadequate connection to foundations, or due to inadequate foundations, a building can overturn.



This panel has node-to-node bracing …

… this one does not

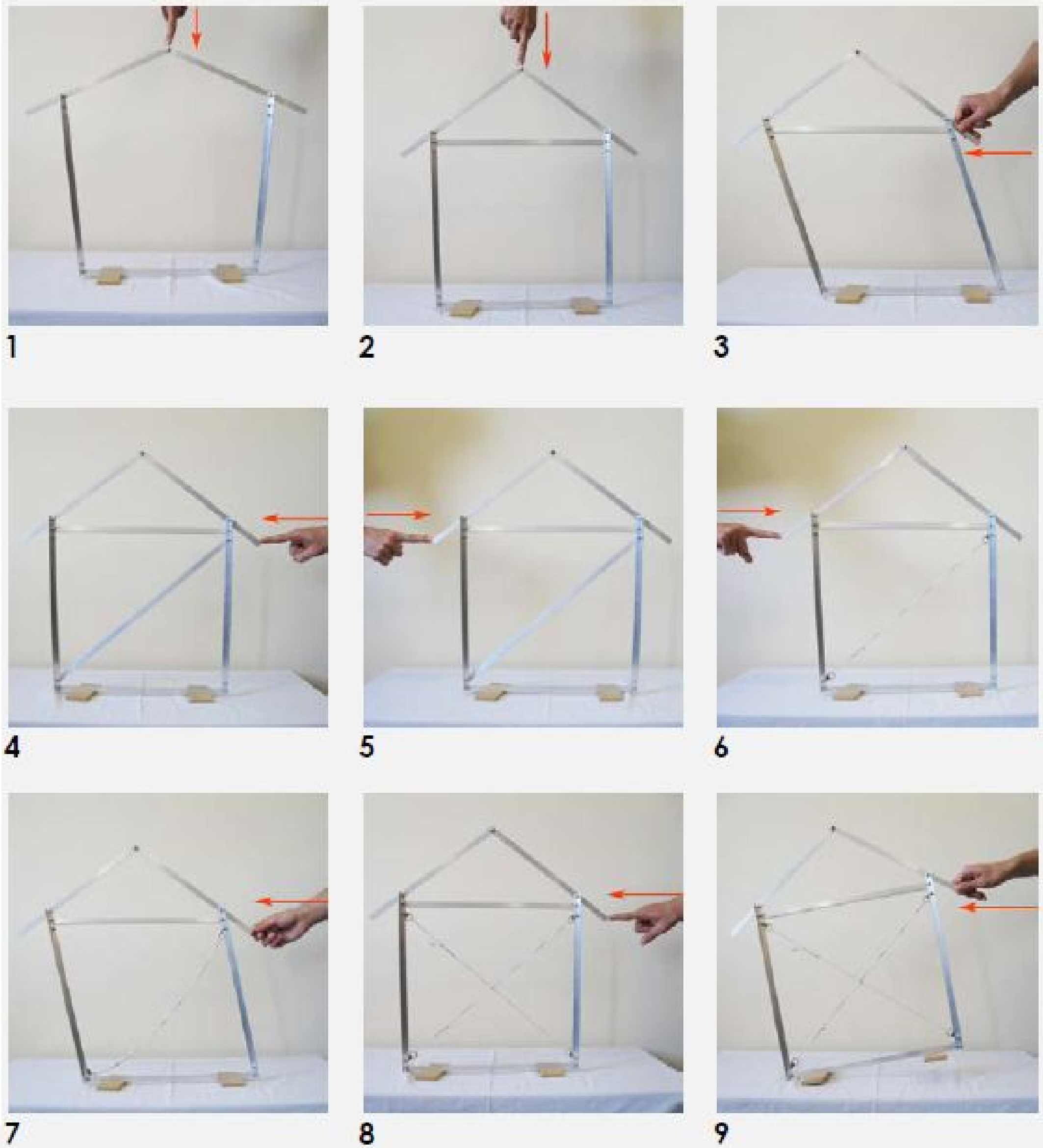


element failure racking failure connection failure sliding overturning

Demonstrating tension, compression and bracing

One way to demonstrate the efficiency of node-to-node bracing is to use the aluminium model and to apply pressure by hand to demonstrate the effect of wind forces at each step.

1. Build the model as shown in image #1 and apply a vertical pressure on the roof. The walls spread out and the roof drops. By lifting up on the roof (up-lift) it can be shown that the walls lean in
2. Add a tie-beam between the walls and put the same pressure again. This is now strong.
3. But if you put a horizontal pressure on the wall, the model will distort, or rack.
4. Add a rigid bracing and apply the same load. The brace acts in compression and the model is rigid.
5. Put the same pressure but on the other side. The brace is now acting in tension and the model is still rigid. The brace is strong in tension and compression
6. Replace the metal brace with string. Apply the same pressure again. The brace also acts in tension and stabilises the model.
7. Put the same pressure on the other side. The string brace does not work in compression.
8. Add a second diagonal string brace and test it again. Both pieces of string act in tension but in opposite directions. This makes the model stable.
9. Apply a bigger force on the model. As the whole structure tips, this shows that the connection to the foundation has to be strong enough to resist the overturning effect of strong winds.



