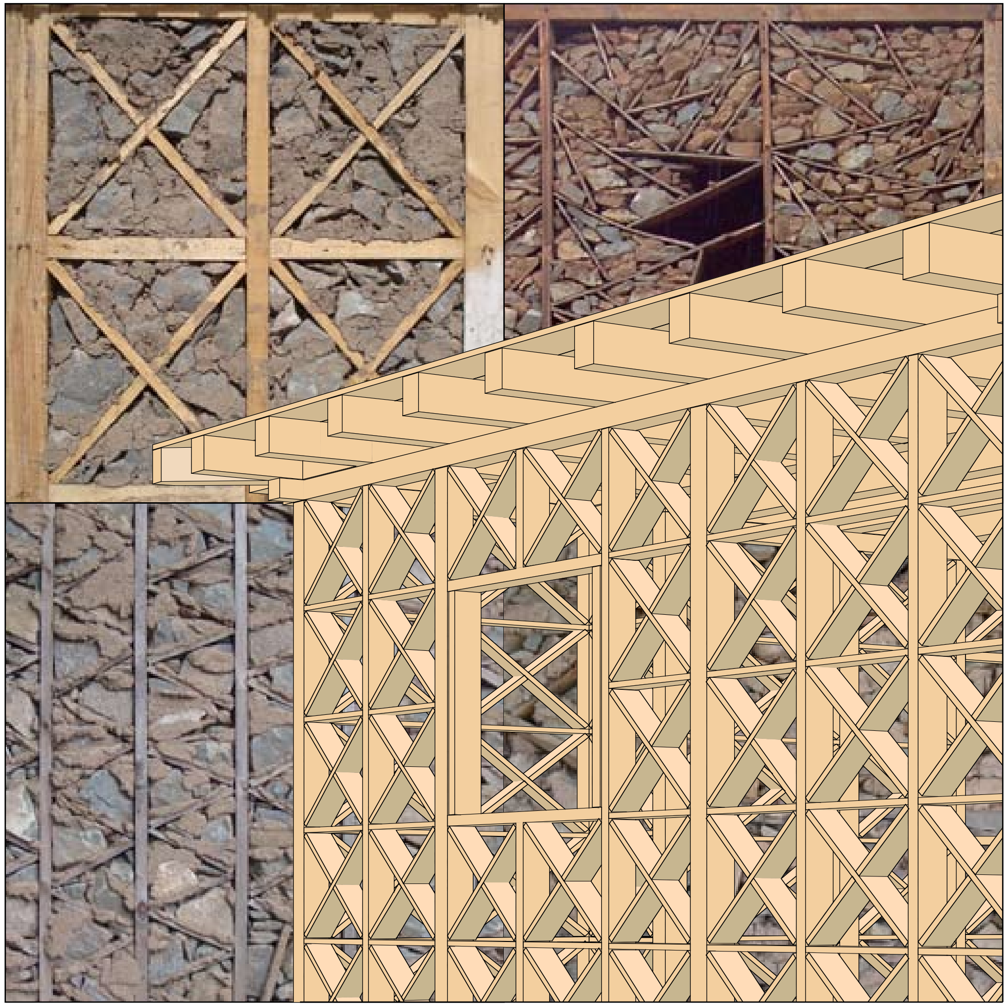

DHAJJI CONSTRUCTION

For one and two storey earthquake resistant houses

A guidebook for technicians and artisans

United Nations Pakistan
Improving lives and helping people

National Disaster
Management Authority,
Pakistan

Manual prepared by:

Arch. Tom Schacher and Prof. Dr. Qaisar Ali

Copies of this monograph may be requsted from:

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The present manual is a result of of joint research project undertaken by the University of Applied Sciences of Southern Switzerland and the University of Engineering and Technology of Peshawar, Pakistan. Its creation has been made possible through the research grant P-0808-01 from the Rectors' Conference of the Swiss Universities of Applied Sciences (KFH).

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Contents

Foreword

During the Earthquake 2005 most of the buildings in the affected area were completely damaged and required rebuilding as earthquake resistant buildings. This manual provides much needed information on earthquake resistant buildings to Engineers, Technicians, Trainers, Architects, NGOs and House Owners, so as to enable them to ensure safe housing in earthquake prone areas.

I hope that the housing sector and the supervising engineers will take full advantage of this manual while constructing buildings and will ensure that standards prescribed in this manual are followed in letter and spirit to avoid human losses and suffering in any future calamity like earthquakes.

Lieutenant General Nadeem Ahmed (Retired)

Chairman National Disaster Management Authority
Prime Minister's Secretariat, Islamabad

Acknowledgments

We at NDMA are grateful for the valuable contribution of Tom Schacher and Dr. Qaisar Ali in the preparation of this guidebook which would go a long way in the construction of safer houses not only in Pakistan but also in other parts of the world where earthquakes take place frequently.

We are particularly thankful to the assistance extended by the University of Applied Sciences of Southern Switzerland (SUPSI) and NWFP University of Engineering and Technology (UET) of Peshawar Applied Sciences (KFH) which facilitated early preparation of this manual and the support of UNDP and UN-HABITAT for its publication and promotion in Pakistan.

Niamatullah Khan

Senior Member, National Disaster Management Authority

Preface

This manual, and its companion *Bhatar Construction, an Illustrated Guide for Craftsmen*, published by ERRA in 2007, are enormously important documents. They mark a watershed in approaches to post-earthquake recovery methods undertaken with government support. Where such efforts more commonly have focused on engineered construction based on reinforced concrete and steel, both of these manuals have taken the far more creative approach of adapting to modern requirements traditional know-how refined over centuries of trial and error. These systems have demonstrated a remarkable level of earthquake-resistance, especially when compared with the many badly executed modern reinforced concrete buildings which collapsed in the 2005 Kashmir earthquake.

One may reasonably ask "*why advocate the use of systems of construction that had largely gone out of use with the advent of reinforced concrete?*" For the authors the answer to this question became clear once they started to analyse and understand local construction practice as well as the local socio-economic environment. Traditional building methods were what people could afford and understand, whereas systems based on modern building materials and technologies were too expensive (due to transport costs) and required time consuming training of the workforce.

The promotion of earthquake resistant building methods which are in tune with a society's cultural, economic and technical priorities and potentials is a complex art. A society is made up of many players, from home-owners to authorities, and from illiterate workers to expert engineers, to name but a few. The concerns of each of these groups have to be addressed in their own particular way: Politicians need time, engineers want formulas, technicians ask for explicit drawings and workers learn best by doing.

This manual is but one piece of this complex puzzle. It addresses technicians and artisans, but it also provides government inspectors with a guide to monitoring the reconstruction work effectively. As such, this work is essential in helping empower people in their own recovery in environmentally and economically sustainable ways.

Randolph Langenbach,

Author of: *Don't Tear It Down, Preserving the Earthquake Resistant Vernacular Architecture of Kashmir*, UNESCO, 2009.

Introduction

In the ancient language of carpet weavers, the Old Farsi word 'Dhajji' was used to describe patchwork quilts. Because of its visual similarity the same term was applied to a traditional building technique of the Kashmir mountains. Dhajji construction is made of highly subdivided light timber frames with masonry infills. During the 7.6 magnitude earthquake of October 2005, traditional Dhajji houses have proved to be surprisingly earthquake resistant while nearly half a million other buildings, many of them made with modern building materials, have collapsed.

In less than three years over 120,000 rural houses have been rebuilt using the Dhajji construction technique. This extraordinary achievement was made possible by three factors: an owner driven reconstruction approach, accompanied by an extensive training programme directed at workers and house owners, and last but not least the need of the people to make use of local resources instead of spending their money on costly transport of modern building materials.

However, given the typical low consideration in which traditional architecture stands in many parts of the world, no technical documentation was available to engineers and architects, both in the field and in key offices, nor to artisans. And since the technical detailing of Dhajji construction, as observed in the field, frequently did not come up to the standards of good practise, the need for a proper guideline became imperative.

The present manual intends to fill that gap. It is not only based on the results of extensive lab research at UET Peshawar, including shake table tests on reduced scale models, quasi-static tests on full scale walls and rigorous nonlinear inelastic numerical modelling, but also on a tradition of good practice in timber construction as well as, and most importantly, on the priceless experience of the innumerable field trainers who have worked in the Kashmir mountains since the earthquake.

We expect this guidebook to be a valuable reference for future Dhajji construction, be this in Kashmir or in any other country with a similar geographical and socio-economic environment.

Arch. Tom Schacher

April 2010

Thanks

The authors would equally like to express their gratitude to the following organisations and persons which have facilitated the creation of the present manual:

For their technical inputs:

UN Habitat in Islamabad, Pakistan, and especially Maggie Stephenson, Sheikh Ahsan Ahmed, S.Habib Mughal, Hamid Mumtaz, Babar Tanwir, Sumera Bilal and colleagues of the Rural Reconstruction Programme.

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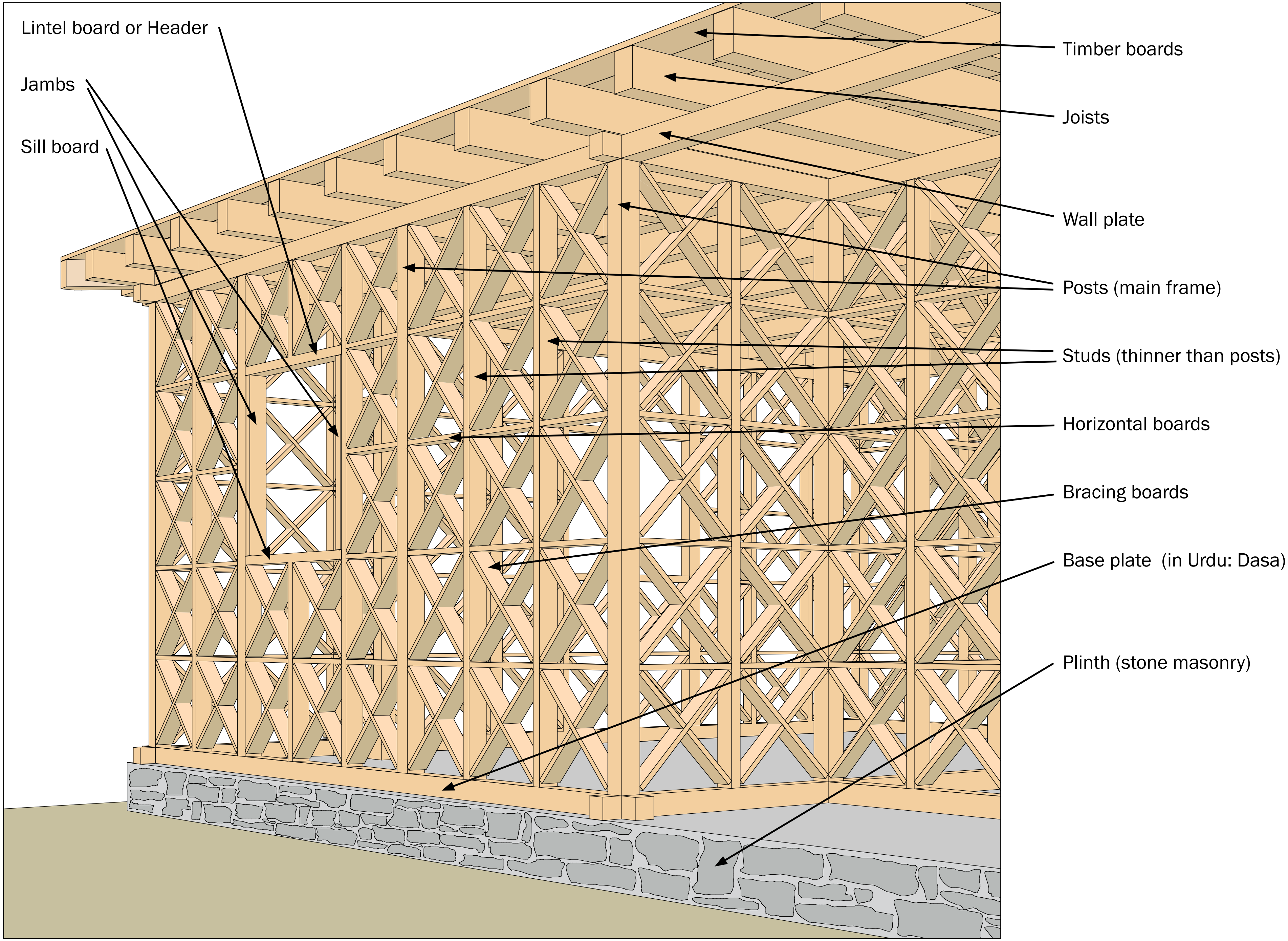
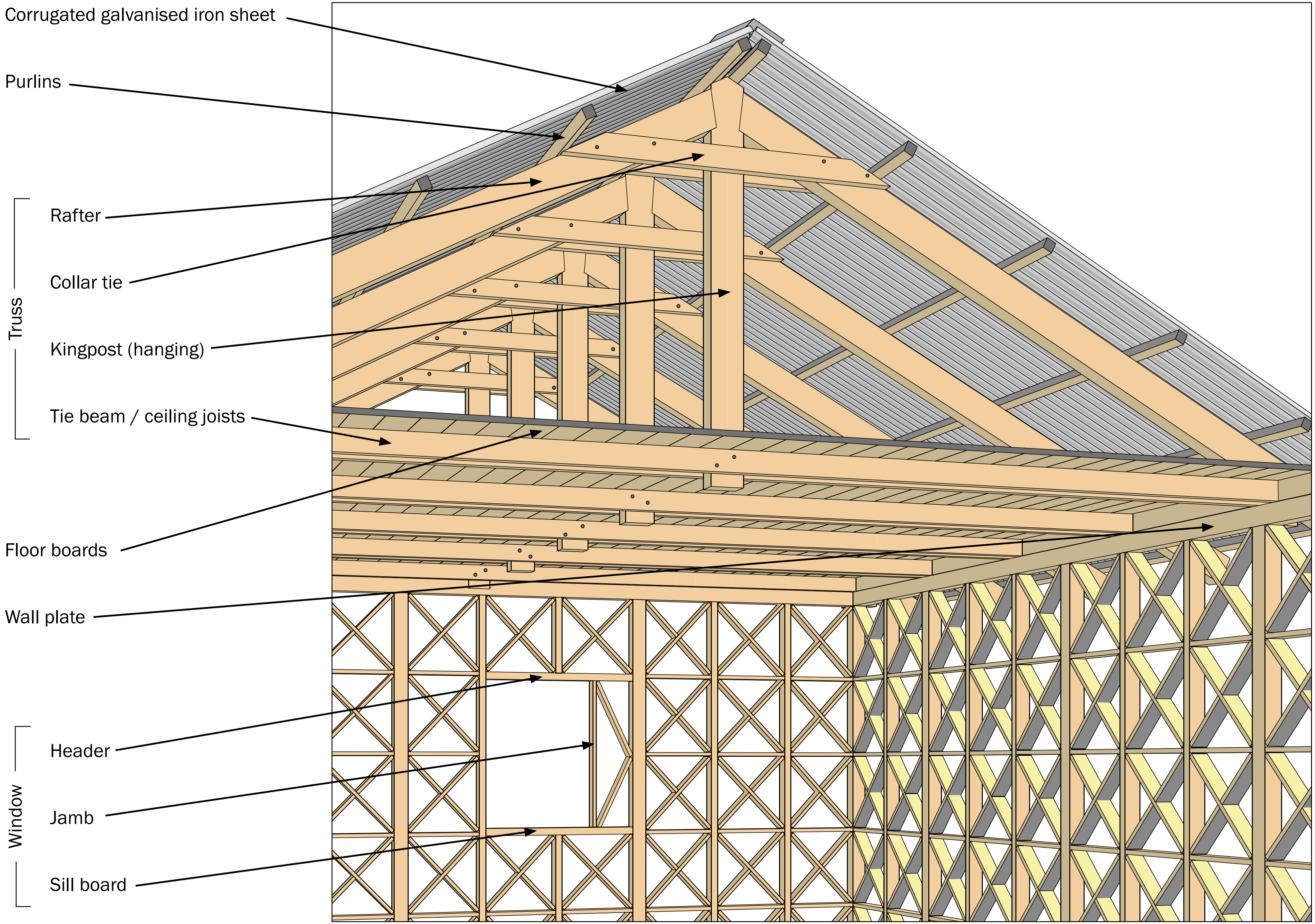
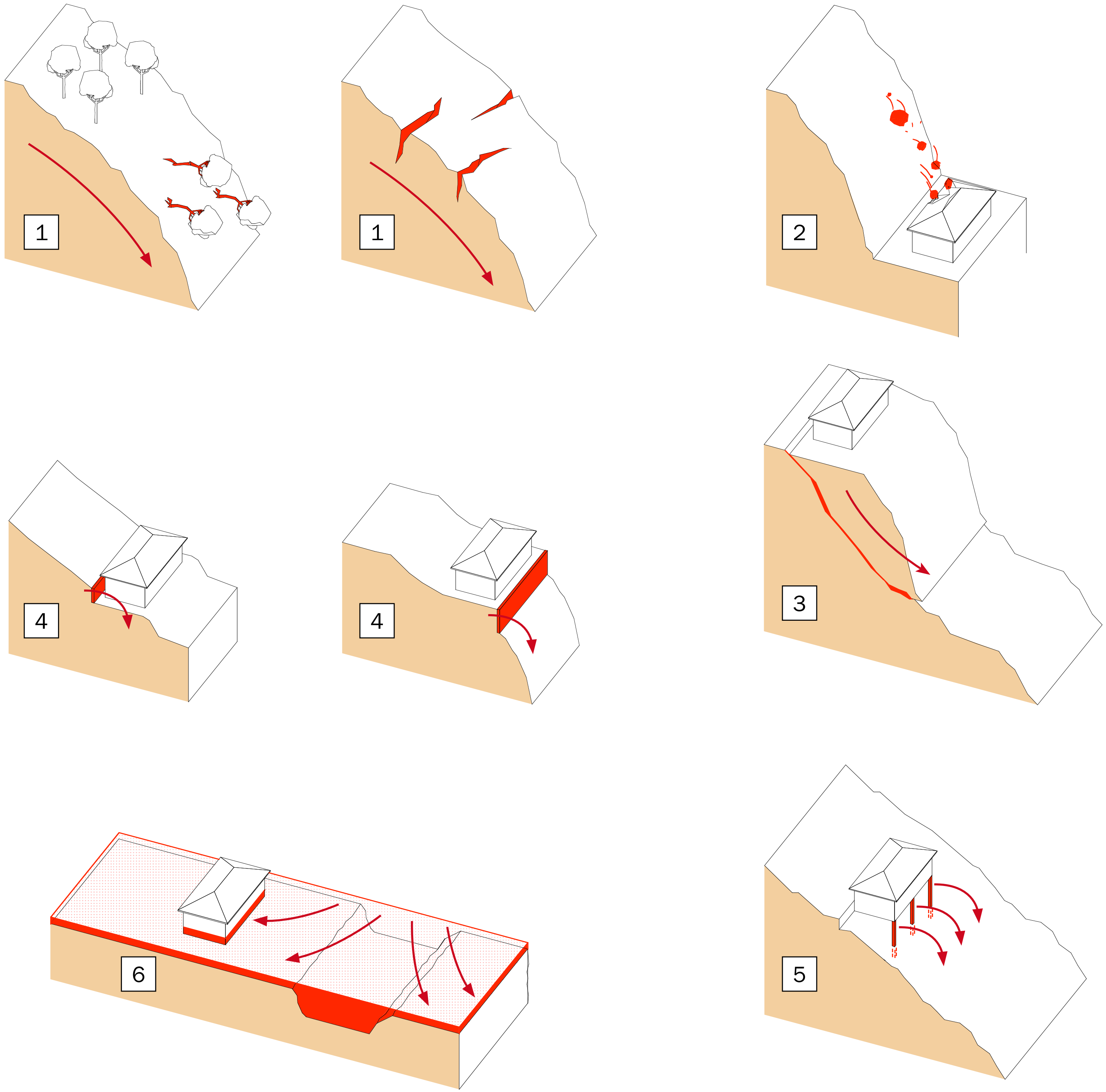


