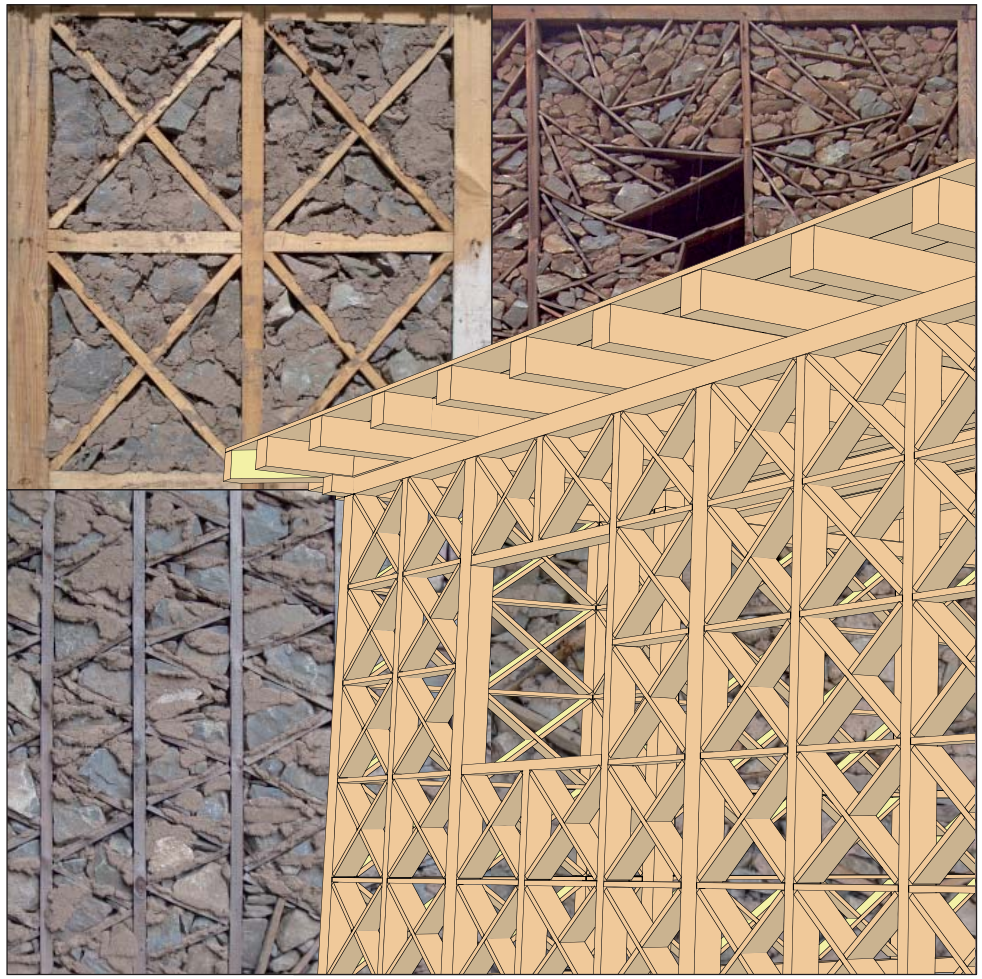
Tom Schacher and Qaisar Ali

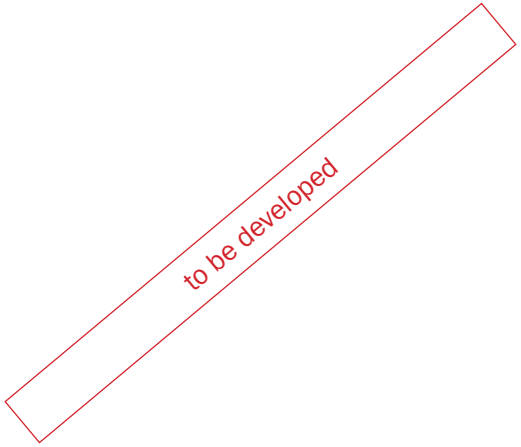


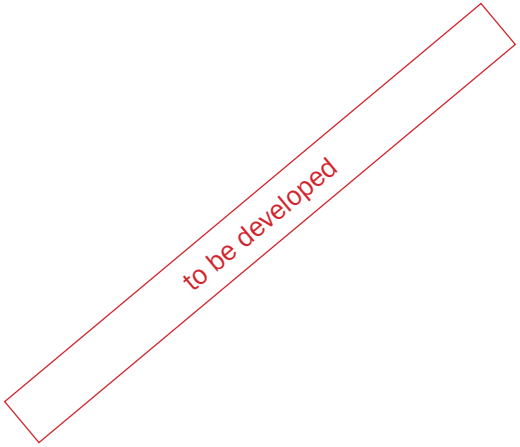
DHAJJI CONSTRUCTION

For one and two storey earthquake resistant houses

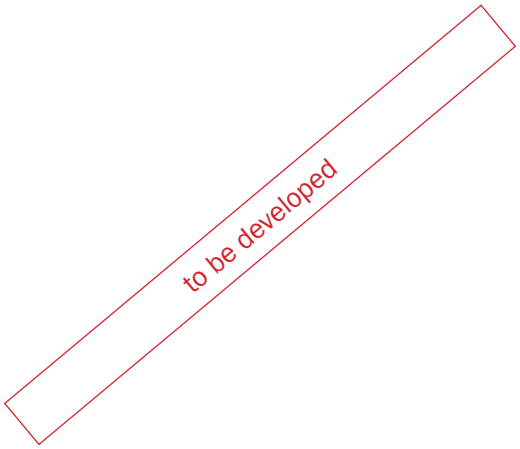
A guidebook for technicians and artisans

Content and layout: Arch. Tom Schacher
Lab research: Eng. Dr. Qaisar Ali
Illustrations: Arch. Beniamino Sartorio





PUBLISHER INFORMATION

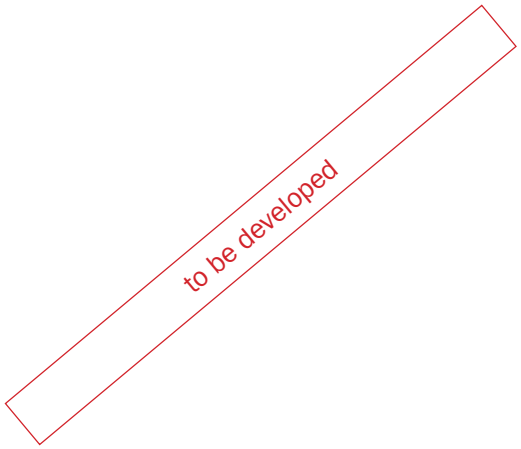


FOREWORD

Joint research project between
the University of Applied Sciences of Southern Switzerland (SUPSI) and
the University of Engineering and Technology Peshawar (UET-P) in Pakistan.

Collaboration with UN Habitat reconstruction programme in Pakistan and
ARUP in Dubai.

etc.



PREFACE

For their technical inputs:

Arch. Maggie Stephenson and her team of UN Habitat reconstruction programe in Pakistan for the feedback from the reconstruction programme in Kashmir and logistical support.

Eng. Kubilay Hicyilmaz of ARUP Dubai for the numerical modelling of dhajji structures.

Arch. Randolph Langenbach of Conservationtech for his valuable contributions and suggestions during our long email discussions.

Eng. Richard Hughes of ... for participating actively in our forum and sharing his experience with us.

For their logistical support:

UN Habitat reconstruction programme in Pakistan

Swiss Agency for Development and Cooperation office in Mansehra, Pakistan.

For their financial support:

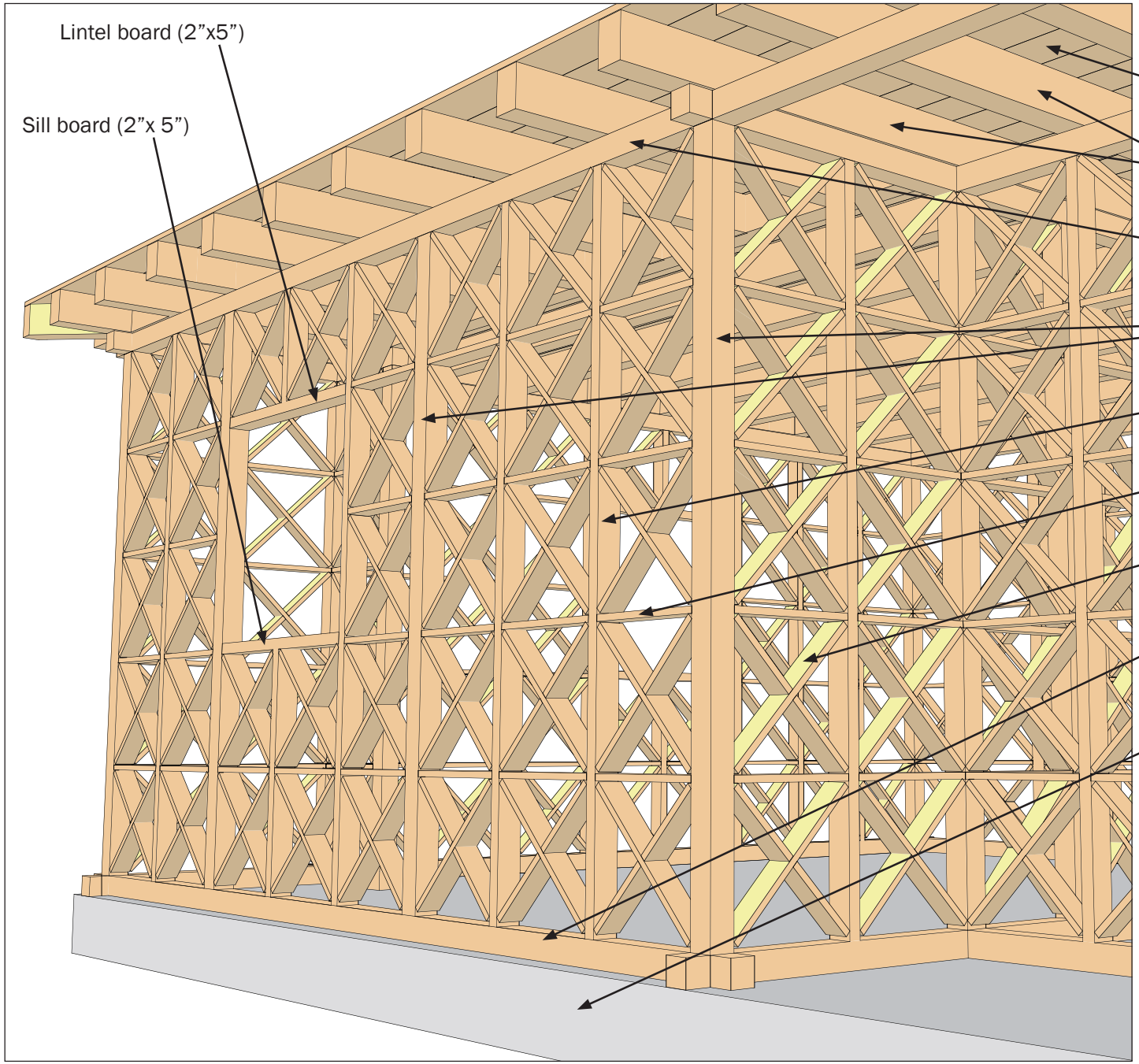
Swiss Agency for Development and Cooperation, through KFH research grant.