CONNECTIONS IN TIMBER FRAME BUILDINGS

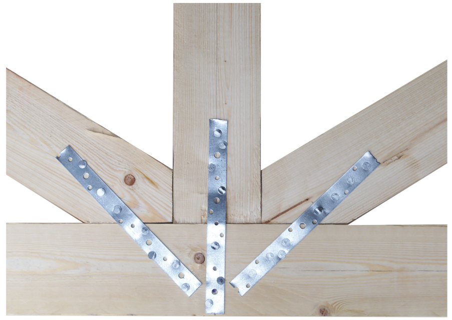
A building is only as strong as its weakest point. Every element of the building – the roof, the walls, the foundations – must be well connected together.
We have already seen that joints and connections have to be strong in both compression and tension. Most joints are stronger in compression than tension: in other words they can be pulled apart easily. **Hurricane strapping** is commonly used to make connections strong in tension, but it must be used correctly. It is cheap and easy to apply. Where it is not available, it can be snipped from the edge of a sheet of galvanised steel.

Hurricane strapping

The photograph shows a typical use of hurricane strapping. It is strong because the **steel strap** is extremely strong in tension and the **nails** are very strong in **shear**.
The strap is often perforated with quite large holes. These reduce the cross-sectional area and therefore the strength of the strap: it is best to obtain strap that has no holes. The cross sectional area should be about $20mm^2$.
The strap must be aligned in the direction of the "pull". If this is done wrong then the nails will simply pull out. The photographs show examples and explain this better than words. There should be three nails (2.5mm thickness and with wide flat heads) on both sides of the joint. The joint should be strapped on both faces.
Every connection should be strapped unless there is clear evidence to show that it is not required.

knee brace with strapped connections

a section of a truss



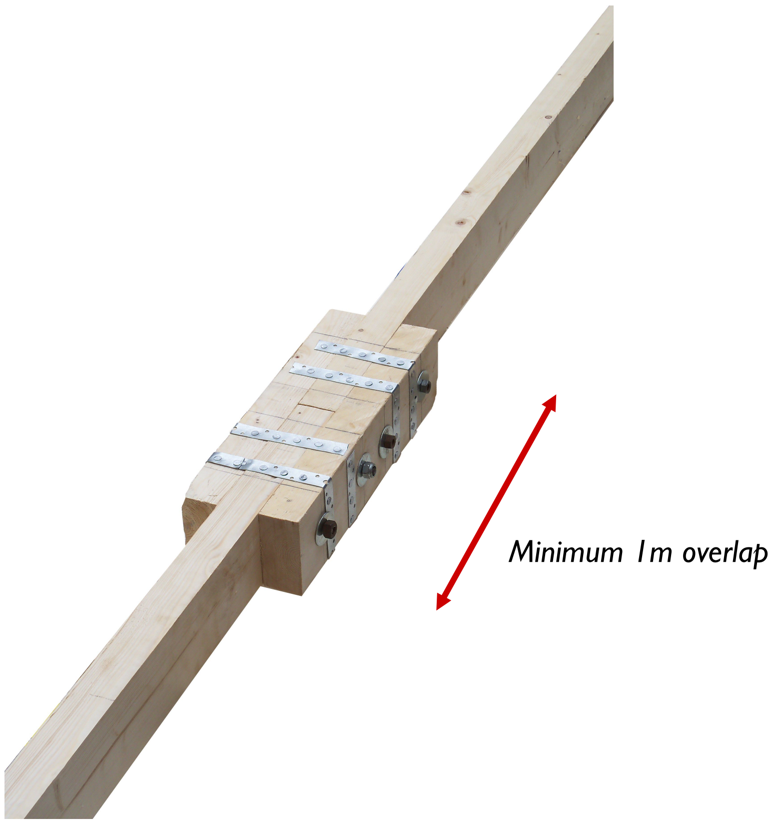
connection between a stud and a top or bottom rail

Making a join in a beam – a splice or a scarf joint

The most important message here is: **don't make a join in a beam (or any other structural member) unless you absolutely have to.**

The second is: **never join a beam in the middle of its span.**

It is unfortunately very common to see lengths of timber joined together in ways that are very inadequate. Any such connection should be checked carefully by an engineer. Some splice joints may work well in compression and tension (and so would be acceptable for the tie member in a roof truss, for example) but they would be very weak in bending.



Connecting the building to its foundations

To prevent the building from sliding or overturning it must be well connected to its foundations. This is more thoroughly discussed in the following section.

FOUNDATIONS

The foundations of a building are its "good pair of boots". Foundations serve two purposes: to spread the weight of the building; and to prevent overturning and sliding. In hazard-prone areas of the world and with single-storey light-weight buildings, the second purpose becomes every bit as important as the first. The weight of the foundations and the connection between them and the structure are vitally important. As always, a qualified engineer should oversee the design.

In flood prone areas, houses are often built on earthen plinths. The foundations need to go through the plinth to below the original ground level.

For simple buildings there are two kinds of common foundation: strip and pad. **Strip foundations** run continuously under all the load-bearing walls while **pads** may be used under isolated columns or peers (point loads). A hybrid is also possible where, for instance, in a post and beam structure there are pad foundations under the posts, but strip foundations running between one post and the next to support an infill wall. The table below shows the minimum width for a strip foundation for varying ground conditions (*adapted from Mitchell's Building Construction)*.