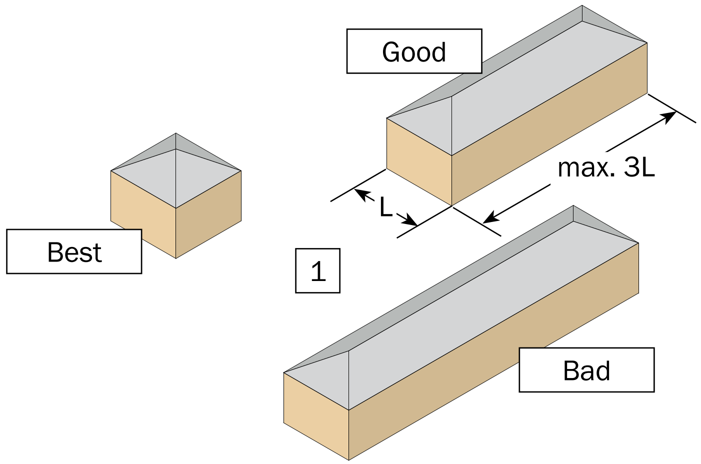
Lintel board or Header
Jambs
Sill board
Timber boards
Joists
Wall plate
Posts (main frame)
Studs (thinner than posts)
Horizontal boards
Bracing boards
Base plate (in Urdu: Dasa)
Plinth (stone masonry)

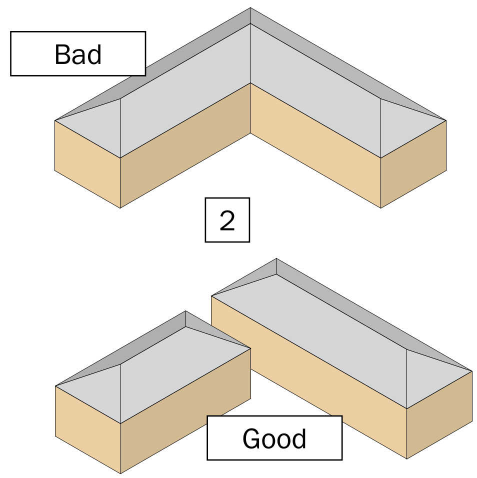

Corrugated galvanised iron sheet
Purlins
Truss
Rafter
Collar tie
Kingpost (hanging)
Tie beam / ceiling joists
Floor boards
Wall plate
Window
Header
Jamb
Sill board

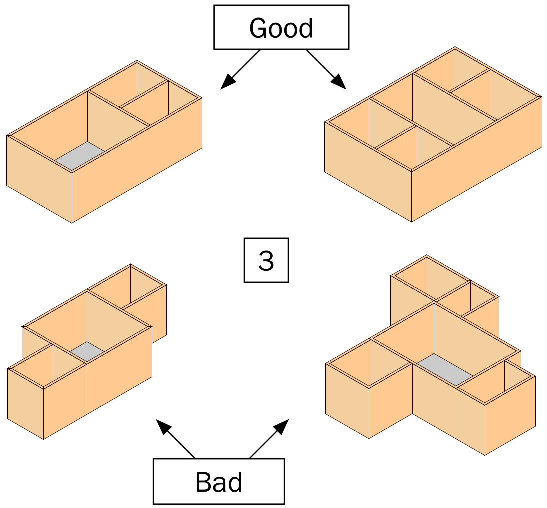


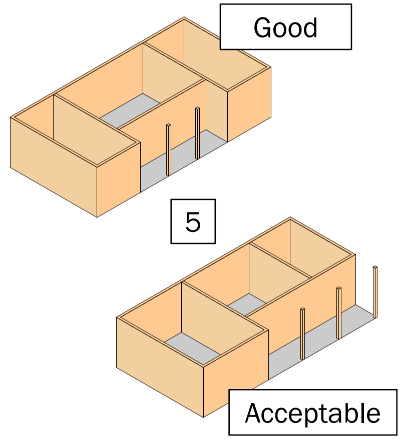
1. Don't build on or below a terrain with cracks or where trees are bending downward in an un-natural way. These are signs that the ground is moving.
2. Don't build at the bottom of a steep slope: rocks might fall on your house.
3. Don't build next to a precipice: it might break off.
4. Don't build next to a badly made retaining wall: it might fall over during an earthquake.
5. Don't build on free-standing posts: they will fall over during an earthquake.
6. Don't build near a course of water: it might overflow and wash your house away.

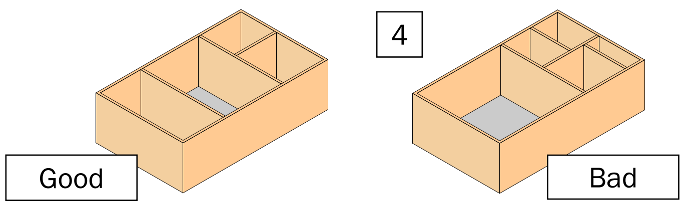
1. Proportions:
   A square form is best. Don't make buildings longer than 3 times their width.
2. Shape:
   Keep the shape of the building simple. Subdivide it into single blocks if necessary.
3. Planning:
   Start with a simple volume and subdivide it into the rooms you need. Don't proceed the other way around, by sticking rooms together in order to get the final form of the house.
4. Balance:
   Evenly distributed inner walls ensure equal strength of the buidling in all parts. Therefore don't place all small rooms on one side and all big rooms on the other side of the house.
5. External walls:
   External walls without openings are strongest. Windows and verandas weaken the walls. Keep them to a minimum.
6. Shop window front:
   Avoid having a 'shop window front' taking up an entire side fo the building. This side of the house will be weak and collapse quickly, leading to the collapse of the rest.

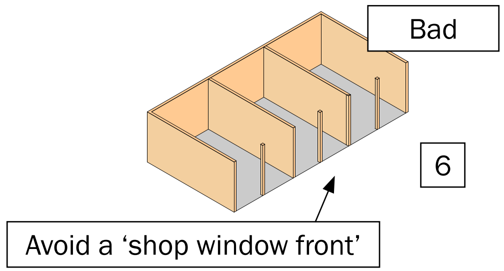


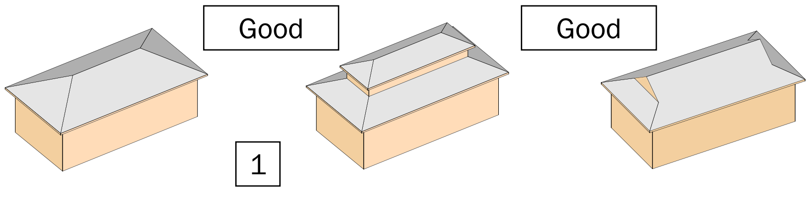






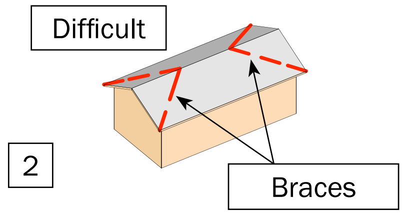




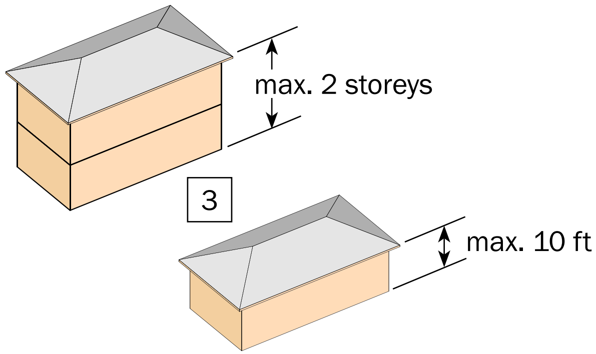


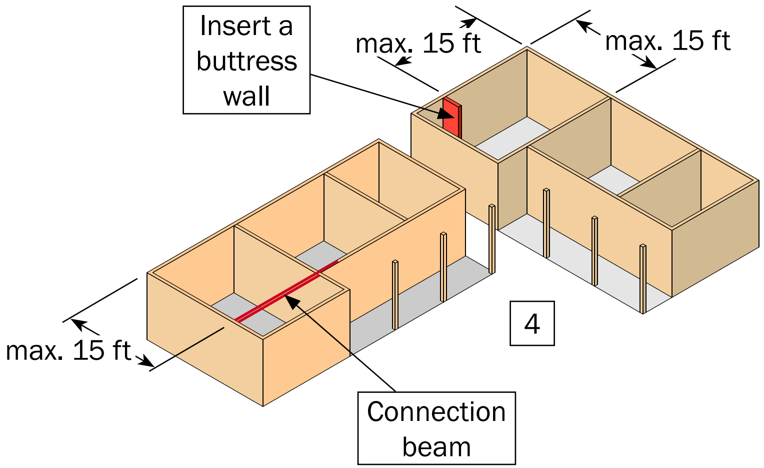
Hipped roof

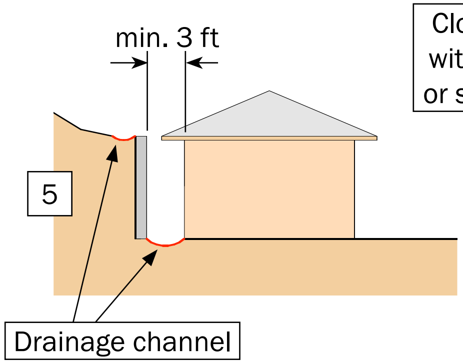
Dutch gable roof

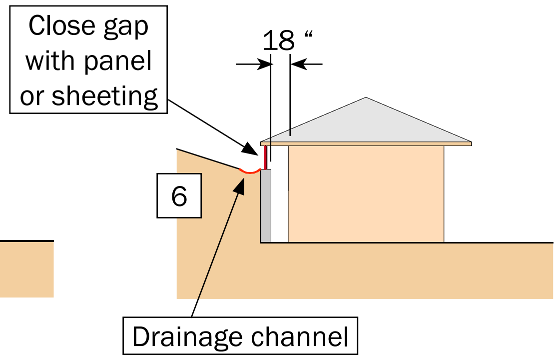


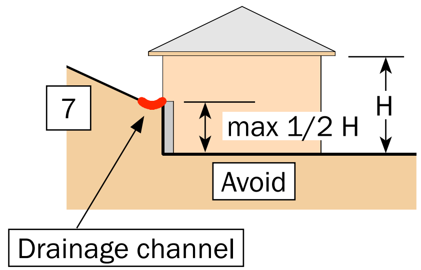
Pitched roof





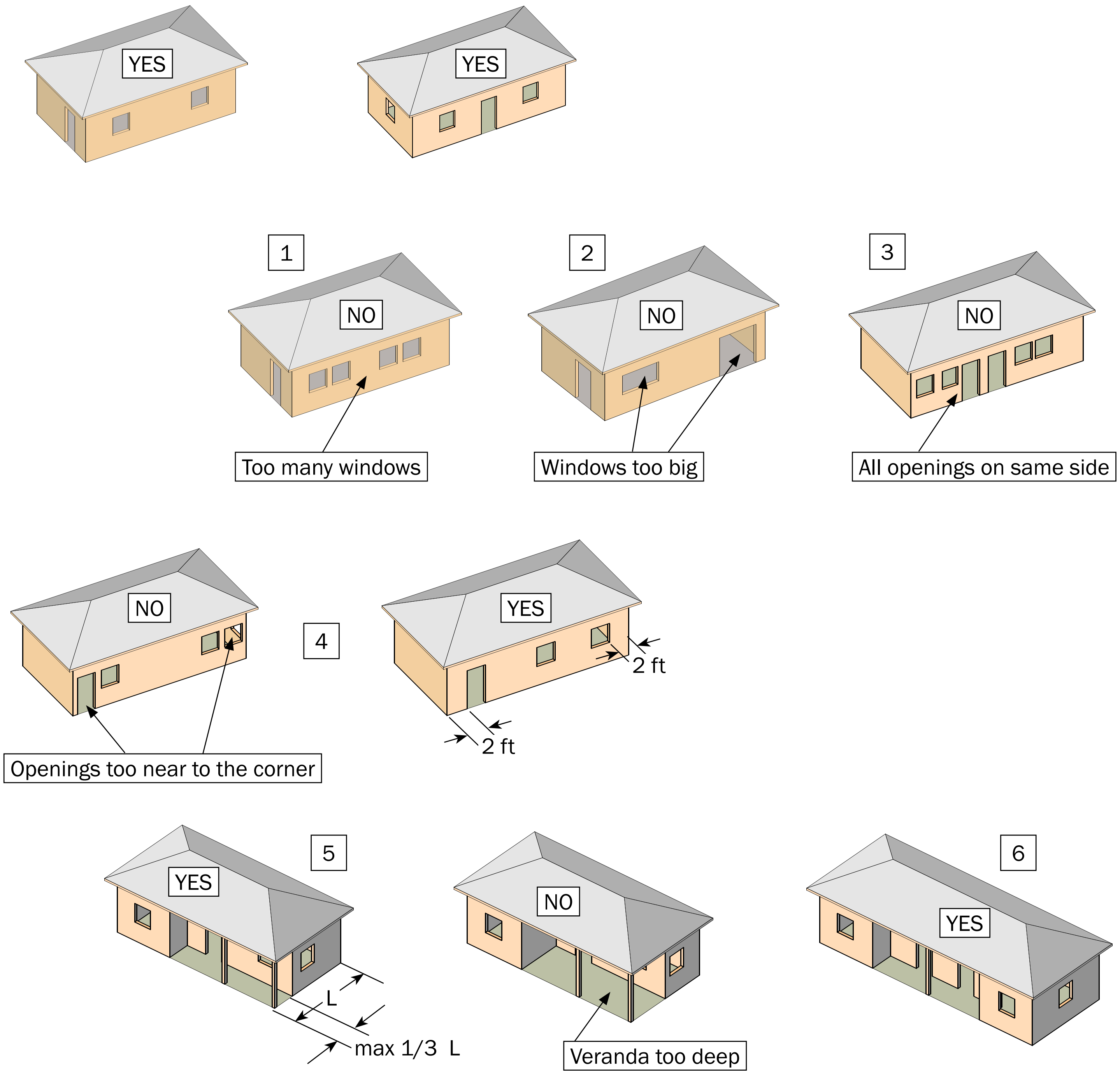


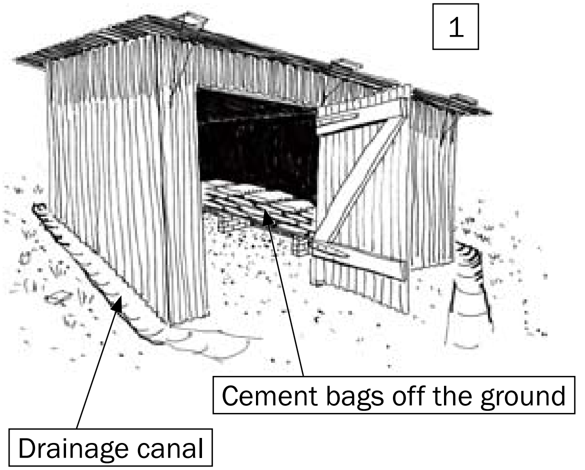


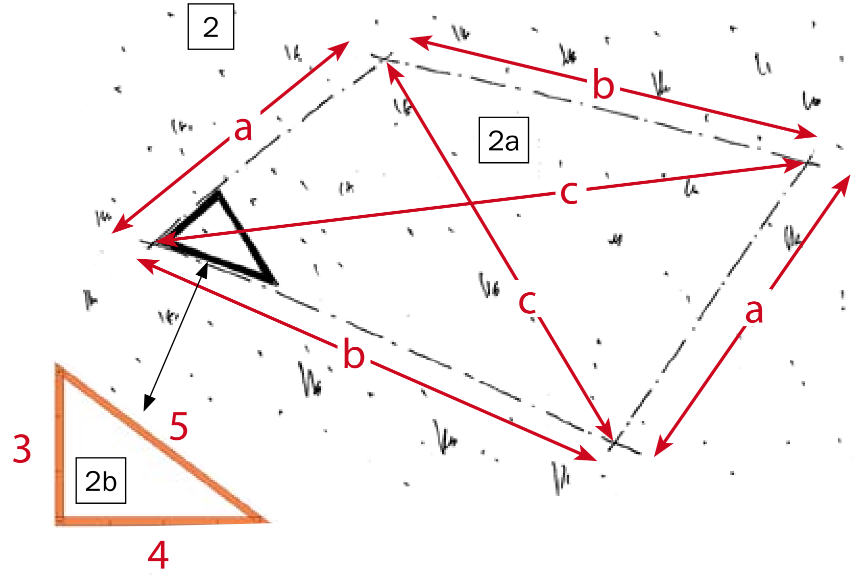


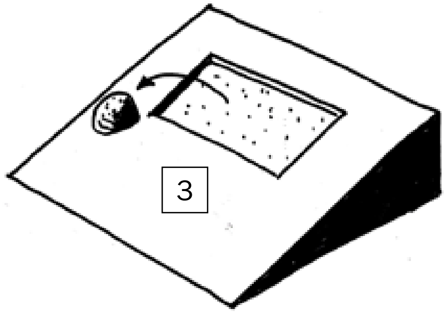
1. Roof types:
   Hipped roofs (4 slopes) are stronger than pitched roofs (only 2 slopes) because they don’t fall over.
2. If a pitched roof is used, it must be braced inside.
3. Maximum heights:
   Height per storey: max 10 ft.
   Height of house: max 2 storeys
4. The length of a wall must not exceed 15 ft. If the wall is longer, it has to be braced in between, either by a buttress wall or a beam well connected to another wall in the same direction.
5. Distance to retaining wall is at least 3 ft. The ground shall be shaped as a watertight drainage channel with a slope towards the sides of the house.
6. If space is limited, the retaining wall may be put at 18” (which still allows a person to pass). In this case however, it must be lower than the house wall, and the upper part shall be closed by a panel to avoid snow drift.
7. The least favourable solution is using the retaining wall as a back wall to the house. In this case the retaining wall must be very well built and not be higher than half of the height of the house wall. Great care must be taken with the drainage channel.

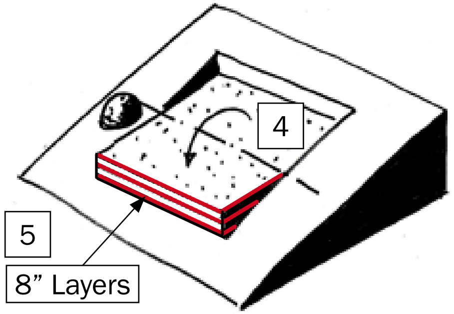
1. Windows and doors are weak points. make as few as possible.
2. Smaller windows are better than big ones.
3. Avoid placing all windows and doors in the same wall.
4. Keep windows and doors at least 2 ft from the corners.
5. Verandas should not be deeper than 1/3 of the depth of the building.
6. Verandas placed in the middle of the building are better.