Philip Morris International

Preface cont'd: to be developed

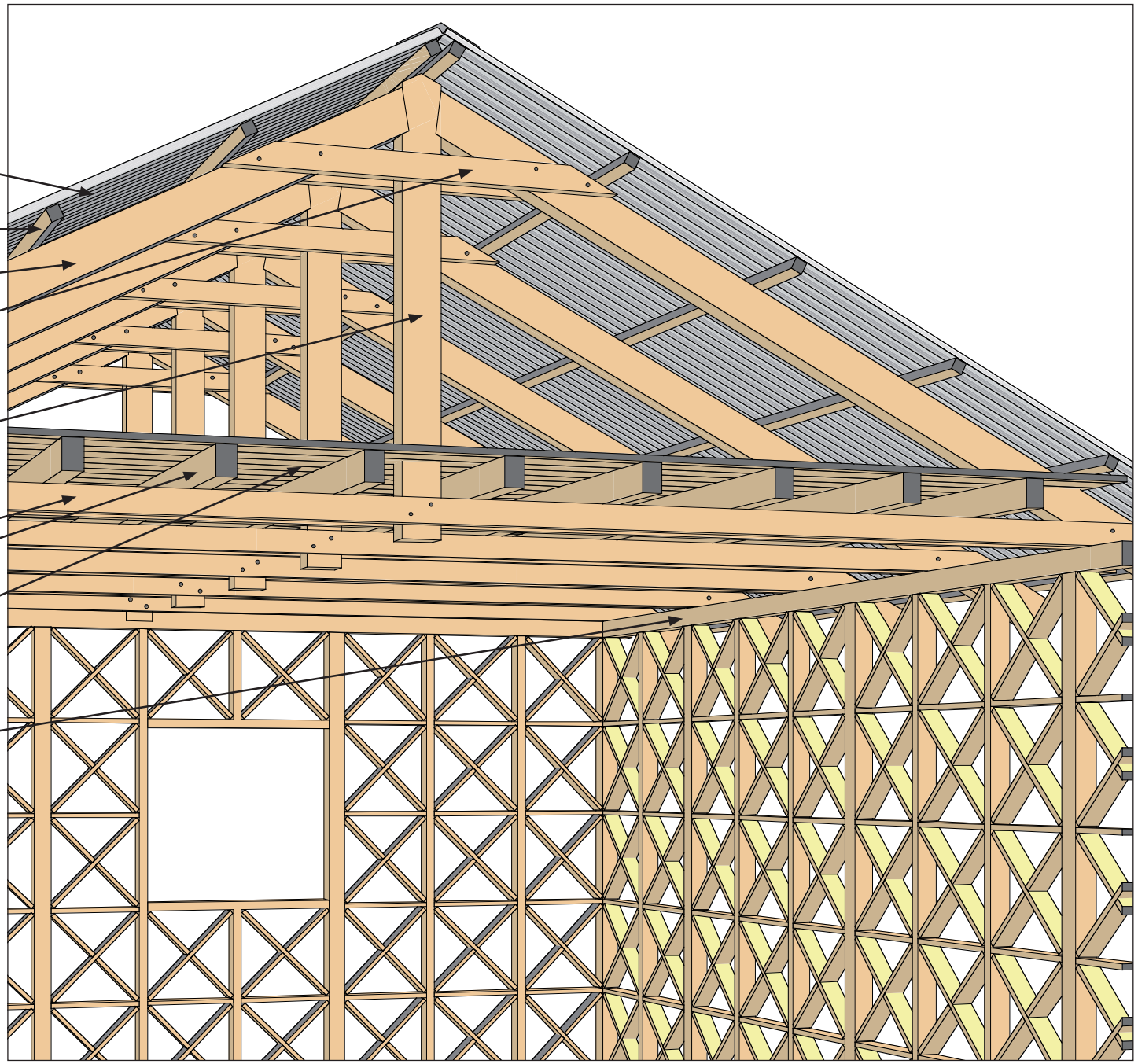
to be developed

ACKNOWLEDGEMENTS



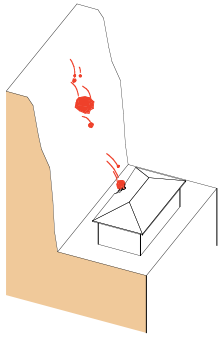
Note:

Posts are bigger than studs.

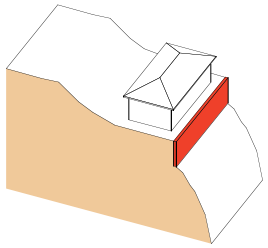


Note:

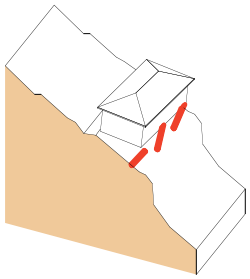
Beams are bigger than joists.