The foundations must be dug down below all organic matter to firm sub-soil. There should be no loose soil in the bottom of the trench.

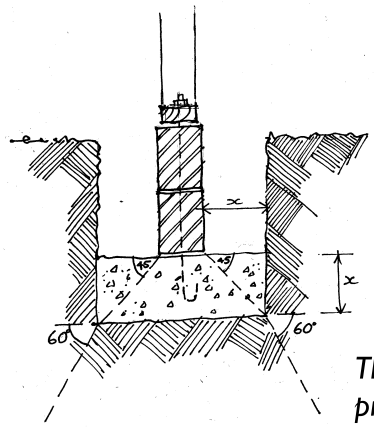
Subsoil types	***Condition of subsoil***	***Means of field identification***	***Min width of strip foundation for single storey light-weight building (ie timber frame or single skin brick)***
Gravel / sand	compact	Requires pick for excavation. 50mm peg difficult to drive in more than 100mm	300mm
Clay / sandy clay	stiff	Requires pick. Cannot be moulded with hands	300mm
Clay / sandy clay	firm	Can be excavated with spade. Can be moulded with strong finger pressure	300mm
Gravel / sand / silty sand / clayey sand	loose	Can be excavated with spade. 50mm peg easily driven in.	400mm
Silt / clay / sandy clay / silty clay	soft	Readily excavated, easily moulded in fingers	500mm
Silt / clay / sandy clay / silty clay	very soft	A natural sample of clay exudes between the fingers when squeezed in a fist	600mm

Foundations are commonly made from poured concrete or a combination of large stones and concrete. However there must be adequate and secure connections and it is recommended that hold-down bars should be located at every corner, either side of every door-way and at a minimum of 600mm spacing. In areas of high earthquake risk the foundations are often reinforced or incorporate **a ring-beam**.
Always seek specialist support to ensure that the foundations are designed for appropriate wind and earthquake forces.
The diagram below shows a possible foundation design. It shows how the load spreads through the foundation at 45° and how, therefore, to calculate the minimum thickness of the strip.

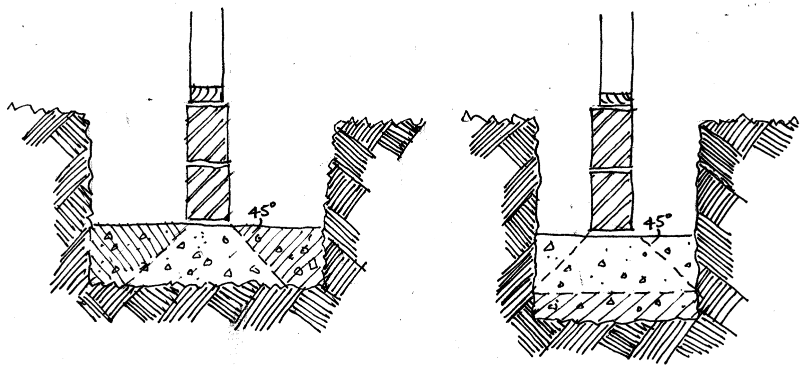
Understanding foundations

1. Foundations have two main purposes: a) to spread and support the weight of the building and b) to prevent the building from overturning or sliding. The table above gives widths of foundations that will support the weight of a light building.
2. The table does not give the **weight** of foundation that is required to counter the tendency of a building to overturn in a strong wind. This depends on both the weight of the structure and the **geometry of the building** (both the plan shape and height). Contrary to what you might expect, a light building needs **heavier** foundations than a heavy one. This can be easily demonstrated by blowing on a light box and then a heavy box: the light box can overturn more easily and so needs heavier foundations.
3. The building has to be properly **tied down** to the foundations. It is essential that the ties cannot pull out or break out. It is recommended that connections are at 600mm spacings and at every corner and either side of doorways.

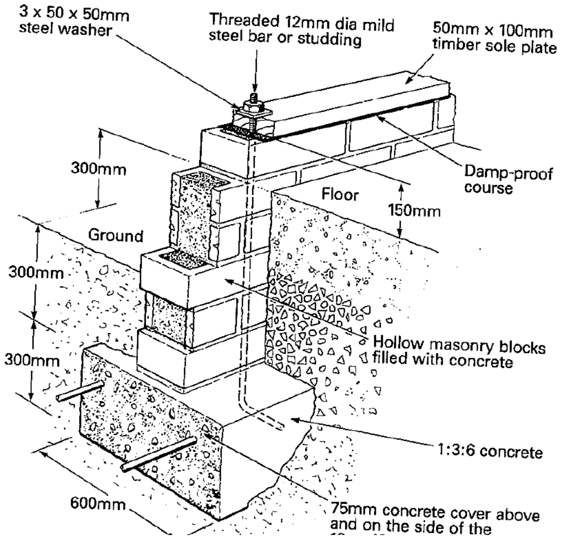
It is easy to make the foundations either too wide or too deep, as the load follows a 45° angle. This is best illustrated by the diagrams below.