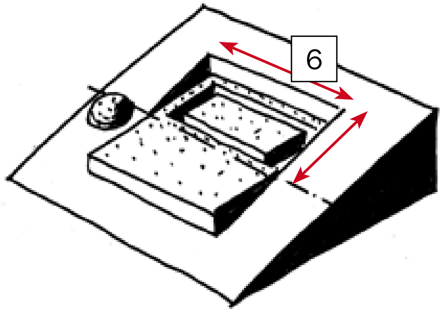


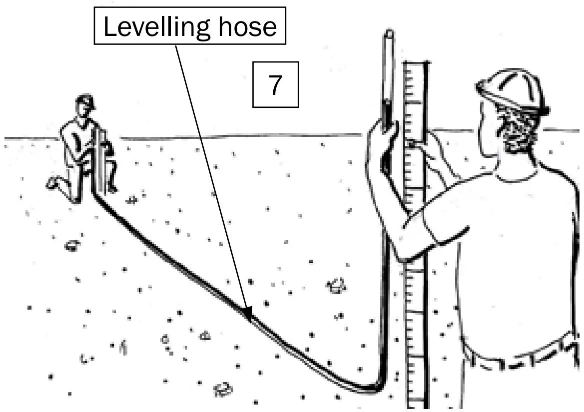


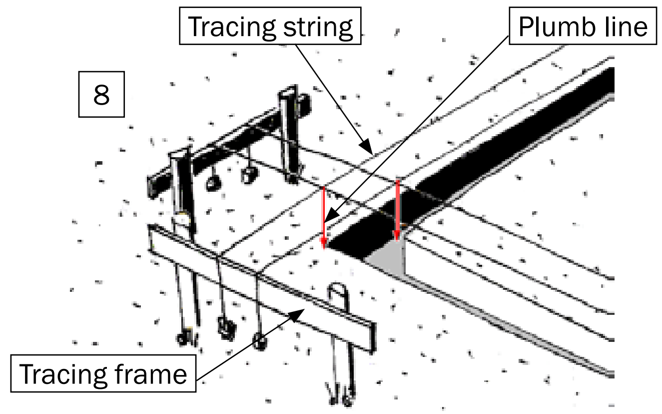










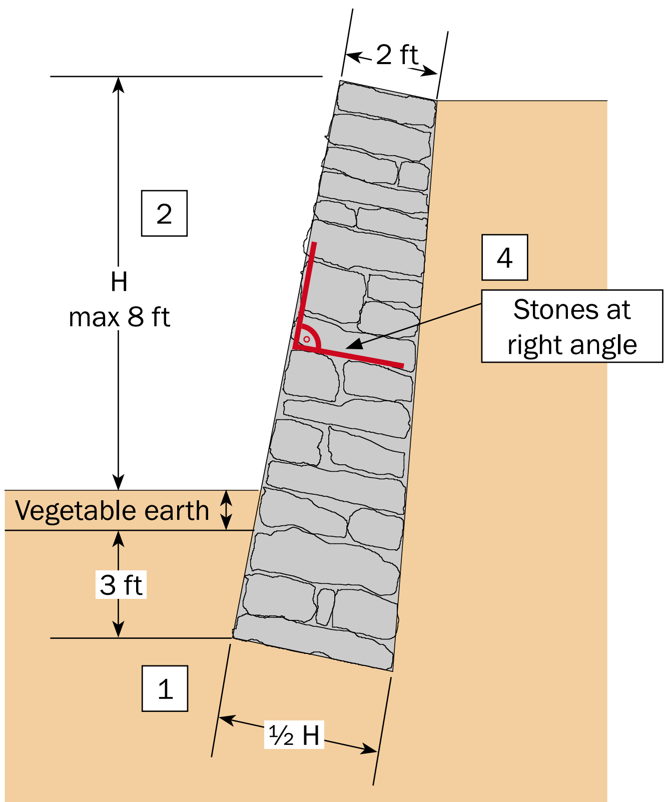


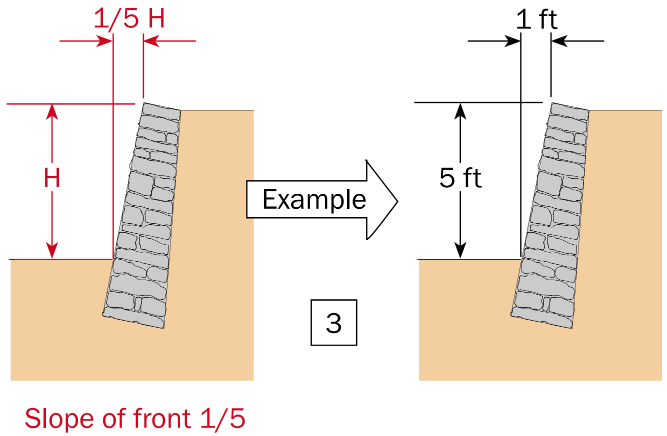
1. Build a shed to keep cement, steel and tools out of rain. Keep cement bags off the ground. Add drainage around the shed.
2. Trace the area to be excavated (house outline plus 3-4 ft on either side). To ensure right angles, there are two methods:

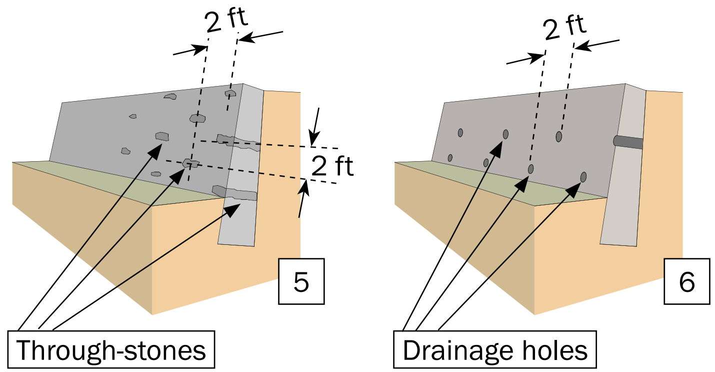
   a) Make sure that the opposing sides a/a and b/b are parallel and have the same length. Then verify the diagonals c/c: they must be exactly the same.

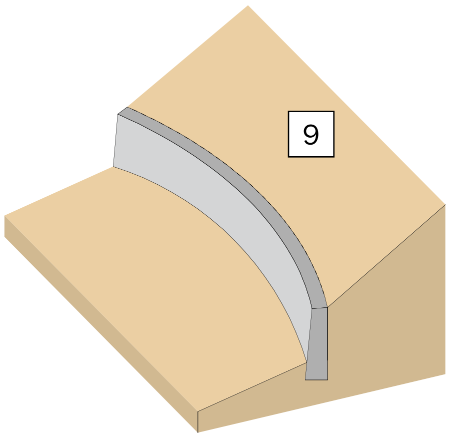
   b) Make a triangle with sides of EXACTLY 3’, 4’ and 5’. For a bigger triangle use 6’, 8’, 10’.
3. Clear this area of vegetation and debris. Then remove the topsoil and store it nearby for later use.
4. Dig out the hard soil to create a level surface for house. Dug out material may be deposited right in front of the house to create a terrace.
5. Compact deposited soil every 8 inches of thickness. .
6. Dig the foundation trenches in the original soil (not in the deposited terracing material !).
7. For levelling use a transparent water hose
8. Place the tracing frames at 2 ft from the trenches to be made and place strings that mark the foundations.

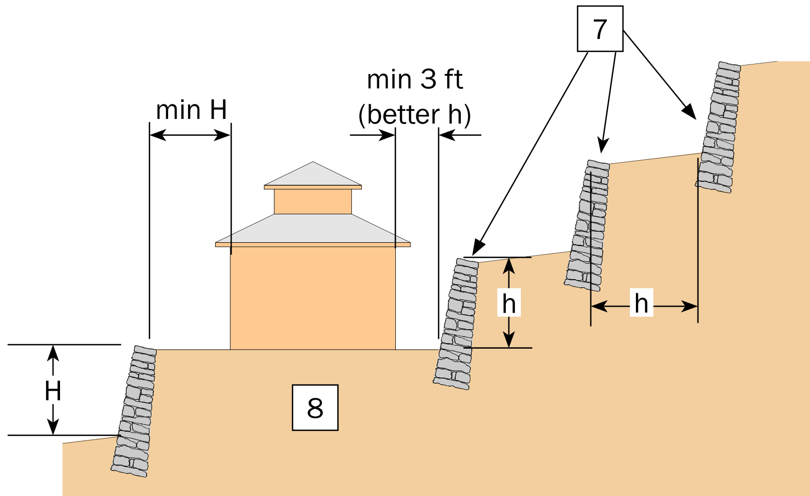
1. Start the retaining wall 3 ft below vegetable soil and prepare a base half as wide as the finished wall height.
2. Maximum heigth of a retaining wall should not exceed 8 ft. The lower the wall, the stronger it will be.
3. Incline the front of the wall in a ratio 1:5. That is, for every 5 ft of height, go 1 ft back.
4. Incline the stones at a right angle to the front.
5. Place as many ‘through-stones’ as possible, but at least every 2 ft along the height and length of the wall.
6. If mortar is used, leave 4”x4” drainage holes in the lower part of the wall, every 2 ft.
7. Instead of making one high wall, subdivide it into several lower walls, stepping back each time the same distance as the heigth of the lower wall.
8. Keep the building away from the retaining walls.
   • On the lower side at least the same distance as the heigth of the wall.
   • On the upper side at least 3 ft from the retaining wall.
9. Curved retaining walls are stronger.

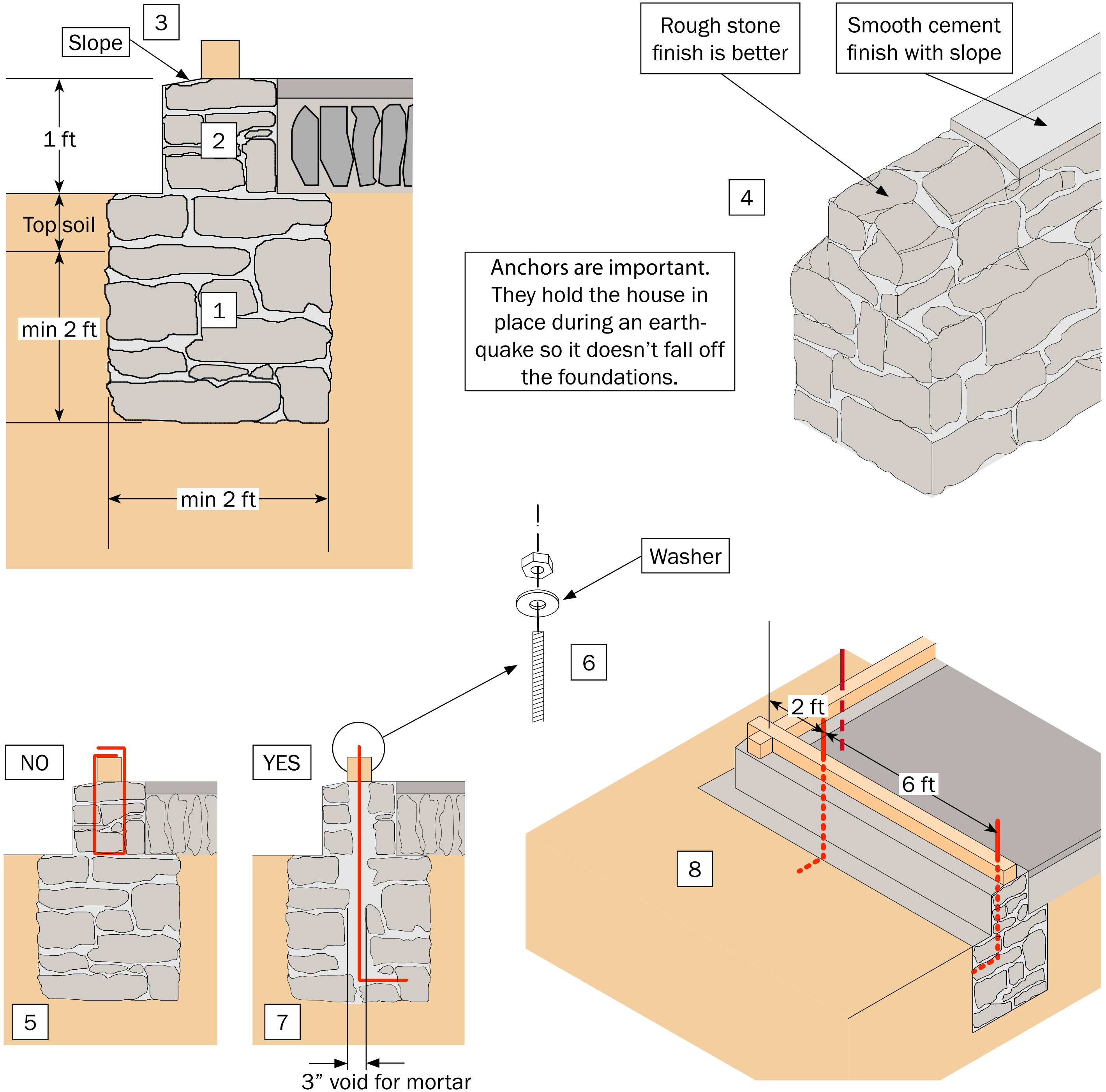






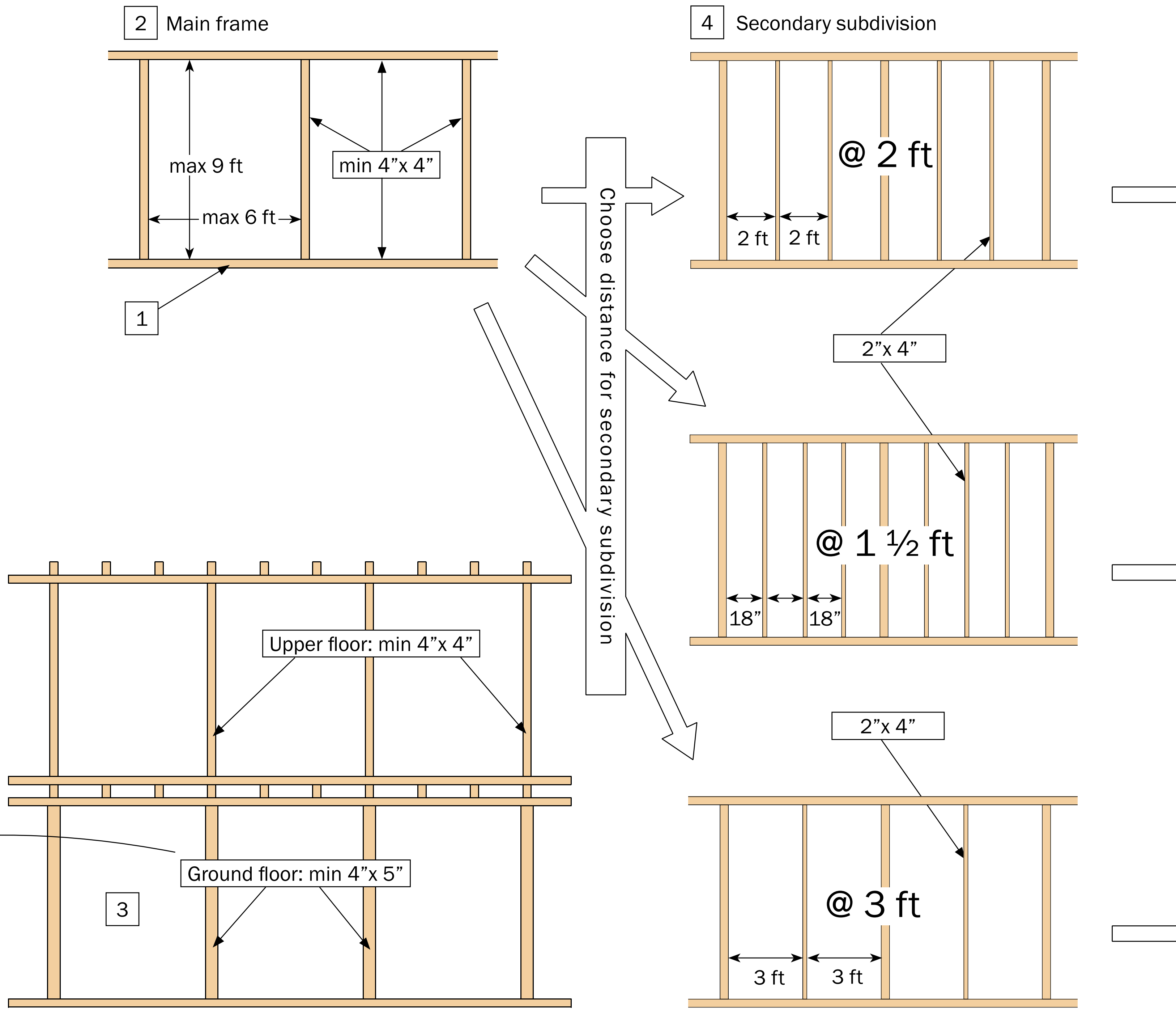


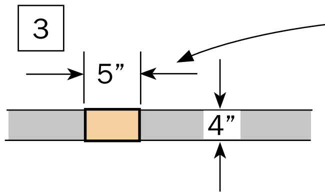




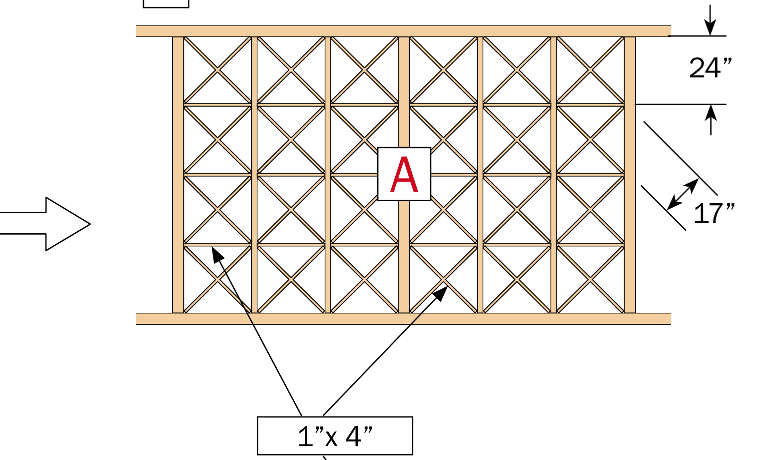
1. Depth and width:
   Foundations must be at least 2 ft deep in solid ground (except on rock) and at least 2 ft wide.
   For 2 storey buildings, foundations should be at least 2'-6" wide.
2. Add a plinth of 1 ft on top of the foundation to keep the base plate away from the ground.
3. Finish the outer part of the top surface of the plinth with a slope towards outside to drain water away from the base plate.
4. It's better to keep the top surface of the foundation irregular to avoid water getting trapped under the base plate.
5. Don't use straps or rebars placed in the plinth.
6. If available, use galvanized anchor rods with a thread. If galvanized rods are unavailable, paint the rods before use with anti-corrosion paint.
7. Place the anchor rods while making the foundation and make sure that the rods are embedded in 1" of mortar all around (cement mortar protects against rust). Fill in mortar by and by while raising the foundation and compact well.
8. Keep the first anchor rods 2 ft from the corner and place the following less than 6 ft apart.

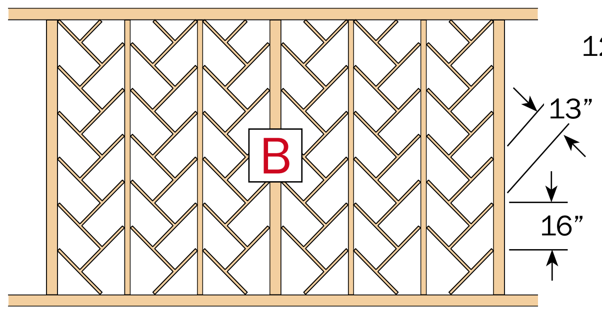
1. For the main frame use only the best timber available. The base plate should be in rot resistant wood (e.g. cedar) or be treated with wood preservatives (read suggestions on pages 24-25).
2. The posts of the main frame are made of timber with a minimal cross section of 4”x 4” placed at 6 ft spacing centre to centre.
3. For two storey buildings the posts on the ground floor should be stronger and have a minimum cross section of 4”x5”. Place the larger side of the post in the direction of the wall.
4. For the secondary subdivision use timber half as thick as the posts (that is 2”x 4” instead of 4” x4”) and place it at 2 ft, 3 ft or 18” depending on the chosen final subdivision pattern.