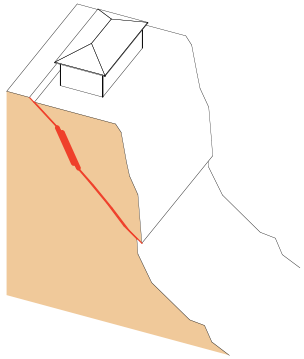
1



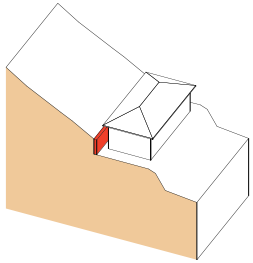
2



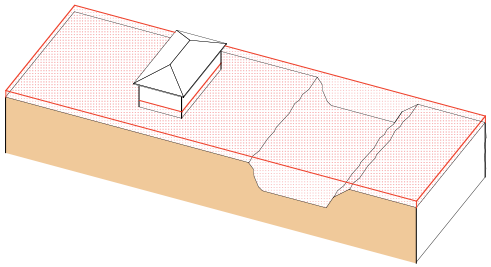
3



4



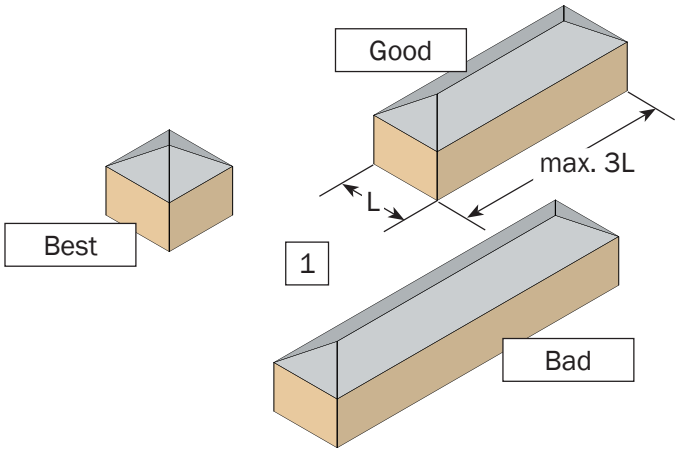
5

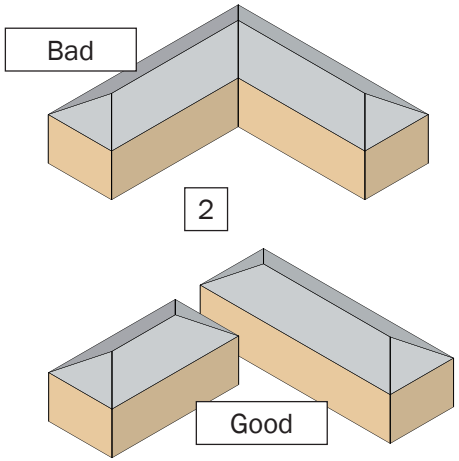


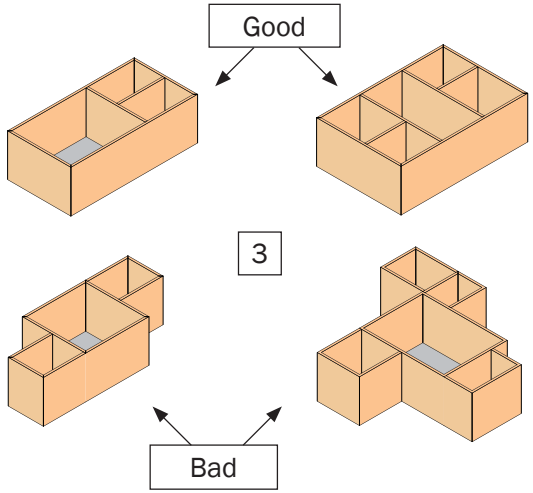
6

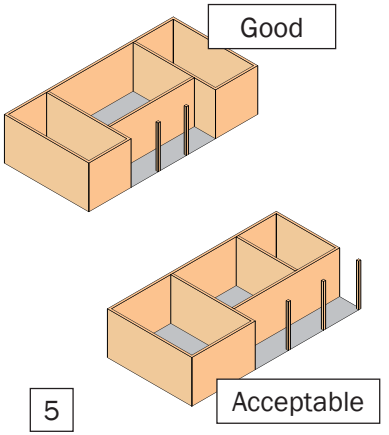
1. Don’t build next to a steep slope: rocks might fall on your house.
2. Don’t build on top of a retaining wall: it might break away during an earthquake.
3. Don’t build on stilts: they will fall over during an earhtquake.
4. Don’t build next to a precipice: it might break off.
5. Don’t build next to a retaining wall: snow will get trapped between the house and the wall.
6. Don’t build near a course of water: it might overflow and wash your house away.