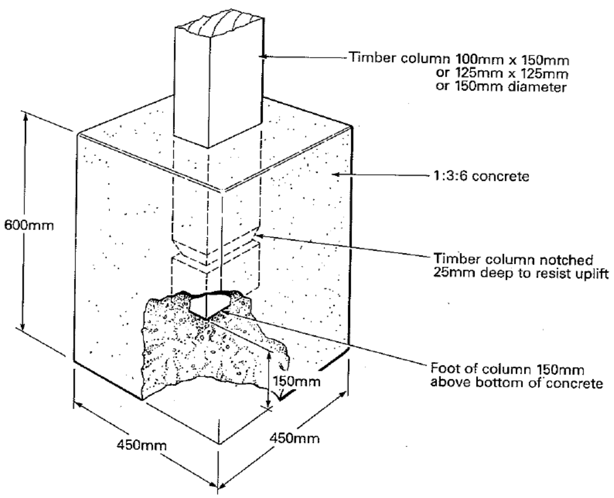
This is a correctly proportioned foundation



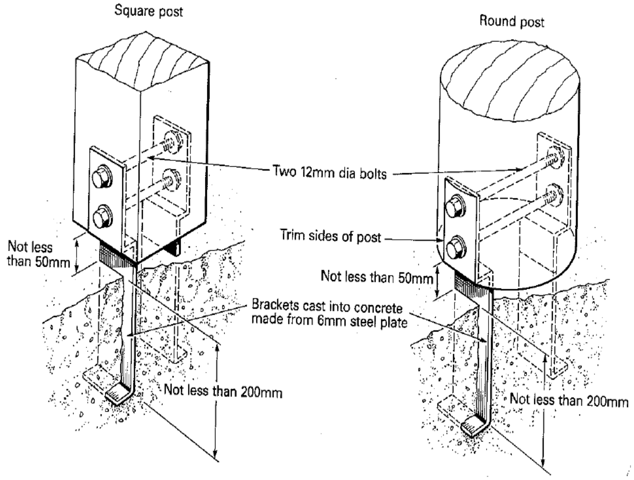
From the point of view of supporting the weight of a building, the shaded area of these foundations are redundant.



1.

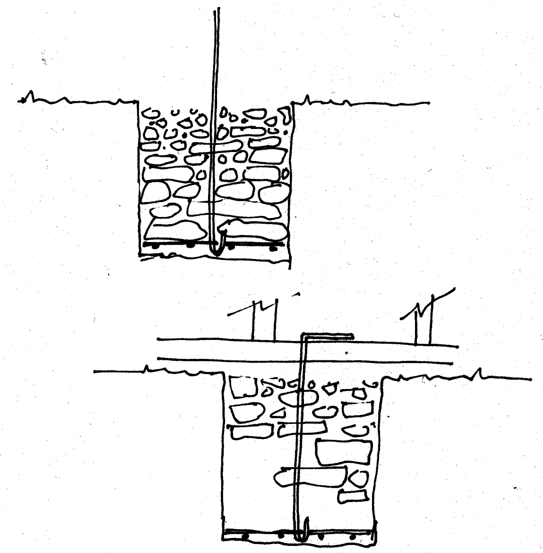


2.



3.

Drawings above from *Cyclone resistant housing – BRE*



1. *An example of a well-designed foundation for a timber frame building*
2. *This design will work well for a post & beam construction – notice how a notch has been cut into the timber to prevent the post from pulling out – but it is vulnerable to rot and termite attack.*
3. *This is more sophisticated design that reduces the risk of rot and termite attack, but needs specially made steel brackets.*
4. *This is a design for rubble foundations that might be appropriate after an earthquake (when there is often a lot of rubble) and for temporary structures. Note that special consideration has to be given to tying down the structure. See appendix for more details of this design.*

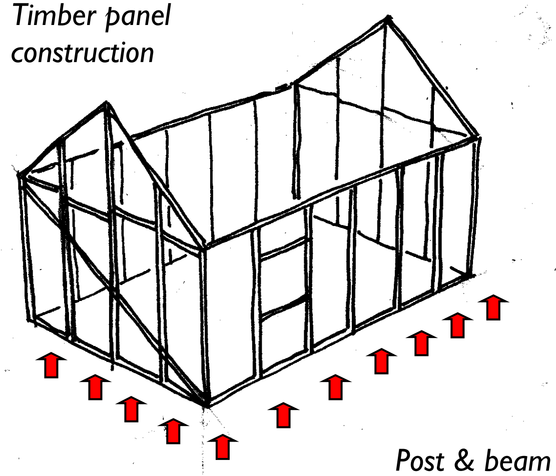
4.

TIMBER FRAME CONSTRUCTION

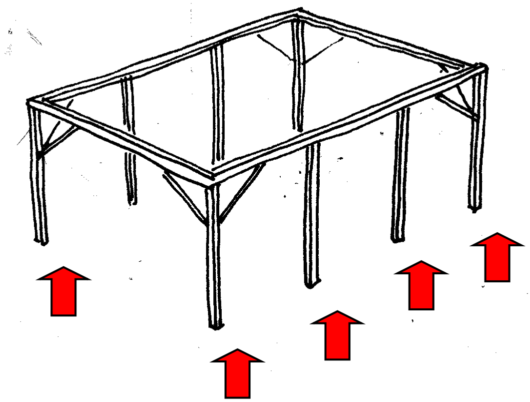
Here we will mainly consider **timber panel construction**. There are many ways to build in timber and around the world different practices will be commonplace. There is no right way nor wrong way. However careful adherence to the **principles** of good building practice should help guide the designer towards sensible decisions. **Post and beam** construction is very common in many cultures and it is important to understand how it differs from panel construction. The diagrams summarise the differences clearly.