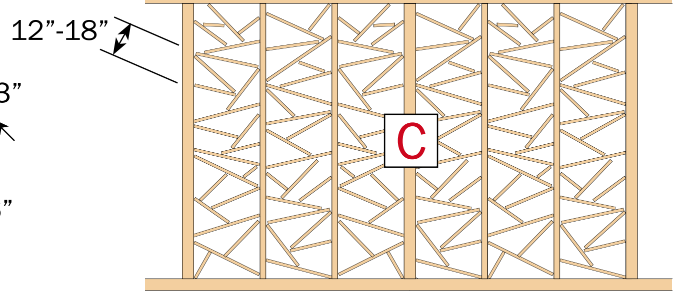


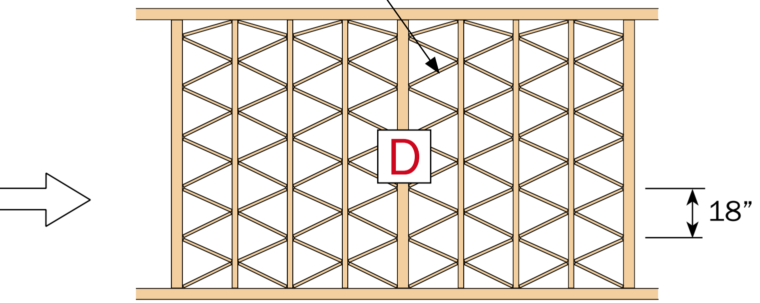


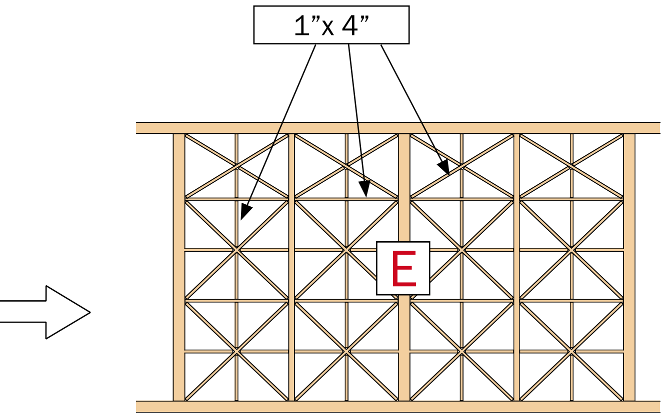
5 Final subdivision

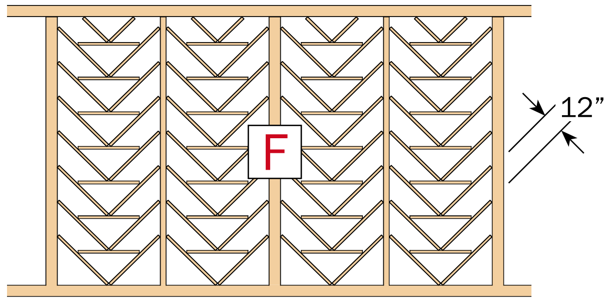










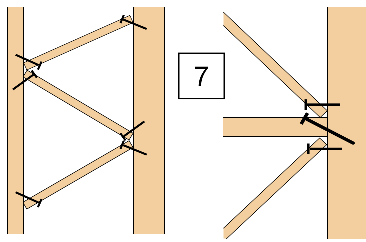


Timber and nail needs for 1 wall element of 6 x 8 ft		
Pattern	Timber in cft	Number of nails (all sizes)
A	3.75	106
B	3.29	88
C	3 to 4	100 to 120
D	3.85	108
E	3.04	94
F	3.25	78

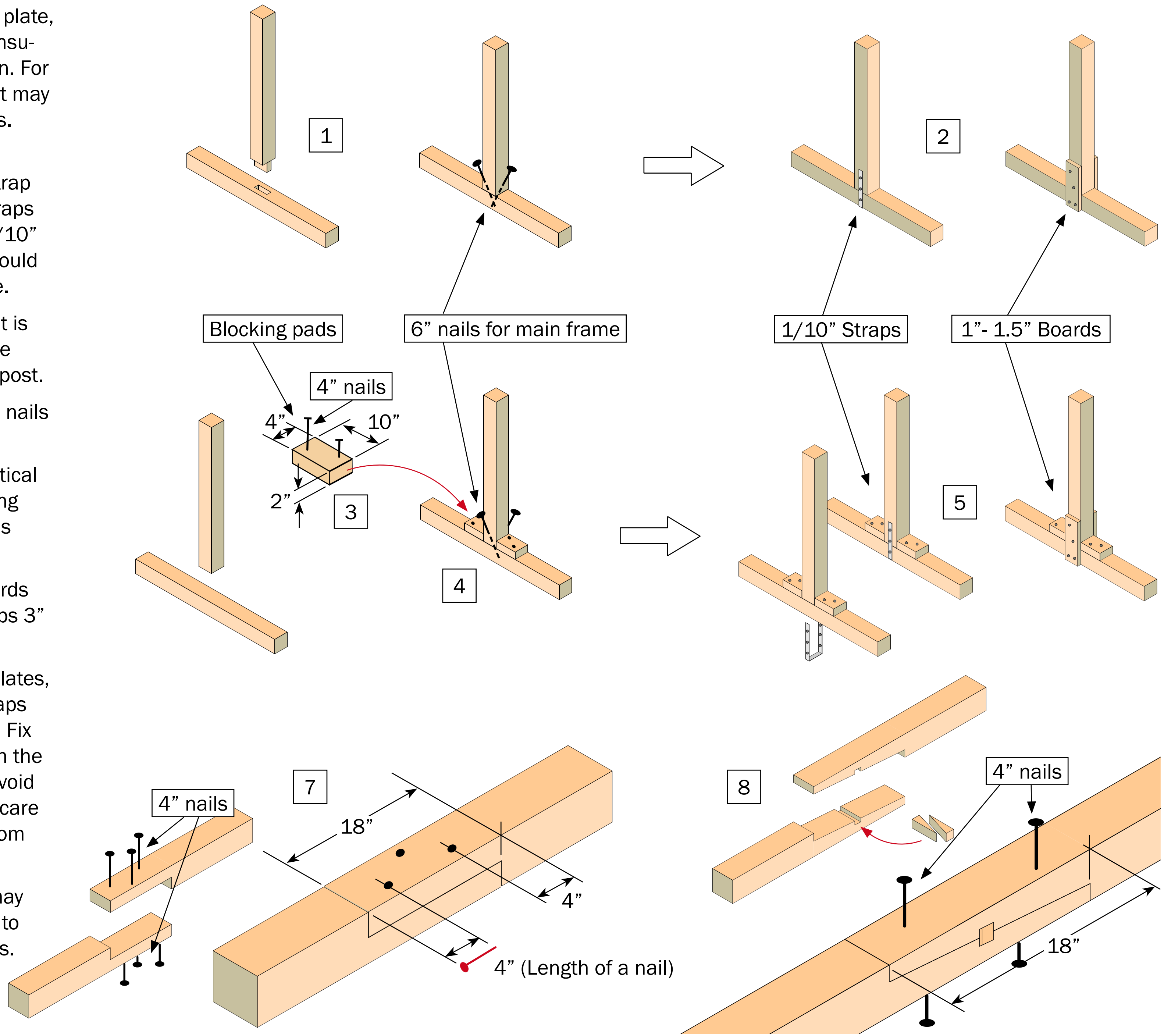
5. Walls can be subdivided in various ways. The strength of the finished wall depends on the quality of connections and the number of bracing boards.

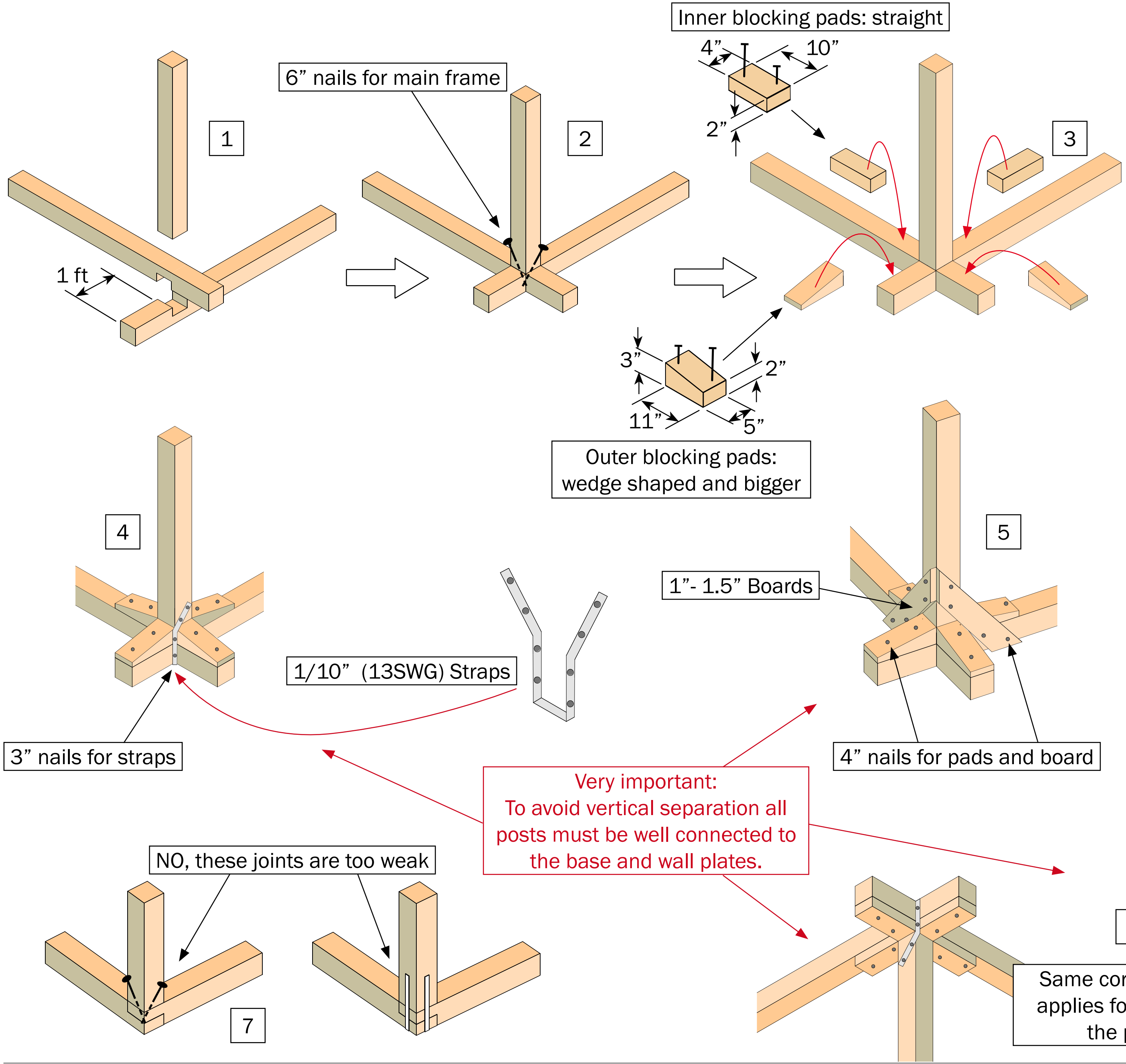
6. Nail sizes:
   - 6” nails to connect the main frame elements (4”x 4”),
   - 4” nails for 2” boards (use 2 nails at each end)
   - 3” nails for 1” boards.

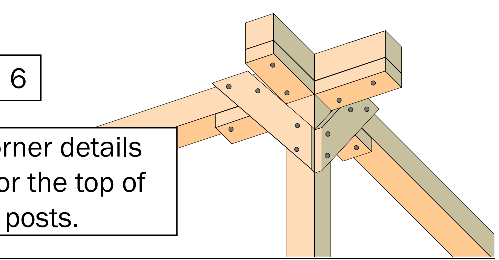
7. Don’t save money on nails. Whenever two pieces of timber meet, connect them with nails.



1. To fix the posts on the base plate, a mortise and tenon joint ensures the strongest connection. For additional strength, the joint may be secured with two 6” nails.
2. To secure the joint against vertical movement, nail a strap or boards on both sides. Straps must not be thinner than 1/10” or 13 SWG (2.5mm) and should go all around the base plate.
3. If no mortise and tenon joint is used, blocking pads must be added on both sides of the post.
4. Secure the joint with two 6” nails against lateral sliding.
5. Secure the joint against vertical movement by adding a strong strap or short timber boards inside and outside.
6. For all blocking pads or boards use 4” nails. To secure straps 3” nails should be used.
7. To join base plates or wall plates, use a nailed lap joint. The laps should be at least 18” long. Fix it with three 4” nails on both the upper and lower sides. To avoid splitting of the timber, take care to keep the nails 4” away from the ends.
8. A scarf (or Kashmiri) joint may also be used. It’s advisable to secure the joint with 4” nails.

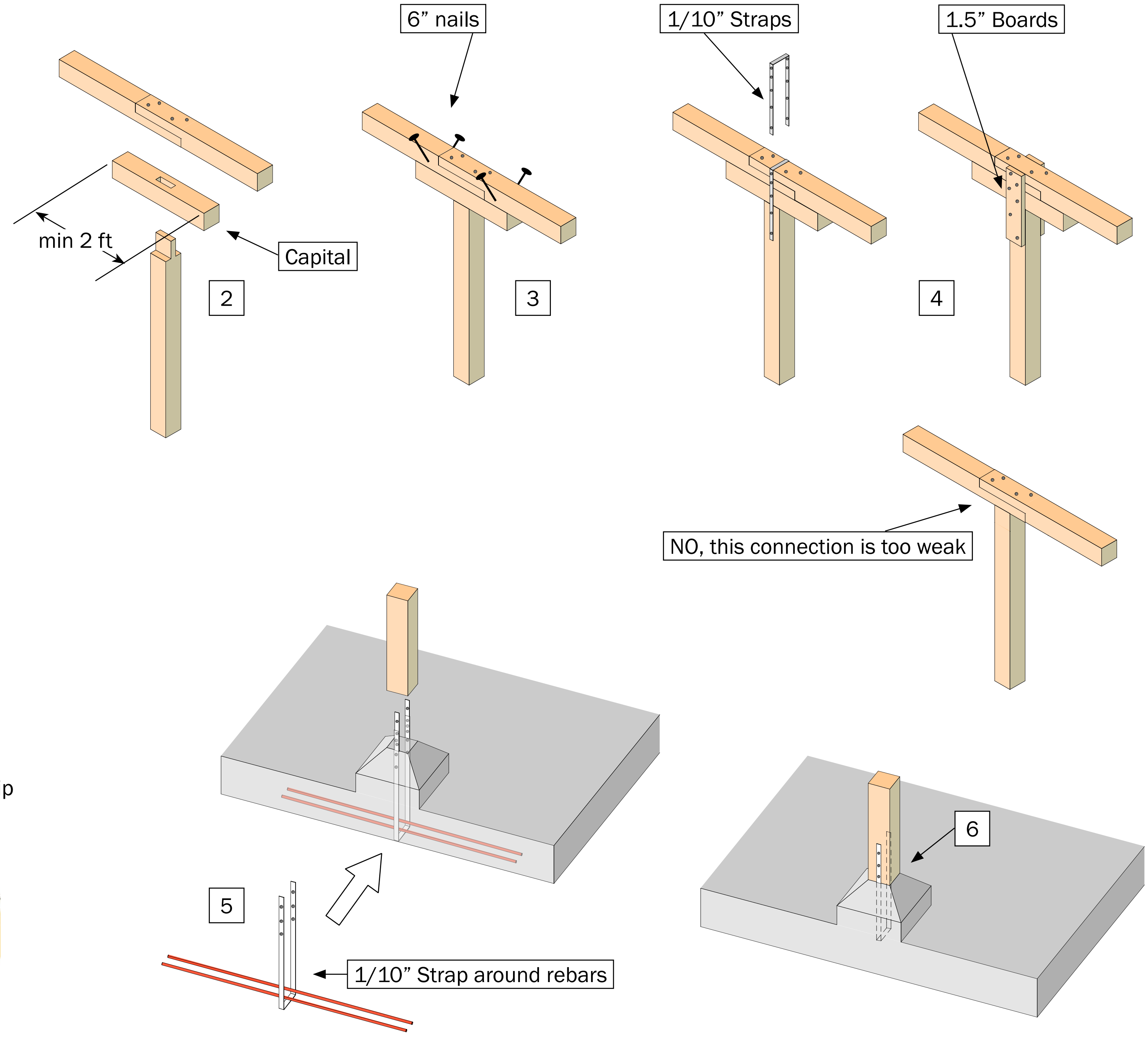


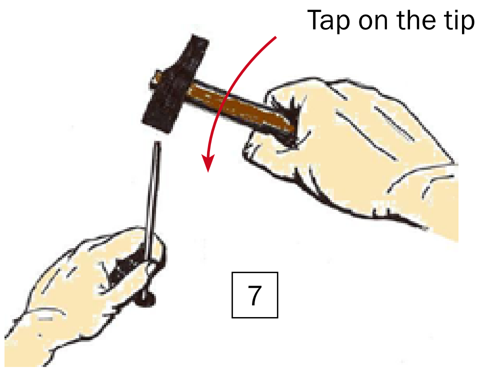


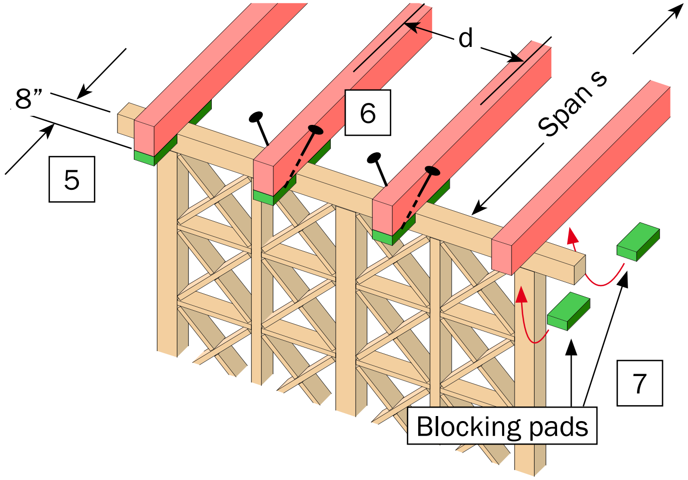


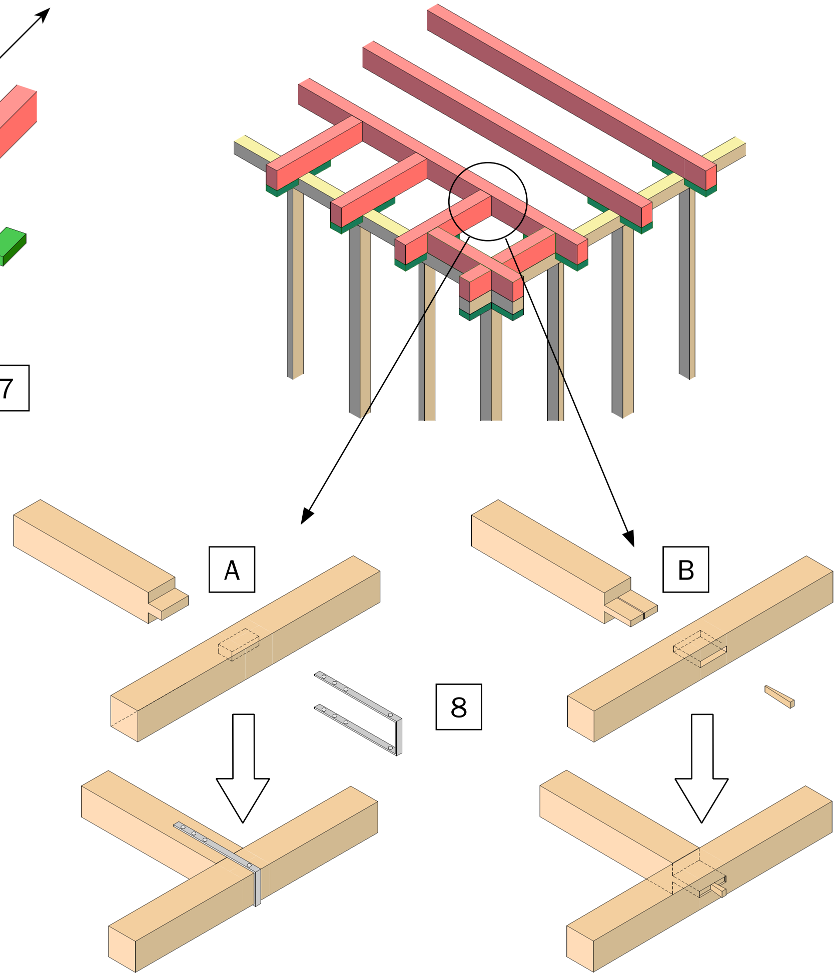
1. Corner joints must be made with greatest care, as they are particulalry at risk during an earthquake. Join the base plates with a cross lap joint. To ensure strength leave 1 ft of timber after the joint.
2. Secure the posts with two 6” nails driven diagonally through the joint.
3. Add blocking pads on all four sides and fix each of them on the base plate with two or three 4” nails. The outer pads should be wedge shaped and bigger to protect the base plate ends against rain.
4. Fix the post to the base plate to avoid uplift during a quake. If a strap is used, it must be 1/10” thick (13 SWG, 2.5mm). The strap should be made of galvanized iron.
5. Diagonal timber boards of 1” or 1 ½” thickness can replace the strap.
6. The same details apply for the connection between posts and wall plate. Here however simple, non conical pads can be used.
7. Never use nailed half lap joints in the corners. They are not strong enough, even with straps.