Timber panel construction	Post and beam
All the timbers can be readily available 100 x 50mm. The diagonal braces can be 100 x 25.	The timber dimensions will vary and the posts should be at least 100 x 100.
The panels can either be made off-site in a "flying factory" or built with simple hand tools on-site	Construction always has to be carried out on-site, and requires a greater degree of accuracy. Often it will be a construction method that is familiar to local builders.
The wall panels are easy and quick to erect and can be dismantled simply	
The load of the walls is spread along the length of the foundations. Although this kind of construction is always referred to as "framing", in fact it behaves more like a "load-bearing" structure	It is a "frame" structure with the loads being transferred to the ground through the columns. The columns become "point loads" which can be carried on pad foundations.
The gable wall can be built up as one panel. This is stronger than either in-filling the gable or using another truss.	
No timber needs be in contact with the ground	With good foundation detailing, no timber need touch the ground. In practice, however, the posts are often buried in the ground or embedded in concrete.

Timber panel construction



Post & beam



Making the walls

The photographs take you through the process of building the wall panels.

1. **Construct the panels**
   The **studs** are nailed to the **bottom** and **top** rails (note that these can also be referred to as sole and head plates, or wallplates). The technique of nailing at an angle is called **skew nailing** and is good practice. Make sure that all the studs are exactly the same length. The spacing (referred to as **centres)** between the studs may depend on the dimension of the boards that are used for cladding. 600mm, 800mm and 1000mm centres are all common. The wall panels must be checked to make sure they are square. This is done by checking the diagonal measurement from corner to corner: they must be exactly the same.

2. **Brace it**
   It is very little extra work to set the diagonal brace into the studs. This has the advantage of leaving the outside face of the building with no protrusions and this makes cladding it much easier. With this construction technique a brace of 100 x 25mm is adequate. This is because the brace is fixed to each of the studs spanning only the short distance between them.

3. **Hurricane strapping**
   Make sure that every connection is properly strapped. [Where the brace crosses the studs there is no need for strapping as the direction of the load does not tend to pull out the nails. The nails are strong in shear].

4. **Stand it up**
   The panels are connected to each other to enclose all four sides of the house. The panels can be nailed together, but if screws or bolts are easily available then this would be stronger and easier to

1.
The panels are constructed on the ground.

2.
This is skew nailing. Note how the nail is at a slight angle.

3.
Fixing hurricane strapping.

dismantle. Strapping the vertical joins is also a good idea. Ceiling level corner bracing gives the building extra strength.

5. **Cover it**
   The walls can now be covered in wooden boards, plastic sheeting or other locally available material. If they are being covered in plywood to provide the racking strength, then the temporary bracing can be removed.

Building the roof

Understanding a roof structure, designing and building it are not easy tasks. Described here is just one solution that is suitable for light-weight roof covering such as corrugated steel sheeting. If tiles or thatch are being considered then a different roof structure would probably be more appropriate. There is an introduction to different roof types in Annex (and also ref Roof structure guide). A structural engineer should always be consulted.

1. **Build a king-post truss**
   The purpose of a truss is to span from one side of the building to the other without any intermediary support. The photograph shows a king-post truss. Note that it is made of 100 x 50mm timber **on edge**. Care must be taken to lay the truss out correctly, cut the joints as tight as possible and strengthen with hurricane strapping.

2. **Lift into position**
   Great care has to be taken when lifting a heavy truss into position on the top rail of the wall panel. It must be temporarily braced to

4.
The panels are lifted into position and fixed together. Note the diagonal bracing.
In this photo the trusses have also been put in place.

5.
The structure is covered in plastic sheeting.

6.
The roof truss and the longitudinal ceiling tie are in position.
Note the hurricane strapping.

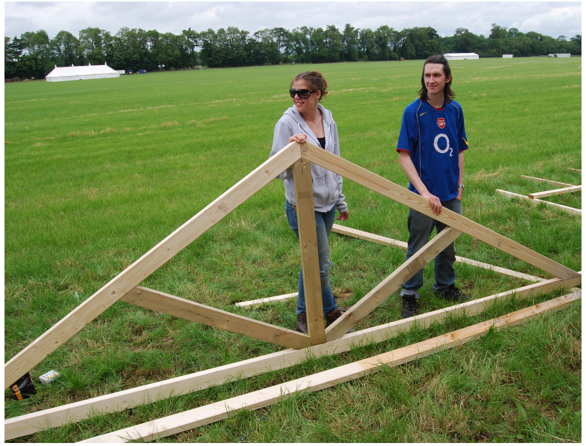
make sure that it does not fall over. There must be a stud immediately below the point of support and if the roof covering is going to be heavy then the engineer may insist on a **double stud**.

3. **Purlins next**
   It is essential that the purlins are placed **on edge** and are very securely fixed to the truss and the gable end. The connection between the purlin and the truss is all that prevents the roof from flying off. J-hooks (see diag) are often used but are sometimes hard get hold of. Hurricane straps work well.

to

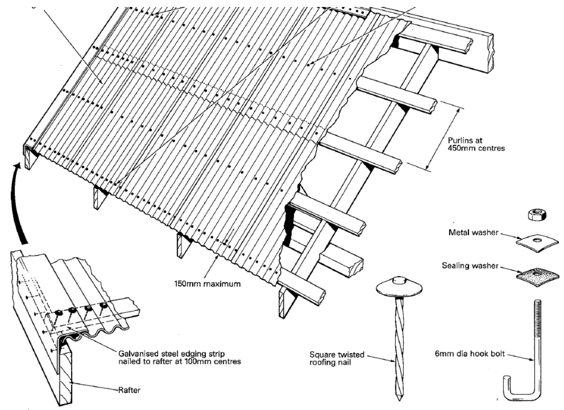
4. **Diagonal bracing**
   The roof can be braced by nailing a 100 x 50mm timber to the underside of the purlins. Ceiling level bracing is also required to prevent the bottom tie of the roof truss buckling in compression. The photograph 8 shows an arrangement that strengthens the walls at the level of the top rail, prevents the truss tie from buckling and also provides extra strength to the gable end where the long continuous studs might otherwise be susceptible to bending under excessive wind loading.

5. **Finally the roofing sheets**
   Where there is a sudden change of direction the up-lift wind forces increase. In other words, all the edges of a roof are especially vulnerable and at danger of peeling off. Along all four edges of the roof, the roofing sheets must be nailed or screwed at **every** corrugation.



7.
This is a king-post truss. The hurricane strapping has not yet been fixed.

8.
Diagonal ceiling bracing has now been fixed. Diagonal bracing in the ***roof plane*** *has still to be included.*



9.
Roof sheets must be well fixed at the edges and purlins securely attached with J-hooks or hurricane straps.

SETTING OUT – making sure that the house is square, plumb and level

It is important for a building to be set out accurately so that it is square, level and vertical (plumb). If this is done inaccurately at the beginning of the process then this will affect the quality throughout. However it is quite easy to achieve a high degree of accuracy using very simple equipment.

Setting out a perfect right angle

Any triangle with sides that measure 3,4 and 5 units will always form a **right angle (90°)**[2]. Any units of measurement can be used: so it could be 3,4 and 5 feet, or 3,4 and 5 metres. The diagram explains this best. The bigger the triangle the more accurate will be the right angle.

Practically, it is very important to measure the distances with something that cannot stretch. Steel tapes work well, but string tends to stretch and give a false measurement.

Using a water level

Using a Plumb Bob

[2] This is know as Pythagoras' Theorem and is referred to as a 3,4,5 triangle (Pythagoras's Theorem states that for a right angled triangle the relationship between the sides is always $a^2+b^2=c^2$; so for a 3,4,5 triangle 9+16=25).