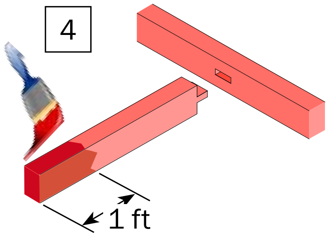
1. If a wall plate joint comes to rest on top of a post, a capital must be added.
2. The capital can be fixed to the post with a mortise and tenon (best solution). Otherwise blocking pads with nails can be used as described on the previous page
3. Fix the wall plate to the capital with 6” nails.
4. Then add a strap or boards.
5. For the footing of veranda posts, prepare a concrete block with an embedded strap anchored around two rebars placed in the plinth.
6. Keep the top of the concrete block slightly smaller than the post so that water doesn’t get trapped underneath.
7. To avoid splitting of the timber, slightly flatten the tip of the nails before use.

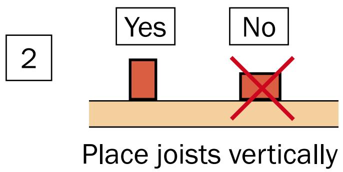








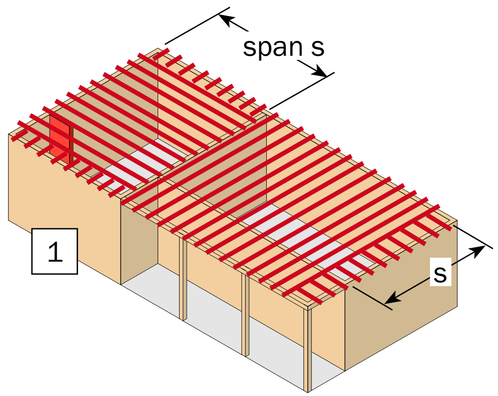




1. In order to use timber effectively, place the joists in the direction of the shorter distance between walls. This distance is called span.
2. For the same reason, place the joists vertically.
3. With the help of the table below, choose the joist size according to the length of the span and the distance between the individual joists.
4. Treat the joist ends with wood preservative for a depth of 1 ft (see page 25).
5. Place the joists on top of the wall plates. Let them stick out 8” on both ends.
6. Fix the joists with 6” nails.
7. For additional strength, add the blocking pads and fix them with 4” nails.
8. Joists are jointed with mortise and tenon and secured with straps (A) or with wedges (B).

3 Table for the dimensioning of floor joists
(for the dimensioning of beams for a flat roof, use table on page 27).

Distance **d**	Span **s** 5 ft	6 ft	7 ft	8 ft	9 ft	10 ft	11 ft	12 ft	13 ft	14 ft	15 ft	16 ft	17 ft	18 ft (life load 40 lbs/sqft) (2.0 kN/m2)
2 ft	2x4	2x4	2x5	3x5	3x6	3x6	3x7 4x6	4x7	5x7	5x7	5x8	5x8	5x9	6x9
2'-6"	2x4	2x4	3x5	4x5	3x6	3x7 4x6	4x7	5x7	4x7	6x7 5x8	5x8	6x8	6x9	5x10
3 ft	2x4	2x5	3x5	3x6	4x6	3x7	4x7	5x7	6x7 5x8	5x8	6x8	5x9	6x10	6x11



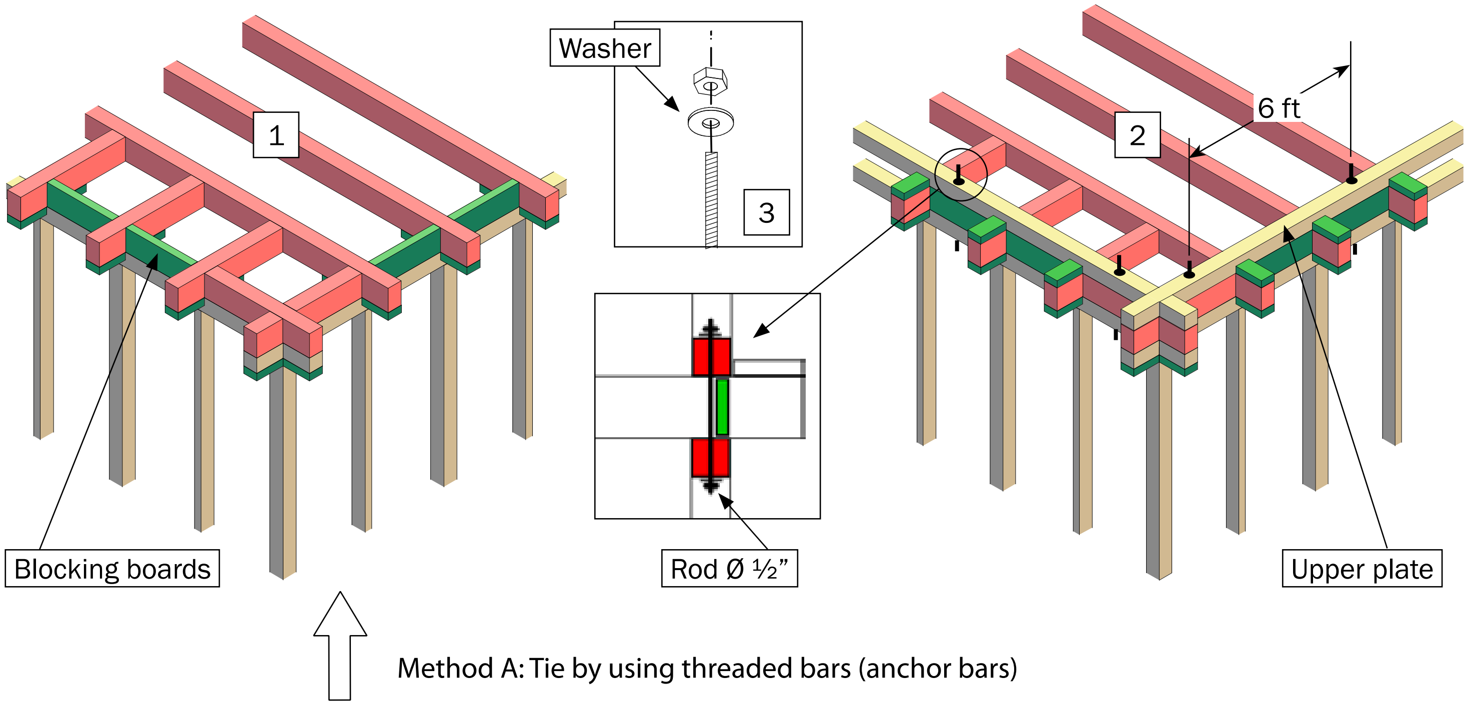
The 'upper plate' acts as a 'base plate' for the roof or the walls of the second storey. There are two methods to fix the upper plate:

Method A: By screwing the upper plate to the lower wall plate through the use of threaded bars.

1. Place the blocking boards between the joists and fix with nails.
2. Add the upper plate and drill holes every 6 ft through this and the lower wall plate.
3. Place the threaded rods with washers and tighten. Washers are important so that the nut doesn't eat into the timber.

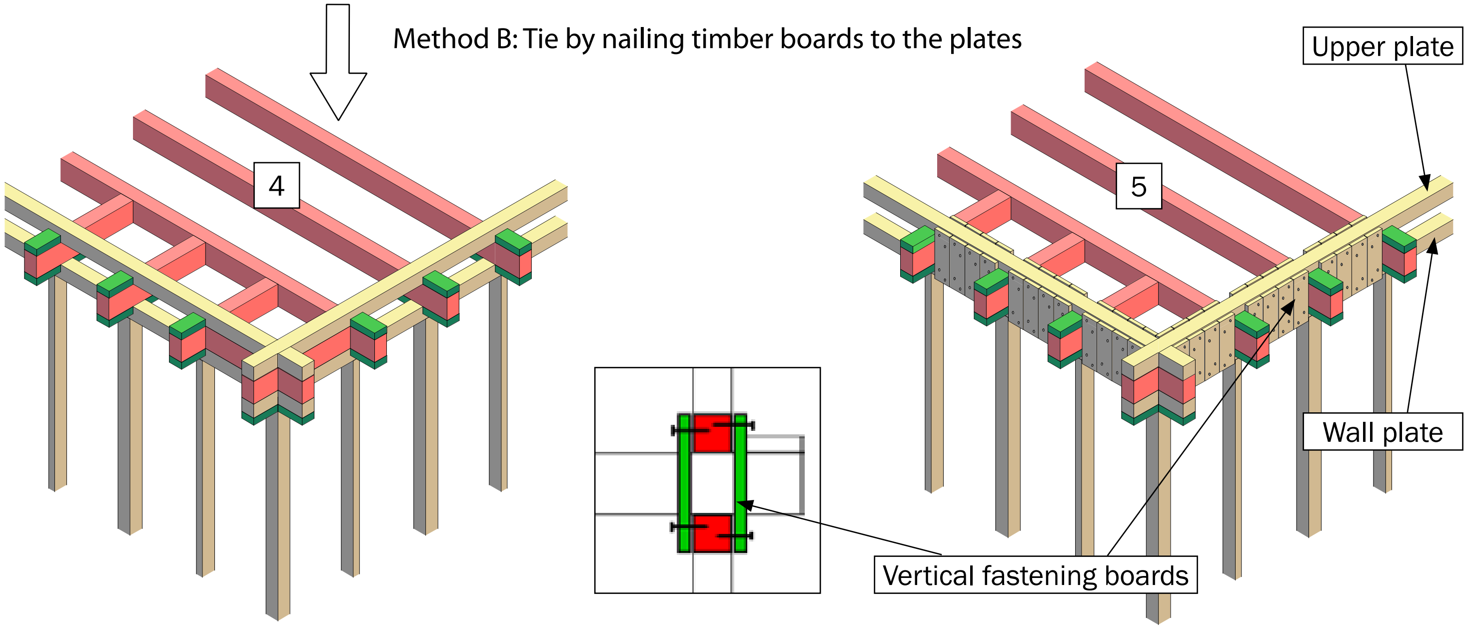
Method B: By tying the upper plate to the lower wall plate through nailed timber boards.

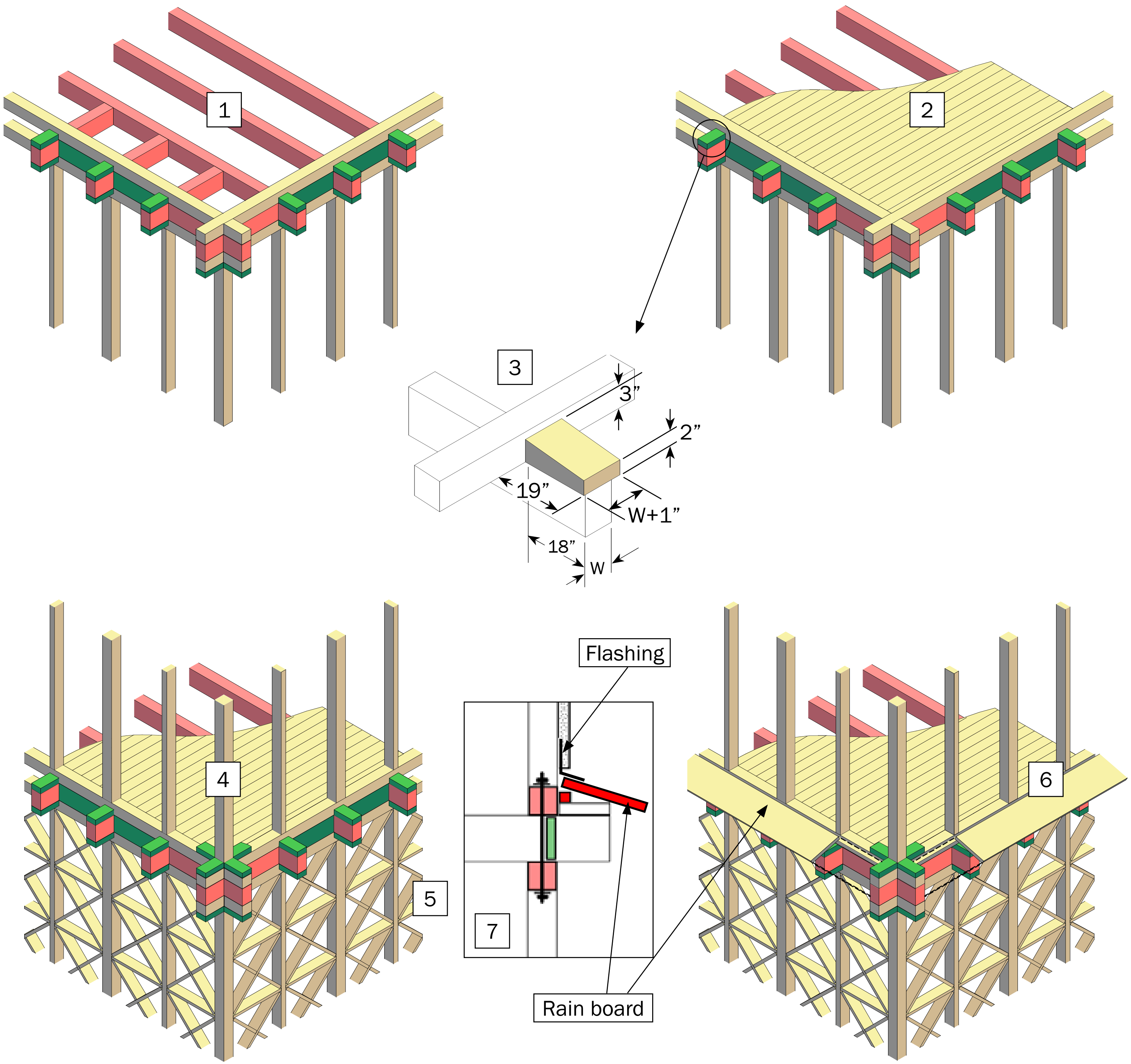
4. Place the upper plate.
5. Nail 1" vertical timber boards against the upper plate as well as the lower wall plate in order to tie them together. This should be done both inside and outside.



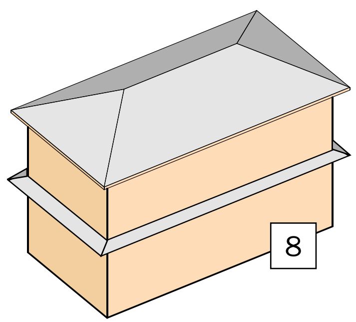
Method A: Tie by using threaded bars (anchor bars)

Method B: Tie by nailing timber boards to the plates





1. The upper plate acts as the base plate for the new wall.
2. Add the floor boards (at least those along the walls).
3. The blocking pads placed on the joist ends will not only help to block the upper plate, but will also protect the joist ends against rain. To let water run off, they should be wedge shaped and slightly larger than the joist ends.
4. Place the posts and fix them with nails and blocking pads as done on the ground floor.
5. Fill in the wall subdivisions like on the ground floor.
6. When straight blocking pads are used, the joist ends must be protected against rain by adding a sloping weather board.
7. Add a metal flashing between weather board and wall structure (before the plaster is put on) to avoid infiltration of rain water.
8. A house with weather boards may look like on this illustration.



Form of roof:

1. Roofs with four slopes (hipped roofs) are stronger than roofs with only two slopes (gable roofs) because the hips act as braces.
2. Gable roofs need additional internal bracings. Moreover, the gable walls are at risk of falling over during an earthquake.

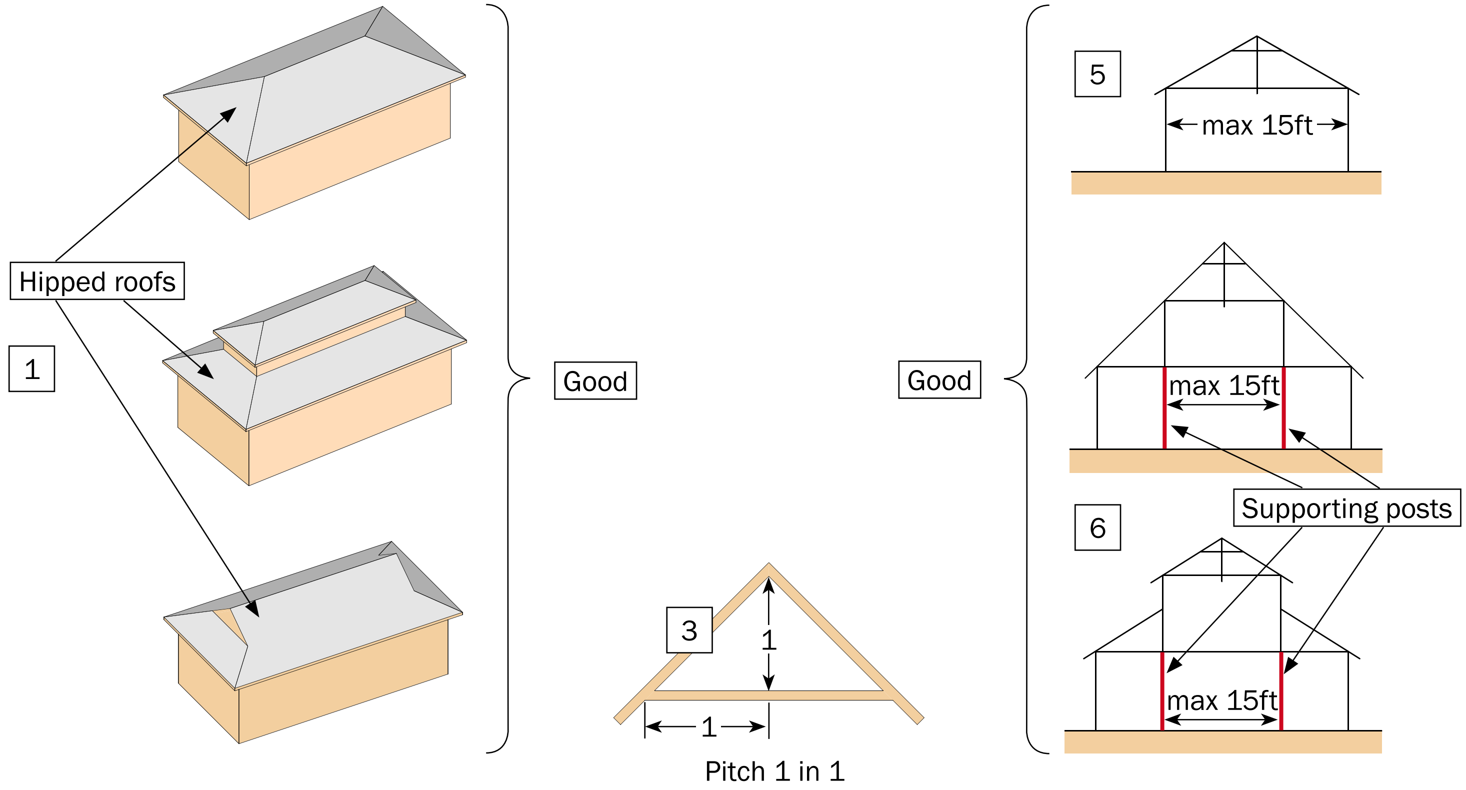
Roof slope:

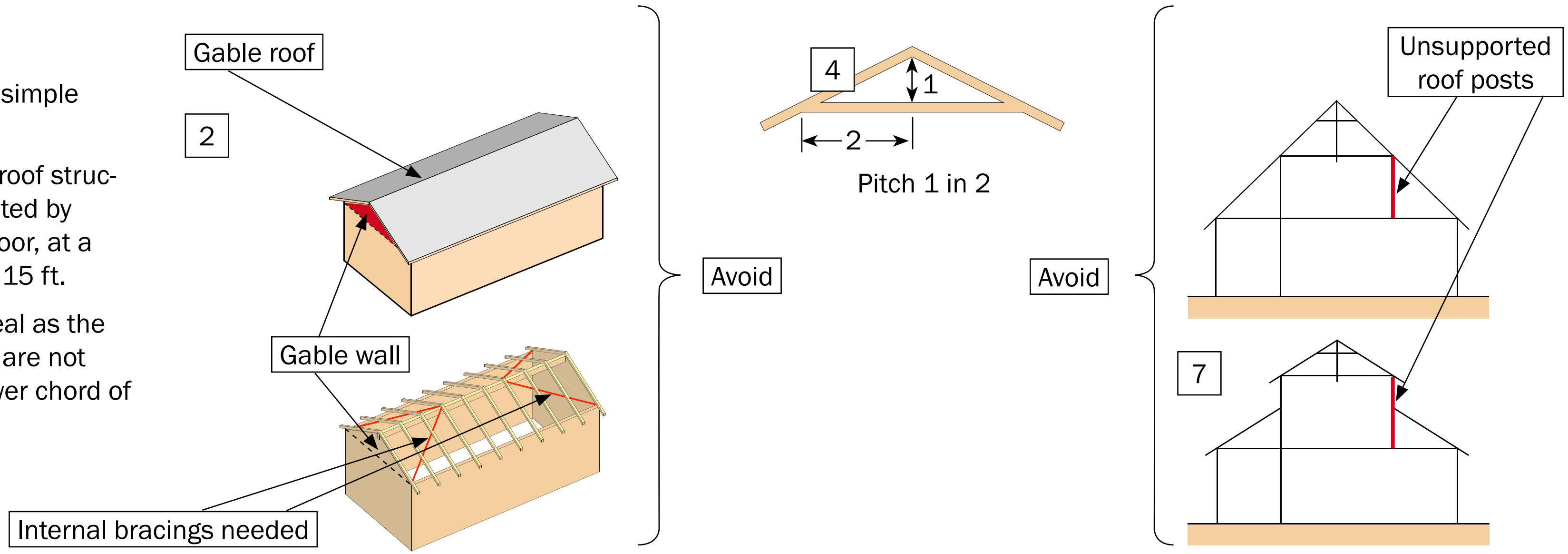
Roofs can have different slopes according to the climate and need:

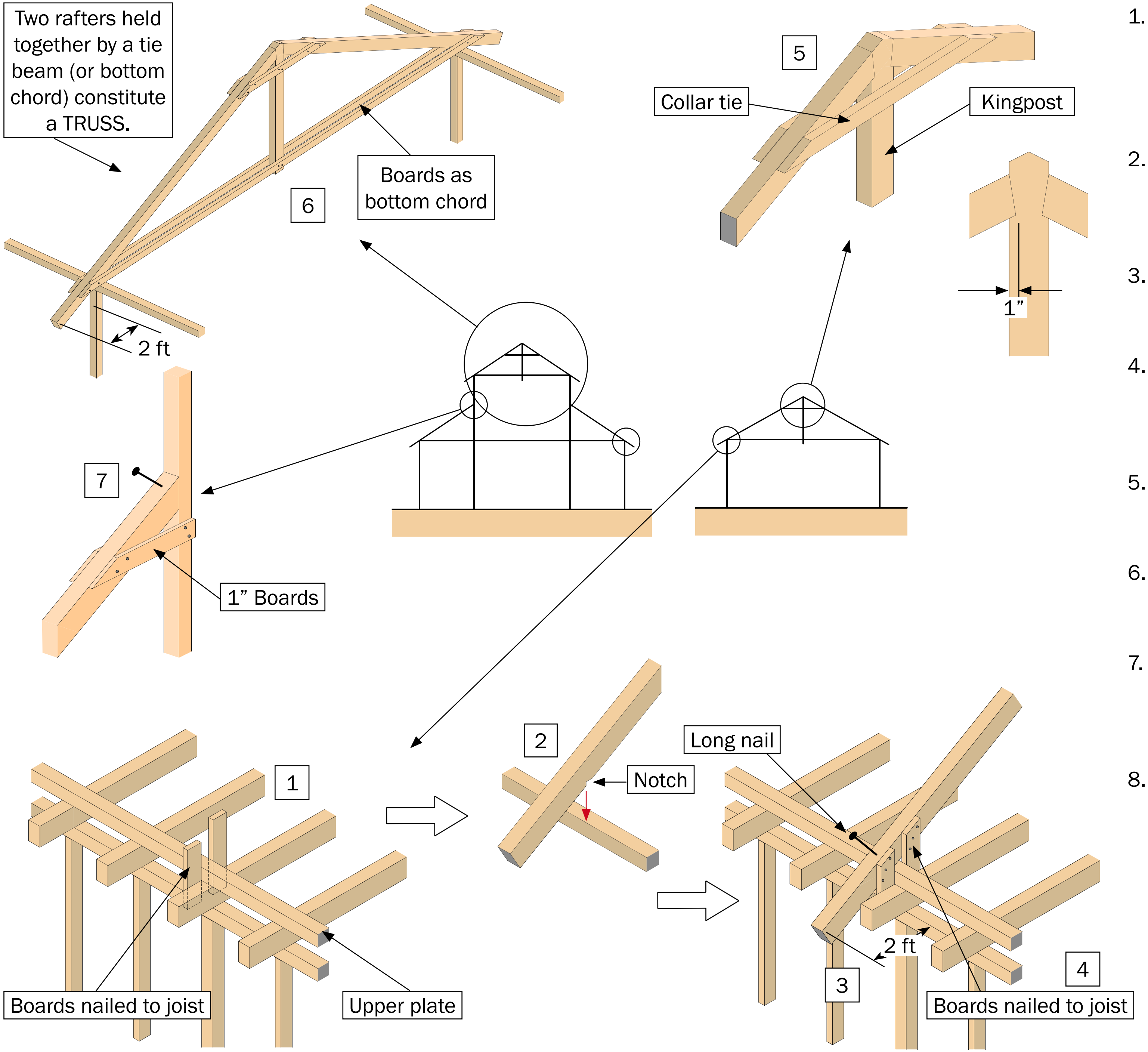
3. In snowy areas, a steep roof is better as the snow will slide off more quickly.
4. Flatter roofs need less timber and sheeting and are better in high wind areas (pitch 1 in 2).

Type of structure:

5. For spans up to 15 ft, simple trusses can be used.
6. For larger houses the roof structure should be supported by posts on the ground floor, at a maximum distance of 15 ft.
7. This solution is not ideal as the roof posts of one side are not supported and the lower chord of the truss may bend.







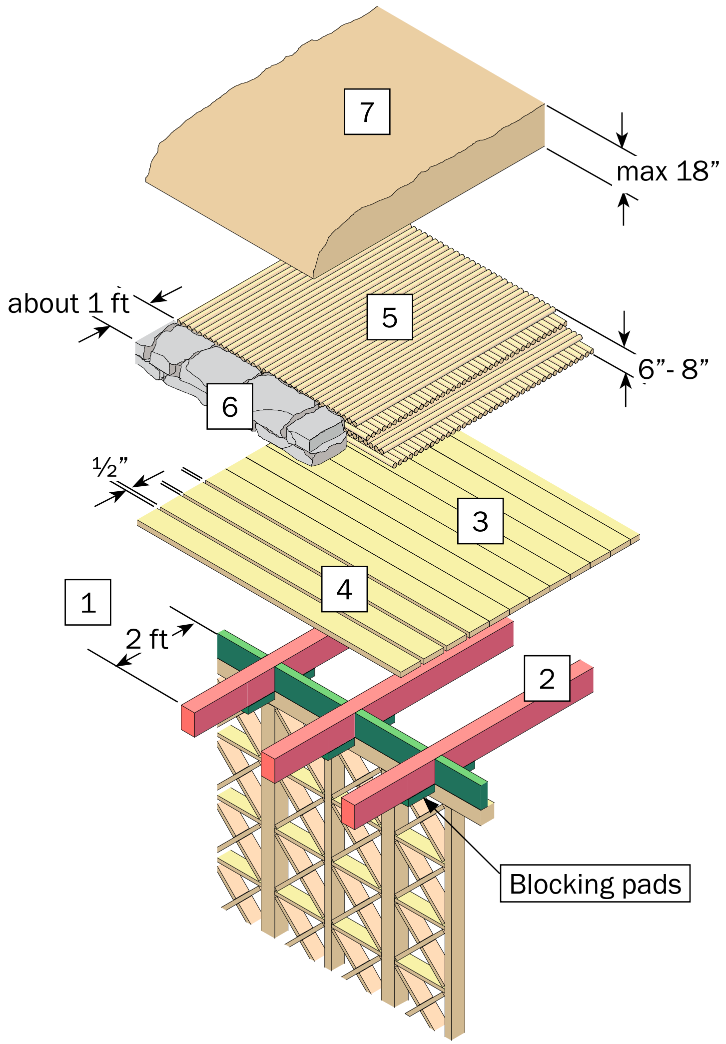
1. Where rafters are to be fixed on the upper plate, start with nailing short vertical boards against the joists on both sides of the upper plate.
2. Place the rafter (with a notch) and nail it down with a long nail (length = thickness of rafter plus 3 to 4 inches).
3. Let the rafters protrude 2 ft from the wall. In high wind areas, this distance may be reduced to 18”.
4. Then nail the vertical boards against the rafter. These vertical boards ensure a stiff connection between the rafter and the joist.
5. Assemble the rafters at the top by using a kingpost and collar ties (1-2” boards).
6. Trusses can also be made by nailing long boards to both sides of the rafters and the kingpost.
7. To fix rafters agains posts, use a long nail and secure the connection with boards nailed on both sides.
8. Never nail rafters against the head of joists. Such a connection is very weak.

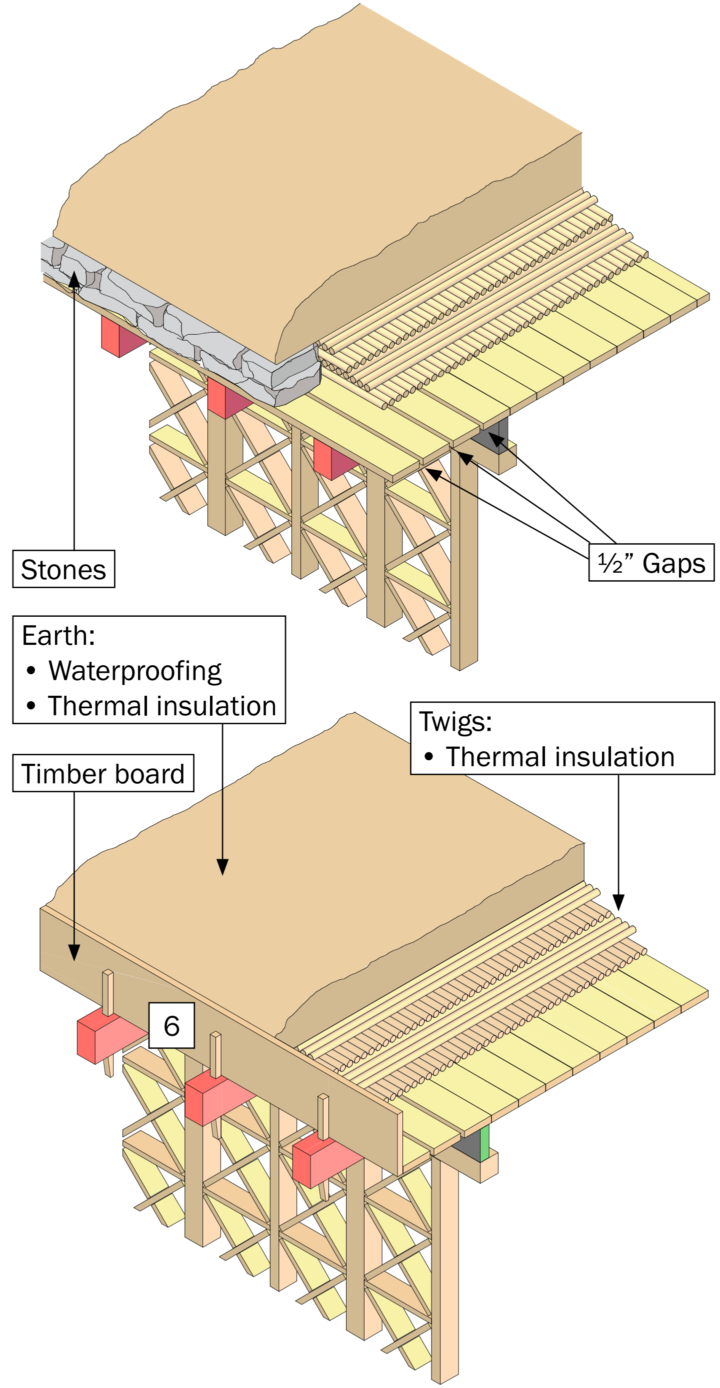
In general, pitched light weight roofs are preferable. However, local habits and needs might require flat roofs.

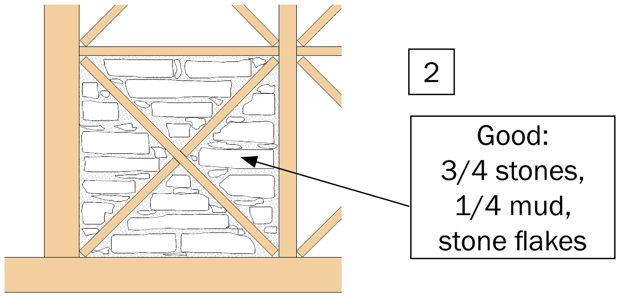
Also, flat roofs as shown on this page have a better thermal insulation thanks to the layer of twigs and the top layer of mud.

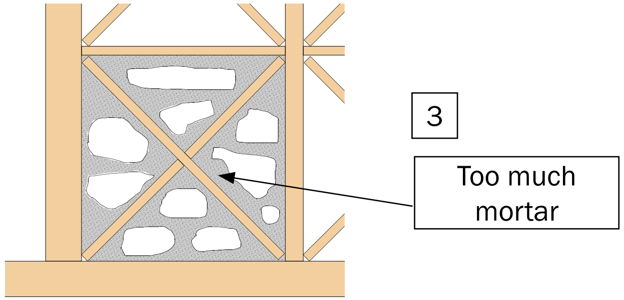
To know the ideal thickness of the various layers, the best material and the proper way to use it, consult experienced local people. Keep in mind however that the mud layer should be kept to a minimum to reduce weight.

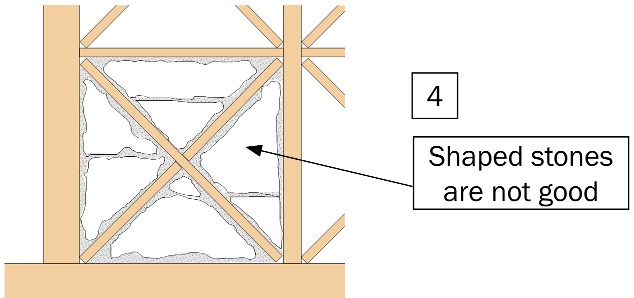
1. Let joists stick 2 ft out from the wall and block with pads.
2. Flat roofs with earth on top are heavy. For the correct dimensioning of the floor joists use the table on page 27.
3. Place a layer of timber boards over the joist structure.
4. Keep 1/2” gaps between the outer boards to allow possible water infiltration to run off.
5. Add a closely packed layer of twigs 6” to 8” thick. The thicker the layer, the better the thermal insulation.
6. Add a stone barrier or a timber board (blocked by pegs) on the outer edge of the roof to contain the layer of twigs.
7. Add a final layer of earth which should not be thicker than 18”.

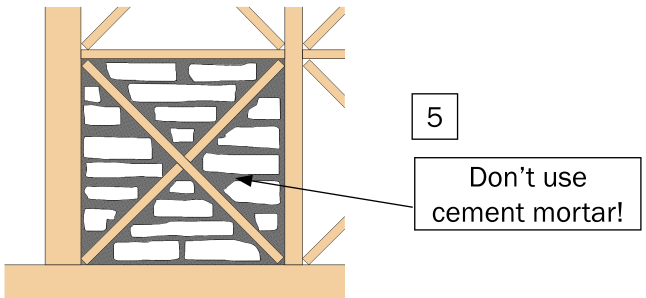


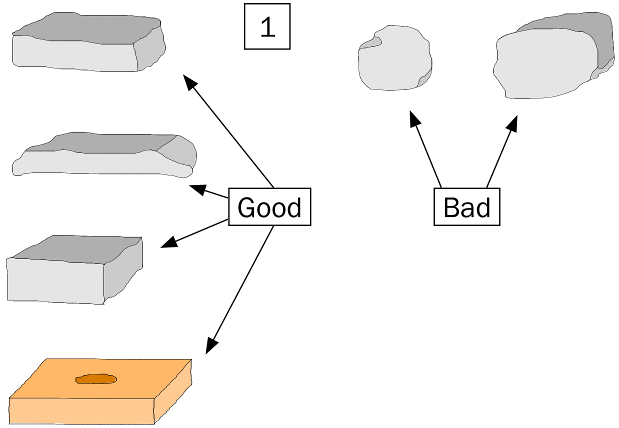


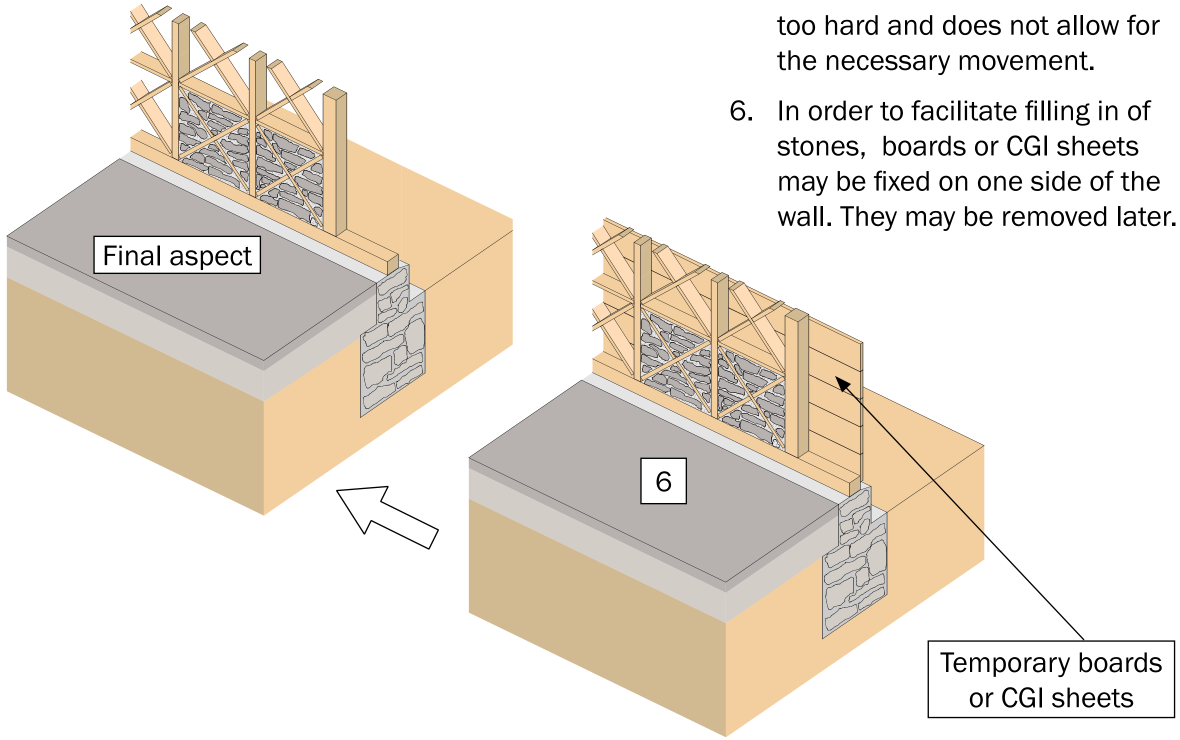












1. For the infills, use flat stones or bricks. Never use round stones as they will fall out quickly.
2. Pack the stones neatly into the gaps with mud or lime mortar. The mortar layers should be around ½” thick and the proportion should not exceed one quarter of mortar for three quarters of stones. Fill remaining gaps with stone flakes.
3. Excessive amounts of mortar should be avoided.
4. Don’t cut the stones in the shape of the gaps. Regular layers of flat stones are better.
5. Don’t use cement mortar. It is too hard and does not allow for the necessary movement.
6. In order to facilitate filling in of stones, boards or CGI sheets may be fixed on one side of the wall. They may be removed later.