APPENDICES

1. Quantities for both Timber Panel construction and Post & Beam – with total volume of timber for comparison

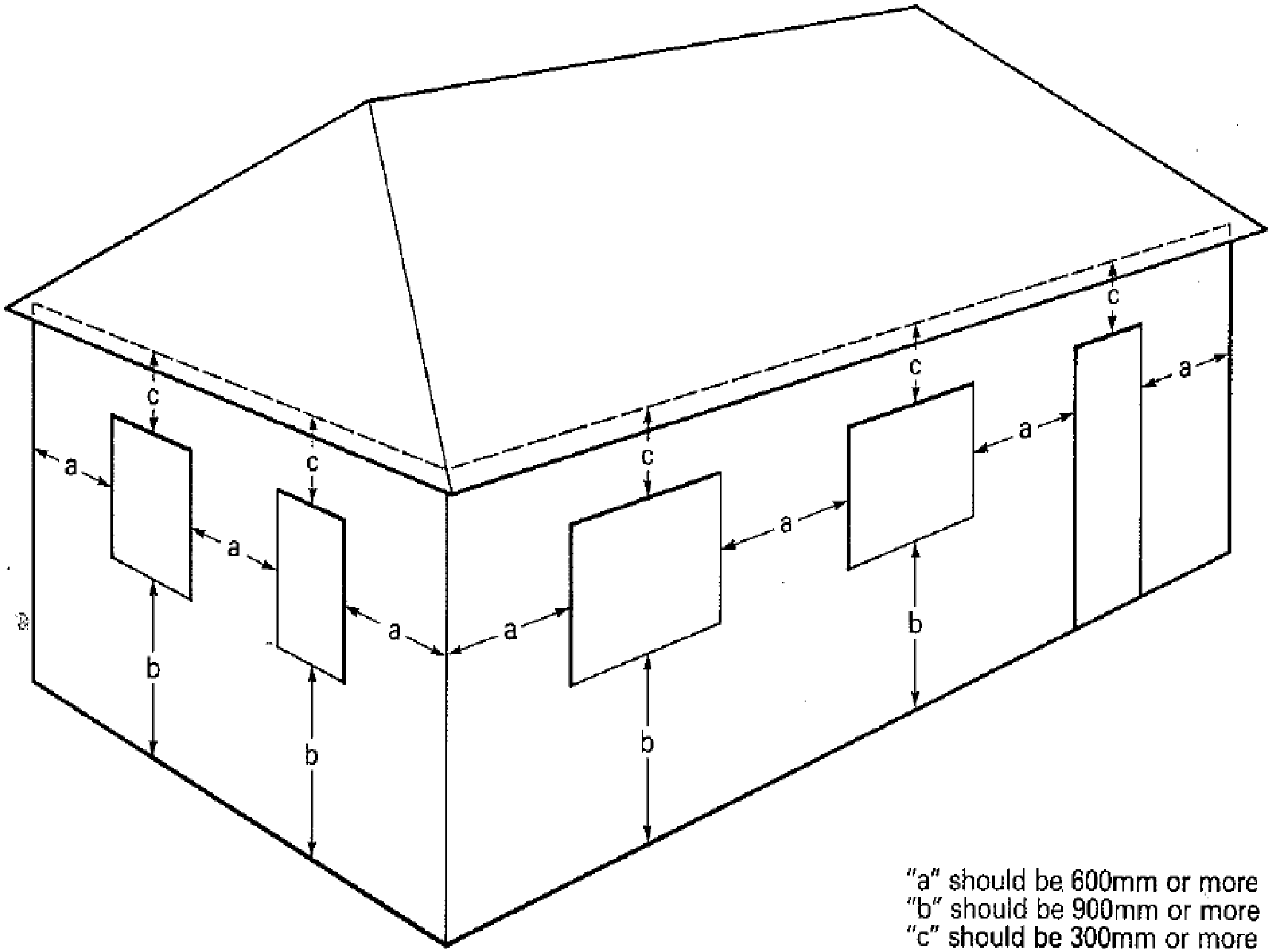
Panel Construction

	number	length	cross section mm x mm	cross section m2	m3
gables	2	4.2	100 x 50	0.005	0.042
	6	3.6	100 x 50	0.005	0.108
	8	2.7	100 x 50	0.005	0.108
panels	16	2.4	100 x 50	0.005	0.192
	8	3.3	100 x 50	0.005	0.132
truss	2	4.2	100 x 50	0.005	0.042
	6	1.5	100 x 50	0.005	0.045
	4	3	100 x 50	0.005	0.06
purlins	6	6	100 x 50	0.005	0.18
roof ties	3	2.4	100 x 50	0.005	0.036
	4	2.7	100 x 50	0.005	0.054
bracing	6	4.2	100 x 25	0.0025	0.063
timber total volume					1.062

Post and Beam

	number	length	cross section mm x mm	cross section m2	m3
posts	8	2.4	100 x 100	0.01	0.192
beams	1	20	100 x 100	0.01	0.2
trusses	4	4.2	100 x 50	0.005	0.084
	12	1.5	100 x 50	0.005	0.09
	8	3	100 x 50	0.005	0.12
purlins	6	6	100 x 50	0.005	0.18
roof ties	3	2.4	100 x 50	0.005	0.036
	4	2.7	100 x 50	0.005	0.054
knee bracing	16	1	100 x 50	0.005	0.08
framing	1	48	100 x 50	0.005	0.24
timber total volume					1.276

2. Windows and doors – minimum dimensions. Note that openings in the shorter wall are best avoided altogether.



To minimise reduction in strength, doors and windows should not be positioned close to corners, eaves of floor.

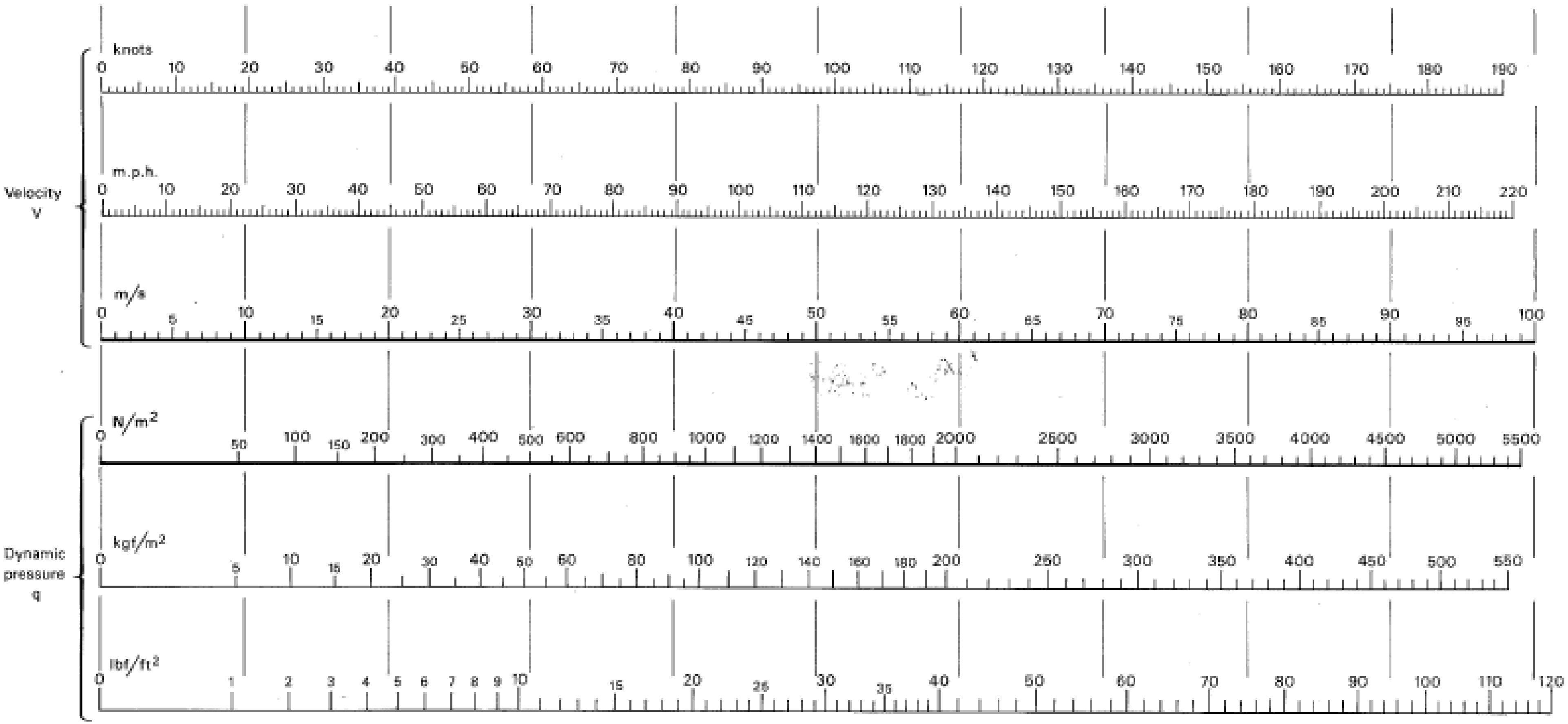
Openings are best avoided in the short side.

For each wall, the total length of wall (all the "a"s added up) should not be less than half the total length of the wall.

Drawing from "*Cyclone resistant housing – BRE*"

ff

3. Conversion chart for windspeed and dynamic pressure and other storm data (from *Cyclone resistant housing* BRE)



1 m/s = 1.95 knots = 2.24 mph
1 kgf = 9.81 Newtons (N) = 2.21 lbf

Table 2 Once-in-50-years design gust speeds for various countries which experience cyclones

	metres per sec (m/s)*
NORTH INDIAN OCEAN	
India	34 – 61
Sri Lanka	36
SOUTH INDIAN OCEAN	
Mauritius	68
Mozambique	31 – 38
Reunion	57
Rodriguez	90
NORTH-WEST PACIFIC	
Hong Kong	71
Japan	27 – 68
Macau	56
Malaysia	25 – 35
Philippines	20 – 69
South Korea	30 – 55
Taiwan	79
SOUTH-WEST PACIFIC	
New Caledonia	35 – 54
Pacific (East) Islands	27 – 52
Samoa	39
NORTH ATLANTIC	
Antigua	53
Barbados	53
Bermuda	60
Grenada	45
Jamaica	53
Martinique	44
Mexico	27 – 60
Puerto Rico	49
St Barthélemy	53
Trinidad and Tobago	42
Venezuela	29 – 42

*1m/s = 1.95 knots = 2.24 mph

MPH	N/m2		saffir-simpson
40	175		
80	700	2 x wind speed; 4 x force	1
120	1600	3 x wind speed; 9 x force	3
160	2850	4 x wind speed; 16 x force	5
200	4500	5 x wind speed; 25 x force	

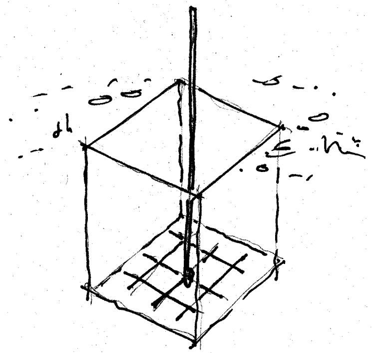
Notice that when the wind speed is doubled, the force increases four times. Five times the wind speed results in 25 times the force.

Force α windspeed^2

For Saffir Simpson hurricane wind scale see
http://www.nhc.noaa.gov/sshws.shtml

4. Suggestion for loose rubble foundations

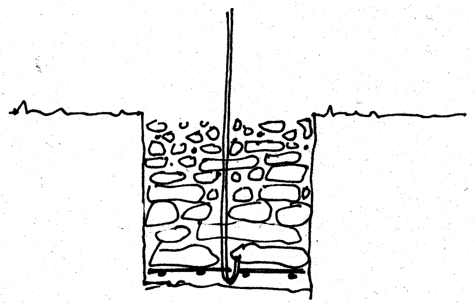
This is not as strong as a poured concrete foundation but might have several advantages



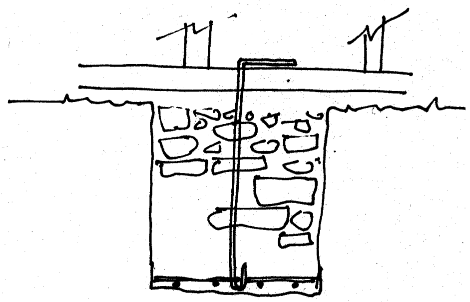
Dig holes – the size and number will depend on the design of the shelter.

Place square of weld-mesh (this might be better as 2 lengths of angle iron in a X) at bottom of each foundation. Min 10mm weld mesh (A393).

Hook a length of 10 or 12 mm re-bar to mesh



Fill hole with rubble from earthquake debris; larger pieces to the bottom. Compact well and fill voids with dirt.



Timber (or steel) structure can be connected by bending the re-bar.

1. No need for cement; dry construction
2. Uses broken up earthquake debris
3. Can be dug up and removed later
4. Avoids burying timber posts
5. Can be back-filled either before or after construction of walls.
6. Will only last until the weld mesh corrodes.
7. Would be improved if the weld mesh could be encased in a weak concrete mix.