Plastering

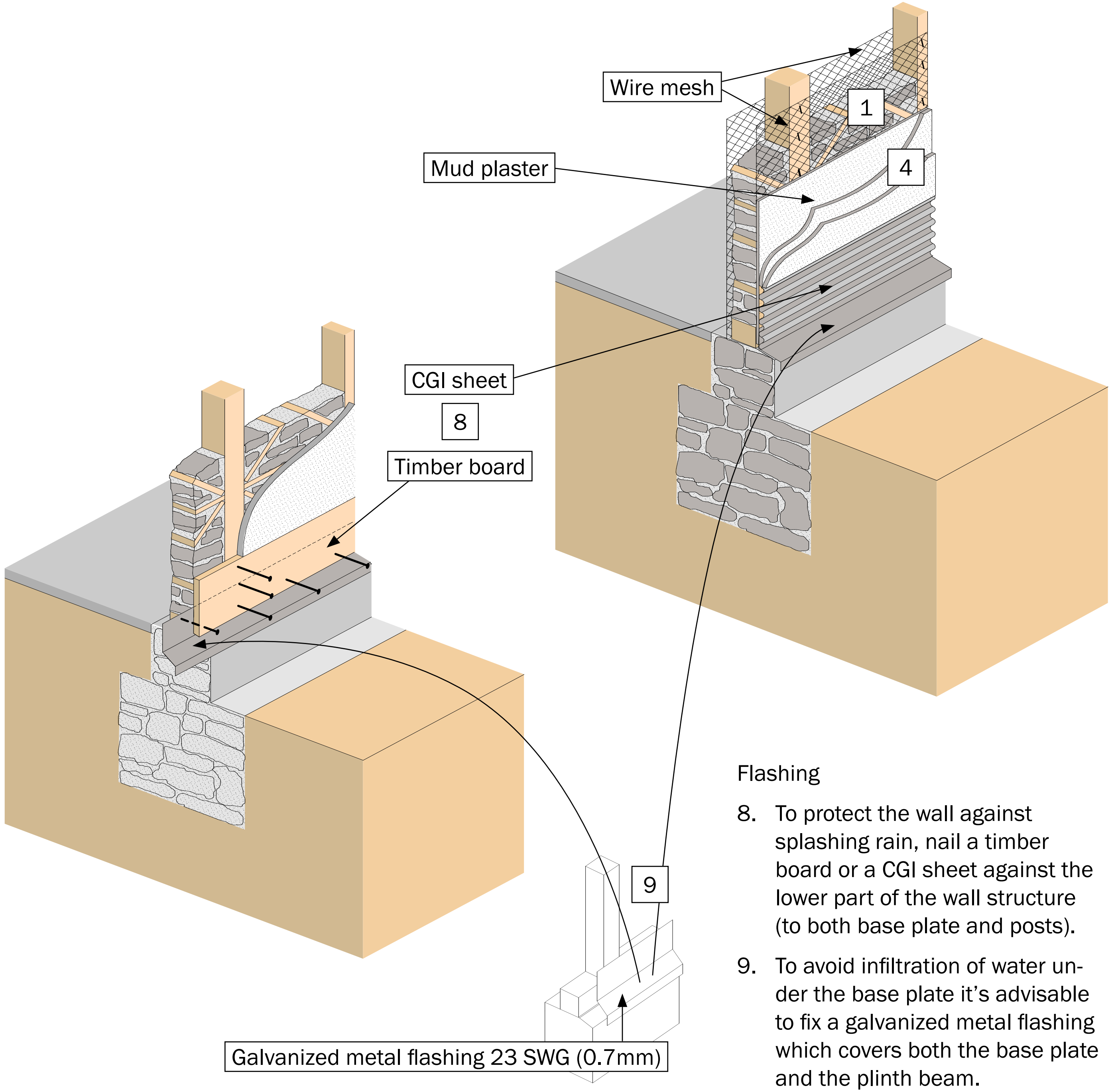
1. For increased strength and to secure the stones against falling out, a galvanized wire mesh can be nailed to both sides of the wall. Make sure that enough nails are used for fixing (every 4-6 inches).

Mud plaster (preferred solution):

2. For plastering, mud or cement plaster may be used.
3. A good mud plaster mix is made of one third of clay, two thirds of sand and a fair amount of pine needles or straw. Look also for local expertise.
4. Apply the plaster in several layers not exceeding ½" each. If you make the layers too thick, they will crack.
5. For paint use white wash (lime). Don't use synthetic paint, it doesn't adhere properly on mud plaster.

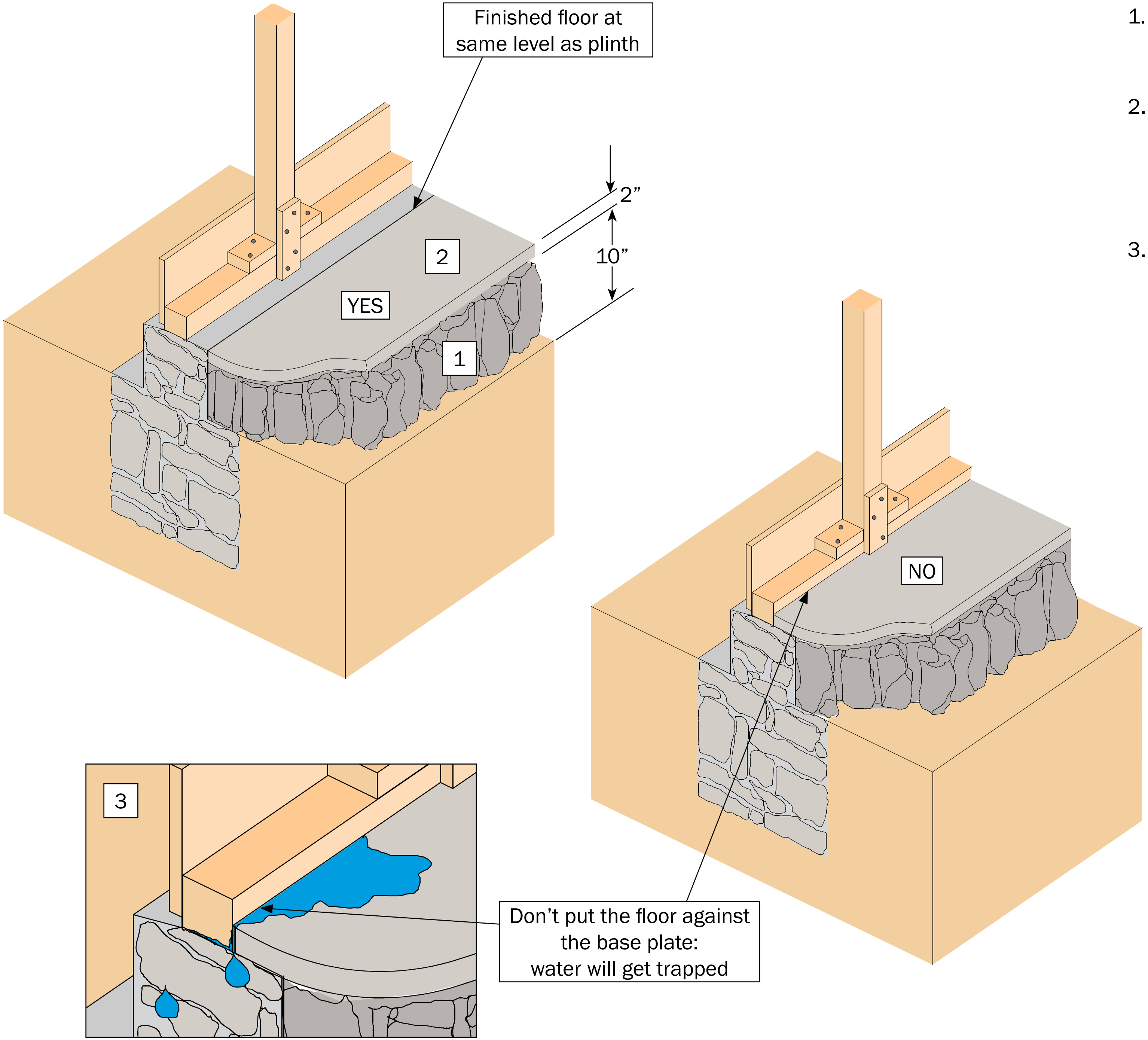
Cement plaster (avoid if possible):

6. If cement plaster is used, all stones in the wall must be cleaned thoroughly to ensure proper adherence of the plaster.
7. When using cement plaster cover the walls first with walls wire mesh. The mesh will ensure that the plaster remains in place.

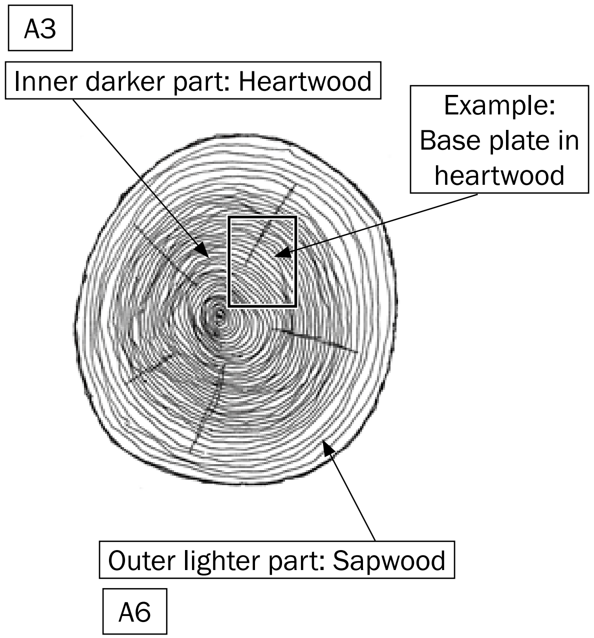


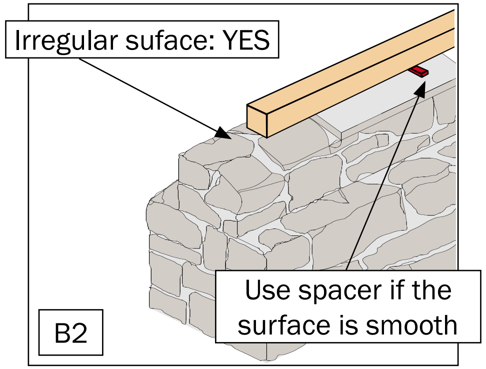
Flashing

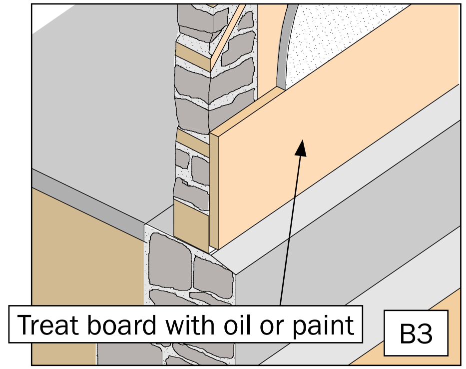
8. To protect the wall against splashing rain, nail a timber board or a CGI sheet against the lower part of the wall structure (to both base plate and posts).
9. To avoid infiltration of water under the base plate it's advisable to fix a galvanized metal flashing which covers both the base plate and the plinth beam.

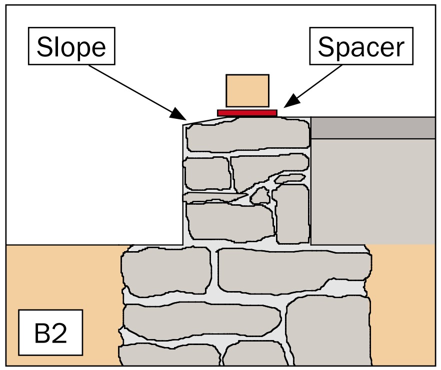


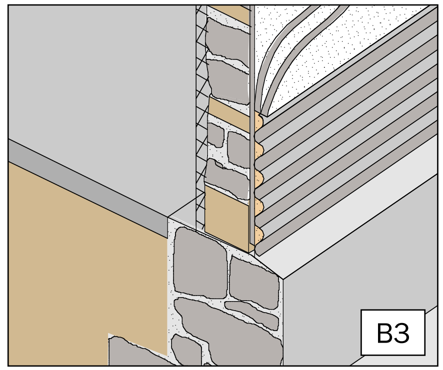
1. To keep off humidity coming from the ground, place a bed of vertical stones on the natural soil.
2. Then add a layer of stabilized earth which is a mixture of earth and cement or earth and bitumen. Ask for local experience for the best mix.
3. The finished floor must not touch the timber base plate as water will get trapped between the floor and the base plate and the timber will rot.











To increase its longevity timber employed in construction must be

A: properly selected,

B: protected,

C: treated.

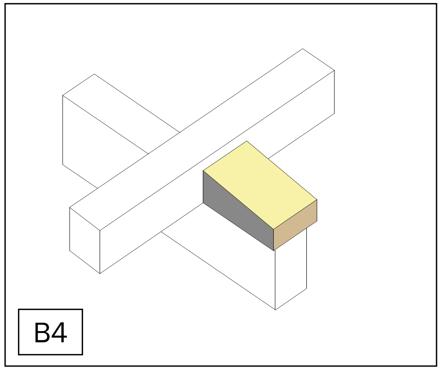
This is particularly important for elements which might get wet, such as the base plate and the posts.

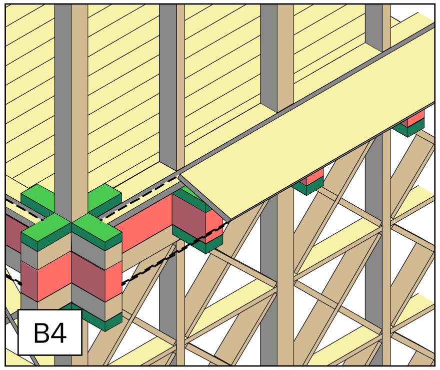
A: Selection:

1. Choose tree species known for their resistance to insects and fungi (e.g. cedar, blue pine, larch, oak, chesnut, etc.).
2. For the most exposed timber elements, such as the base plate, choose the most resistant timber.
3. Make sure that for these parts the beams are cut out of the heartwood. *Heartwood* is the inner dead part of a tree and is much more resistant to decay than the outer *sapwood*.
4. Cut trees in winter when growth has stopped.
5. Use well seasoned timber. Freshly cut (green) timber will shrink and twist over time.
6. Sapwood can be used for internal timber that remains dry.

B: Protection:

1. Timber must not be in contact with earth or water.
2. It's better to place the base plates on an irregular surface so that water can run off or evaporate. If it is placed on a perfect concrete surface, put ½" hardwood spacers under the base plate to keep it away from the concrete surface.





C2

Borates - water solution

For 10 litres of solution, mix the following ingredients:

1. Mix 1 kg (2.4 lbs) of borax with 0.7 kg (1.6 lbs) of boric acid.
2. Add this mixture to 7.5 litres of water in an oversized container (e.g. 12 litres)
3. Stir until the powder has dissolved.
4. Add a final 2.5 litres of water and stir.
5. Use this mixture within 24 hours. Apply with a brush on all timber surfaces.
6. This amount will be sufficient for 500 sqft of wood surface.

C2

Borates - Propylene glycol solution

For 10 litres of solution, mix the following ingredients:

1. Use 5 litres of PROPYLENE GLYCOL (Car anti-freeze liquid). Do not use anti-freeze containing any amount of ETHYLENE GLYCOL. Ethylene glycol is toxic and can be fatal.
2. Heat until gentle boiling. This should be done outside or in a well ventilated room.
3. Add 2.5 kg (5.5 lbs) of borax and stir.
4. Add 2 kg (4.5 lbs) of boric acid and stir until everything is disolved.
5. Add 5 litres of water .
6. Use within 24 hours.
7. This solution is toxic to plants. Cover plants, root systems and surrounding soil with plastic to avoid contamination.
8. This amount will be sufficient for 500 sqft of timber surface.

3. Protect the base plate with a CGI sheet or a weatherboard which should be painted or treated with oil.
4. Do also protect any joist ends sticking out of the walls. This can be done with slightly bigger blocking pads or a weatherboard.
5. Painting of timber elements will also help to protect it.

C: Treatment:

Wood can be treated by applying a water repellent or by using a chemical which will kill fungi and repell insects.

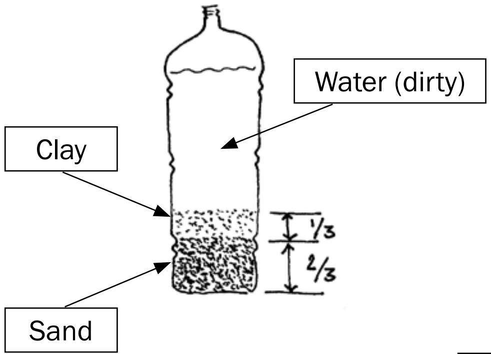
1. Apply old engine oil to all timber parts exposed to rain. Oil treated timber can't be painted afterwards.
2. Better: Apply a proper wood preservative. It can be prepared according to the recipes given above.
3. The wood preservative solutions proposed here are NOT water-resistant and will be washed out if the treated timber is exposed to rain. An additional protection against water is therefore needed.
4. Apply these liquids with a brush on every face of the timber. Timber must be cleaned previously. Apply twice on the front parts of the beams as these do absorb more.
5. Use gloves and protect plants and soil during treatment.
6. Apply treatment before construction!
7. If borates solutions are used, timber can be painted for further protection.

Soil:

1. Soil must not contain any vegetable earth.
2. Make sure that the soil containes no particles bigger than 1/16” (2mm).
3. Mud for plastering should be a mix of 1 part of pure clay and 2 to 3 parts of sand.
4. Sand content of soil can be checked by diluting some mud in a transparent bottle and let it settle for one day. Then measure the height of the various deposits (see illustration to the right).
5. To know the best mix with local materials make a test:
    - Prepare small batches of mixtures with slightly different proportions and apply a ½” layer on a small test surface.
    - Let it dry for several days.
    - Choose the sample with less or no cracks, with a good adherence and no swelling.

Water:

1. Don’t use too much water. Too much water makes the plaster crack while drying.
2. For mud plaster, the use of rain water is preferable.
3. In some parts of the world horse urine is used instead of water. The plaster will become much stronger.



Fibres:

1. Fibres are an important ingredient to improve plaster. They act as an armature, similar to the steel bars in reinforced concrete.
2. You may use vegetable fibres like straw or pine needles, but also animal hair.
3. Usual proportion of fibres is 1-2 lbs per cubic foot (20-30 kg/m3)
4. Fibres are generally cut to a length of 1 to 2 inches though pine needles may also be used at their full length.

Mud plaster is composed of:

- Soil,
- Water,
- Fibres,
- Stabilisation (recommended)

For good adherence, plaster should always be applied on well cleaned stone and timber surfaces or on a mesh (see page 19).

Cut-back (definition)

Cut-back is a combination of asphalt cement and a petroleum solvent. It can be used at normal temperatures. When the solvent evaporates, an asphalt coating is left on the treated surface.
The use of cutback asphalts is decreasing because of environmental concerns (volatile chemicals that evaporate into the atmosphere).

Stabilisation:

Stabilisation of mud plaster increases its resistance. Depending on the type of soil, you should use different stabilisation methods:

Cement based stabilisation:

1. To be used for soil with a very high sand content.
2. Proportion 2% (minimal stabilisation) to 15% (full stabilisation)
3. You may add 2% to 4% of bitumen or cut-back to the mix to increase its water resistance.

Lime based stabilisation:

1. To be used for soil with a high clay content.
2. Proportion: at least 10% of lime.
3. The addition of animal urine or excrements can greatly increase the quality of the plaster. However, the strong smell of ammonia during mixing might disturb.

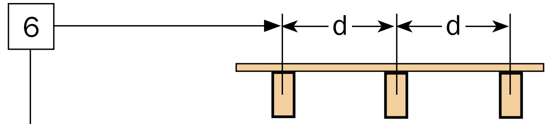
Cut-back based stabilisation

1. For soil which contains neither too much sand nor clay and has been prepared in a powder form.
2. Proportion: 2% to 6% of cut-back.
3. You might have to warm the cut-back to make it more liquid (max. 100°C).
4. Add cut-back only 2 to 3 hours before use.

Table 1: Snow depth and snow weight

Snow depth in ft	*Snow weight (snow load) in psf* 20 psf	30 psf	40 psf	50 psf	60 psf
Fresh snow	4 ft	6 ft	8 ft	10 ft	12 ft
Compact snow	2 ft	3 ft	4 ft	5 ft	6 ft

1 2 3



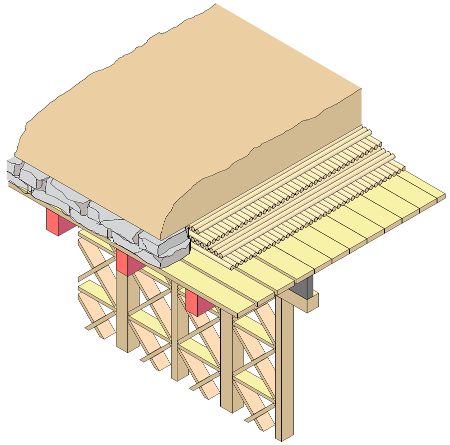


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Table 2: Flat roof with mud cover

Snow load	Distance btw beams d	Span in ft 5'	6'	7'	8'	9'	10'	11'	12'	13'	14'	15'	16'	17'	18'
20 psf	2'	3x5	3x6	4x6	4x7	5x7	5x8	5x8	5x9	6x10	6x10	6x11	7x11	7x11	7x11
	2'-6"	3x6	4x6	4x7	5x7	5x8	5x9	5x9	6x9	6x11	7x11	7x11	7x11	7x12	7x12
	3'	3x6	4x7	4x7	5x8	5x9	6x9	6x10	6x10	7x11	7x11	7x12	7x12	7x13	7x13
30 psf	2'	3x5	3x6	4x6	4x7	5x7	5x8	5x9	5x9	6x10	6x11	6x11	7X11	7x11	7x12
	2'-6"	3x6	4x6	4x7	5x7	5x8	5x9	6x9	6x10	6x11	7x11	7X11	7X12	7X12	7X12
	3'	3X6	4X7	4X7	5X8	5X9	6X9	6X10	6X11	7X11	7X11	7X12	7X12	7X13	7X14
40 psf	2'	3x5	3x6	4x6	4x7	5x7	5x8	5x9	6X9	6x10	6x11	7x11	7x11	7X11	7x12
	2'-6"	3x6	4x6	4x7	5x7	5x8	5x9	6x9	6X10	7x11	7x11	7x11	7x12	7X12	7x13
	3'	4x6	4x7	4x7	5x8	5x9	6x9	6x10	6X11	7x11	7x12	7x12	7x13	7X13	7X14
50 psf	2'	3X5	3X6	4X7	4X7	5X7	5X8	5X9	6X9	6x11	6X11	7X11	7X11	7X11	7X12
	2'-6"	3X6	4X6	4X7	5X8	5X8	5X9	6X9	6X10	7X11	7X11	7X12	7X12	7X12	7X13
	3'	4X6	4X7	4X7	5X8	5X9	6x10	6x10	6x11	7x11	7x12	7x13	7x13	7x14	8x14
60 psf	2'	3x6	4x6	4x7	5x7	5x8	5x8	5x9	6x9	6x11	7x11	7x11	7x11	7x12	7x12
	2'-6"	3x6	4x7	4x7	5x8	5x9	6x9	6x10	6x11	7x11	7x11	7x12	7x12	7x13	7x13
	3'	4x6	4x7	4x7	5x9	6x9	6x10	6x11	7x11	7x12	7x12	7x12	7x13	7x14	8x14
70 psf	2'	3x6	4x6	4x7	5x7	5x8	5x9	6x9	6x10	6x11	7x11	7x11	7x11	7x12	7x12
	2'-6"	3x6	4x7	4x7	5x8	5x9	6x9	6x10	6x11	7x11	7x11	7x12	7x12	7X13	7x14
	3'	4x6	4x7	5x7	5x9	6x9	6x10	6x11	7x11	7x12	7x12	7x13	7x14	7x14	8x14

1. Enquire for the maximum depth of snow in your area (measured on a rather flat and open piece of land, away from houses). However, don’t take into account exceptional years which only happen once or twice in a life time.
2. In table 1 choose the row corresponding to the type of snow:
   - if measured immediately after snowfall, use ‘Fresh Snow’.
   - if measured few hourse to few days after snow fall, use ‘Compact Snow’.
3. Look up the weight of the snow in table 1.
4. Go to the table with the roof slope that corresponds best to your roof:
   - Table 2 for flat roofs,
   - Tables 3, 4 and 5 for pitched roofs.
5. Select the row corresponding to your snow load.
6. Select the row corresponding to the distance between your roof rafters or joists.
7. Select the column with the length of the joist or rafter you need.
8. Pick the corresponding profile for your beams or rafters.

Roof slope: 1 in 2

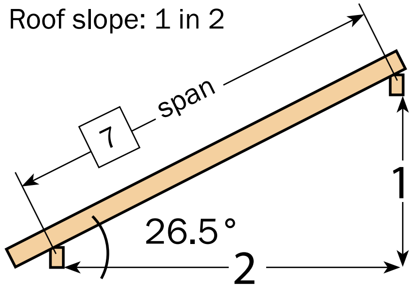

Table 3: Timber profiles for 1:2 roof slopes (26.5°)

Snow load	Distance btw beams d	Span in ft 5'	6'	7'	8'	9'	10'	11'	12'	13'	14'	15'	16'	17'	18'
20 psf	2'	2x4	2x4	2x4	2x4	2x4	2x4	3x4	3x4	3x5	3x5	3x6	3x6	3x6	4x6
	2'-6"	2x4	2x4	2x4	2x4	2x4	3x4	3x4	3x5	3x6	3x6	3x6	4x6	4x6	4x7
	3'	2x4	2x4	2x4	2x4	3x4	3x4	3x5	3x5	3x6	4x6	4x6	4x6	4x7	4x7
	4'	2x4	2x4	2x4	3x4	3x5	3x5	3x6	3x6	4x6	4x7	4x7	4x7	4x7	4x7
	5'	2x4	2x4	2x4	3x5	3x5	3x6	3x6	4x7	4x7	4x7	4x7	5x7	5x7	5x8
30 psf	2'	2x4	2x4	2x4	2x4	2x4	3x4	3x5	3x5	3x6	3x6	3x6	4x6	4x6	4x7
	2'-6"	2x4	2x4	2x4	2x4	3x4	3x5	3x5	3x6	3x6	4x6	4x6	4x7	4x7	4x7
	3'	2x4	2x4	2x4	3x4	3x5	3x5	3x6	3x6	4x6	4x7	4x7	4x7	4x7	4x7
	4'	2x4	2x4	3x4	3x5	3x6	3x6	4x6	4x6	4x7	4x7	4x7	5x7	5x7	5x8
	5'	2x4	2x4	3x4	3x6	3x6	4x6	4x7	4x7	4x7	5x7	5x8	5x8	5x9	5x9
40 psf	2'	2x4	2x4	2x4	3x4	3x4	3x5	3x5	3x6	3x6	4x6	4x6	4x7	4x7	4x7
	2'-6"	2x4	2x4	2x4	3x4	3x5	3x5	3x6	3x6	4x6	4x7	4x7	4x7	4x7	5x7
	3'	2x4	2x4	2x4	3x5	3x5	3x6	3x6	4x6	4x7	4x7	4x7	5x7	5x7	5x8
	4'	2x4	2x4	3x4	3x6	3x6	4x6	4x7	4x7	4x7	5x7	5x8	5x8	5x9	5x9
	5'	2x4	3x4	3x5	3x6	4x6	4x7	4x7	5x7	5x7	5x8	5x8	5x9	6x9	6x9
50 psf	2'	2x4	2x4	2x4	3x4	3x5	3x5	3x6	3x6	4x6	4x7	4x7	4x7	4x7	4x7
	2'-6"	2x4	2x4	2x4	3x5	3x5	3x6	3x6	4x6	4x7	4x7	4x7	5x7	5x7	5x8
	3'	2x4	2x4	3x4	3x5	3x6	3x6	4x6	4x7	4x7	4x7	5x7	5x8	5x8	5x8
	4'	2x4	3x4	3x5	3x6	4x6	4x7	4x7	4x7	5x7	5x8	5x8	5x9	5x9	6x9
	5'	3x4	3x5	3x6	4x6	4x7	4x7	4x7	5x7	5x8	5x9	6x9	6x9	6x10	6x10
60 psf	2'	2x4	2x4	2x4	3x5	3x5	3x6	3x6	4x6	4x7	4x7	4x7	4x7	5x7	5x7
	2'-6"	2x4	3x4	3x4	3x5	3x6	3x6	4x6	4x7	4x7	4x7	5x7	5x7	5x8	5x8
	3'	2x4	3x4	3x5	3x6	3x6	4x6	4x7	4x7	5x7	5x7	5x8	5x8	5x9	5x9
	4'	3x4	3x5	3x5	4x6	4x7	4x7	4x7	5x7	5x8	5x8	5x9	6x9	6x9	6x10
	5'	3x4	3x5	3x6	4x7	4x7	4x7	5x7	5x8	5x8	6x9	6x10	6x10	6x11	6x11

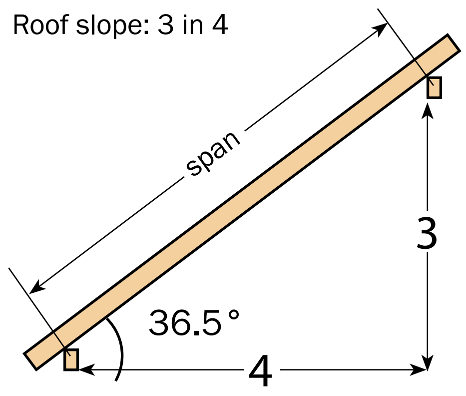

Table 4: Timber profiles for 3:4 roof slopes (36.5°)

Snow load	Distance btw beams d	Span in ft 5'	6'	7'	8'	9'	10'	11'	12'	13'	14'	15'	16'	17'	18'
20 psf	2'	2x4	2x4	2x4	2x4	2x4	2x4	2x4	2x4	3x4	3x5	3x5	3x5	3x6	3x6
	2'-6"	2x4	2x4	2x4	2x4	2x4	2x4	3x4	3x4	3x5	3x5	3x6	3x6	3x6	4x6
	3'	2x4	2x4	2x4	2x4	2x4	3x4	3x4	3x5	3x5	3x6	3x6	4x6	4x6	4x6
	4'	2x4	2x4	2x4	2x4	3x4	3x5	3x5	3x5	3x6	4x6	4x6	4x7	4x7	4x7
	5'	2x4	2x4	2x4	3x4	3x5	3x5	3x6	3x6	4x6	4x7	4x7	4x7	4x7	4x7
30 psf	2'	2x4	2x4	2x4	2x4	2x4	2x4	3x4	3x4	3x5	3x5	3x6	3x6	3x6	4x6
	2'-6"	2x4	2x4	2x4	2x4	2x4	3x4	3x5	3x5	3x6	3x6	3x6	4x6	4x6	4x7
	3'	2x4	2x4	2x4	2x4	3x4	3x5	3x5	3x5	3x6	4x6	4x6	4x7	4x7	4x7
	4'	2x4	2x4	2x4	3x4	3x5	3x5	3x6	3x6	4x7	4x7	4x7	4x7	4x7	5x7
	5'	2x4	2x4	3x4	3x5	3x6	3x6	4x6	4x6	4x7	4x7	4x7	5x7	5x7	5x8
40 psf	2'	2x4	2x4	2x4	2x4	2x4	3x4	3x5	3x5	3x6	3x6	3x6	4x6	4x6	4x7
	2'-6"	2x4	2x4	2x4	3x4	3x4	3x5	3x5	3x6	3x6	4x6	4x6	4x7	4x7	4x7
	3'	2x4	2x4	2x4	3x4	3x5	3x5	3x6	3x6	4x6	4x7	4x7	4x7	4x7	4x7
	4'	2x4	2x4	3x4	3x5	3x6	3x6	4x6	4x6	4x7	4x7	4x7	5x7	5x7	5x8
	5'	2x4	2x4	3x4	3x6	3x6	4x6	4x7	4x7	4x7	5x7	5x7	5x8	5x9	5x9
50 psf	2'	2x4	2x4	2x4	2x4	3x4	3x5	3x5	3x5	3x6	4x6	4x6	4x7	4x7	4x7
	2'-6"	2x4	2x4	2x4	3x4	3x5	3x5	3x6	3x6	4x6	4x7	4x7	4x7	4x7	4x7
	3'	2x4	2x4	2x4	3x5	3x5	3x6	3x6	4x6	4x7	4x7	4x7	4x7	5x7	5x7
	4'	2x4	2x4	3x4	3x6	3x6	4x6	4x7	4x7	4x7	5x7	5x7	5x8	5x8	5x9
	5'	2x4	3x4	3x5	3x6	4x6	4x7	4x7	4x7	5x7	5x8	5x8	5x9	5x9	6x9
60 psf	2'	2x4	2x4	2x4	3x4	3x5	3x5	3x5	3x6	4x6	4x6	4x7	4x7	4x7	4x7
	2'-6"	2x4	2x4	2x4	3x5	3x5	3x6	3x6	4x6	4x7	4x7	4x7	4x7	5x7	5x7
	3'	2x4	2x4	3x4	3x5	3x6	3x6	4x6	4x7	4x7	4x7	5x7	5x7	5x8	5x8
	4'	2x4	3x4	3x5	3x6	4x6	4x6	4x7	4x7	5x7	5x8	5x8	5x9	5x9	6x9
	5'	3x4	3x5	3x5	4x6	4x7	4x7	4x7	5x7	5x8	5x9	5x9	6x9	6x9	6x10

Roof slope: 1 in 1

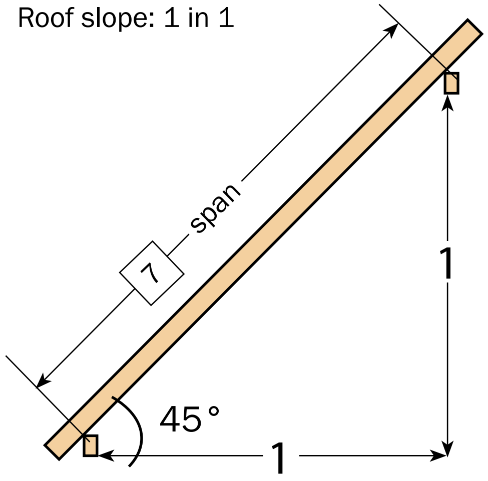

Table 5: Timber profiles for 1:1 roof slopes (45 °)

Snow load	Distance btw beams d	Span in ft 5'	6'	7'	8'	9'	10'	11'	12'	13'	14'	15'	16'	17'	18'
20 psf	2'	2x4	2x4	2x4	2x4	2x4	2x4	2x4	2x4	2x4	3x4	3x4	3x5	3x5	3x5
	2'-6"	2x4	2x4	2x4	2x4	2x4	2x4	2x4	2x4	3x4	3x5	3x5	3x5	3x5	3x6
	3'	2x4	2x4	2x4	2x4	2x4	2x4	2x4	3x4	3x5	3x5	3x5	3x6	3x6	3x6
	4'	2x4	2x4	2x4	2x4	2x4	3x4	3x4	3x5	3x6	3x6	3x6	4x6	4x6	4x7
	5'	2x4	2x4	2x4	2x4	3x4	3x5	3x5	3x5	3x6	4x6	4x6	4x7	4x7	4x7
30 psf	2'	2x4	2x4	2x4	2x4	2x4	2x4	2x4	2x4	3x4	3x5	3x5	3x5	3x6	3x6
	2'-6"	2x4	2x4	2x4	2x4	2x4	2x4	3x4	3x4	3x5	3x5	3x6	3x6	3x6	4x6
	3'	2x4	2x4	2x4	2x4	2x4	3x4	3x4	3x5	3x6	3x6	3x6	4x6	4x6	4x7
	4'	2x4	2x4	2x4	3x4	3x4	3x5	3x5	3x6	3x6	4x6	4x6	4x7	4x7	4x7
	5'	2x4	2x4	2x4	3x4	3x5	3x5	3x6	3x6	4x6	4x7	4x7	4x7	4x7	5x7
40 psf	2'	2x4	2x4	2x4	2x4	2x4	2x4	3x4	3x4	3x5	3x5	3x6	3x6	3x6	4x6
	2'-6"	2x4	2x4	2x4	2x4	2x4	3x4	3x4	3x5	3x6	3x6	3x6	4x6	4x6	4x7
	3'	2x4	2x4	2x4	2x4	3x4	3x5	3x5	3x5	3x6	4x6	4x6	4x7	4x7	4x7
	4'	2x4	2x4	2x4	3x4	3x5	3x5	3x6	3x6	4x6	4x7	4x7	4x7	4x7	5x7
	5'	2x4	2x4	3x4	3x5	3x5	3x6	4x6	4x6	4x7	4x7	4x7	5x7	5x7	5x8
50 psf	2'	2x4	2x4	2x4	2x4	2x4	3x4	3x4	3x5	3x6	3x6	3x6	4x6	4x6	4x7
	2'-6"	2x4	2x4	2x4	2x4	3x4	3x5	3x5	3x5	3x6	4x6	4x6	4x7	4x7	4x7
	3'	2x4	2x4	2x4	3x4	3x5	3x5	3x5	3x6	4x6	4x6	4x7	4x7	4x7	4x7
	4'	2x4	2x4	2x4	3x5	3x5	3x6	3x6	4x6	4x7	4x7	4x7	5x7	5x7	5x8
	5'	2x4	2x4	3x4	3x5	3x6	4x6	4x6	4x7	4x7	5x7	5x7	5x8	5x8	5x9
60 psf	2'	2x4	2x4	2x4	2x4	3x4	3x4	3x5	3x5	3x6	3x6	4x6	4x6	4x7	4x7
	2'-6"	2x4	2x4	2x4	3x4	3x4	3x5	3x5	3x6	4x6	4x6	4x7	4x7	4x7	4x7
	3'	2x4	2x4	2x4	3x4	3x5	3x5	3x6	3x6	4x7	4x7	4x7	4x7	4x7	5x7
	4'	2x4	2x4	3x4	3x5	3x6	3x6	4x6	4x7	4x7	4x7	5x7	5x7	5x8	5x8
	5'	2x4	3x4	3x5	3x6	4x6	4x6	4x7	4x7	5x7	5x7	5x8	5x8	5x9	6x9

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Graymont (?): *Benefits of Cement - Lime Mortar,* http://www.graymont.com/applications_benefits_cement_lime.shtml

Get further information on these websites

ERRA (Earthquake Reconstruction and Rehabilitation Authority) Pakistan: http://www.erra.pk/sectors/housing.asp

UN Habitat Pakistan: http://www.unhabitat.org.pk/newweb/Publications.htm, with all material published by UN Habitat and ERRA for the reconstruction after recent earthquakes in Pakistan.

Traditional-is-Modern Net: Vernacular Architecture and Traditional Construction around the World, http://www.traditional-is-modern.net/LIBRARY.html, find in particular the original training slides used in Pakistan, under 'Basic Training on Dhajji Construction'

World Housing Encyclopedia: http://www.world-housing.net, see in particular: "Historic braced frame timber buildings with masonry infill ('Pombalino' building)", search under 'Portugal' or 'others'.

Half-Timbered Houses stock photos and images: http://www.fotosearch.com/photos-images/half-timbered-houses.html, an inspiring collection of images of a closely related building technique in Europe.

Home Improvement Books: http://chestofbooks.com/home-improvement, an amazing collection of old books on carpentry and woodworks from the beginning of the twentieth century, such as "Elementry Principles of Carpentry" by T. Tredgold.

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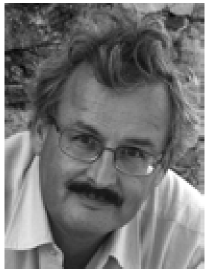

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