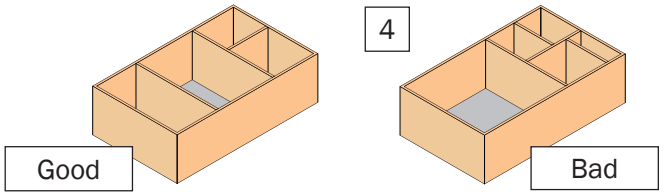
1. Proportions:
   A square form is best. Don't make buildings longer than
   3 times their width.
2. Shape:
   Keep the shape of the building simple. Subdivide it into single blocks if necessary.
3. Planning:
   Start with a simple volume and subdivide it into the rooms you need. Don't proceed the other way around, by sticking rooms together until you get the final form of the house.
4. Balance:
   To make sure that the house has the same strength all over, distribute the inner walls evenly. Don't place all small rooms on one side of the house, and all big rooms on the other.
5. External walls:
   The more external walls the building has, the stronger it is. Avoid having a 'shop window front' with only windows and doors but no walls as this side of the building will collapse quickly, leading to the collpse of the rest.

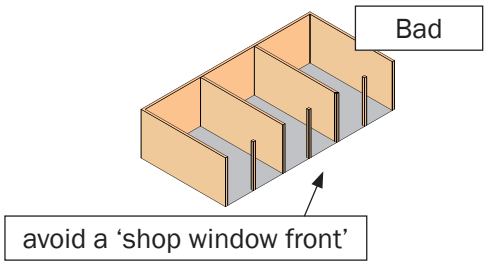


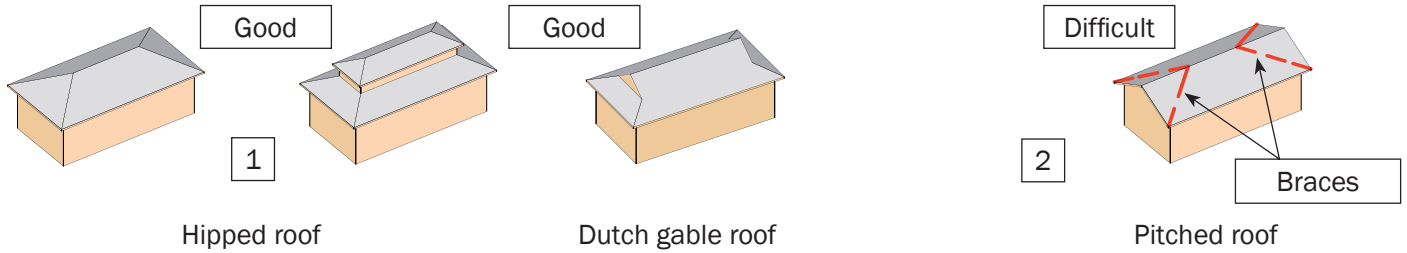


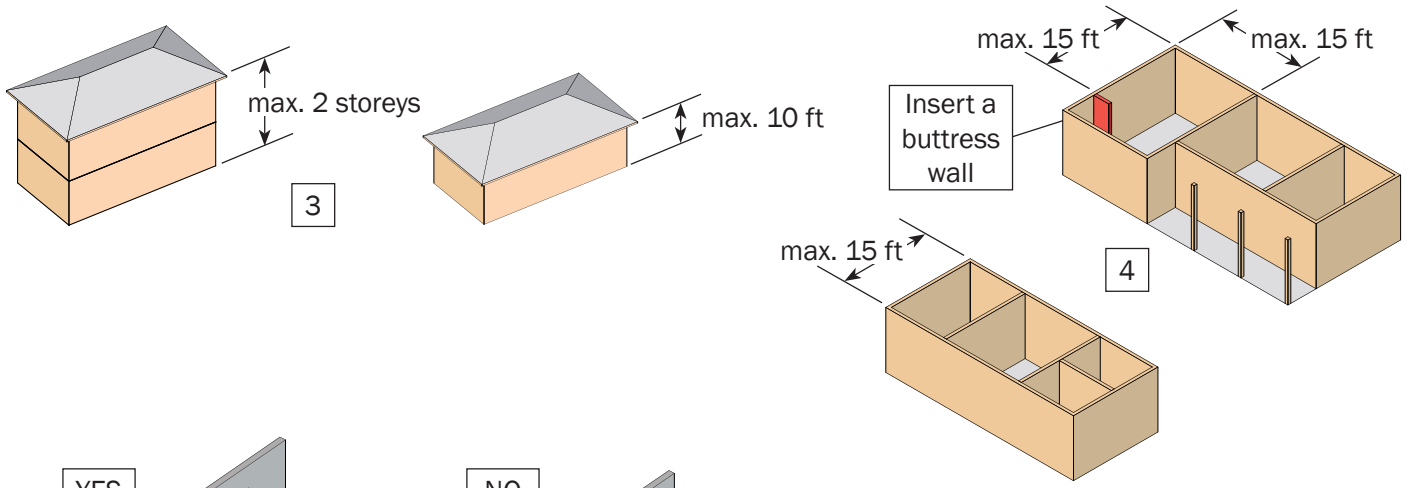


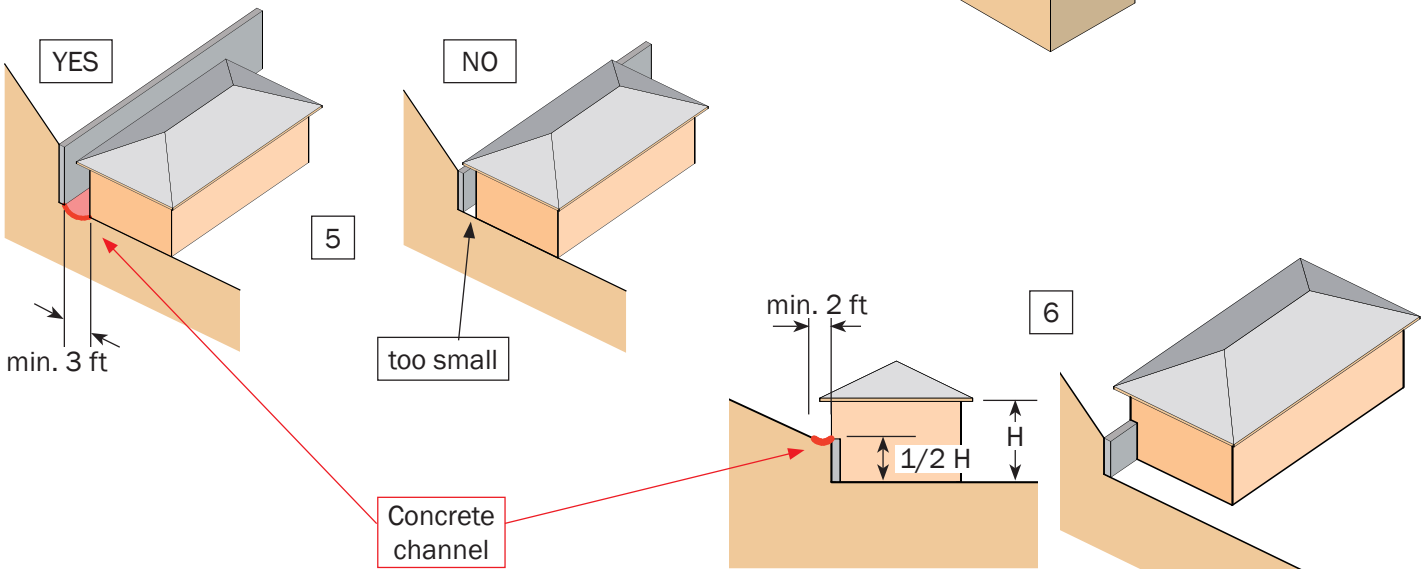






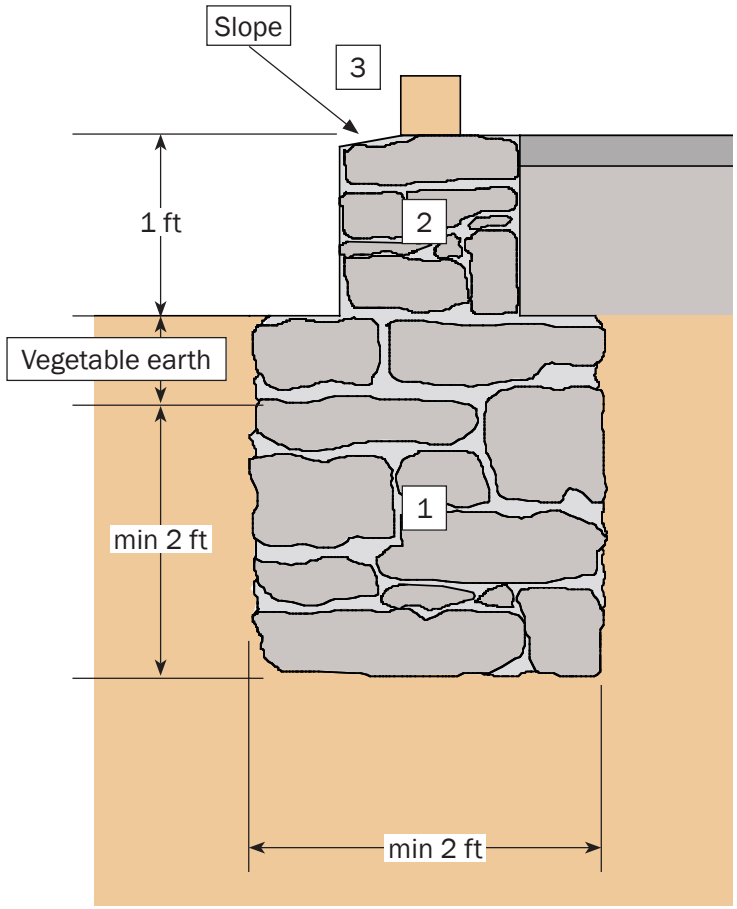


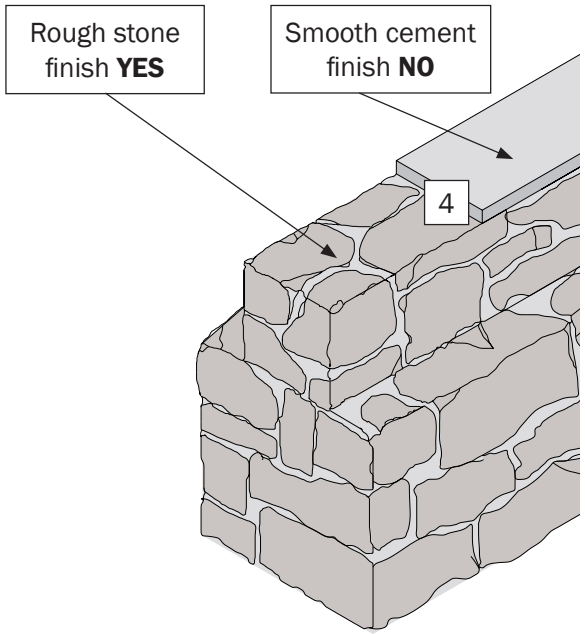


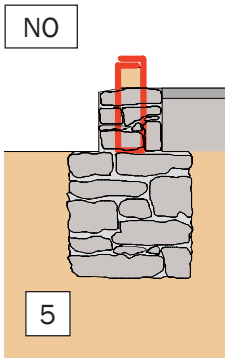


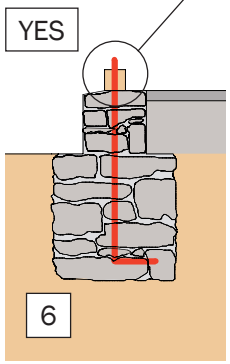
1. Roof types:
   Hipped roofs (4 slopes) are stronger than pitched roofs (only 2 slopes) because they can't fall over.
2. If a pitched roof is used, it must be braced inside.
3. Maximum heights:
   Height per storey: max 10 ft.
   Height of house: max 2 storeys
4. The length of a wall must not exceed 15 ft.
   If the wall is longer, it has to be braced in between.
5. Distance to retaining wall: at least 3 ft. The ground shall be covered with a concrete channel sloping towards the side(s) of the house to drain away rain water.
6. Retaining back wall:
   If there is limited space the retaining wall may be used as a backwall to the house. In this case however:
   • the retaining wall must be very well done and not be higher than half of the height of the wall.
   • a 2 ft wide apron in concrete in the form of a shallow channel must be added on top of the retaining wall. This apron shall have a slope towards the side(s) of the house.

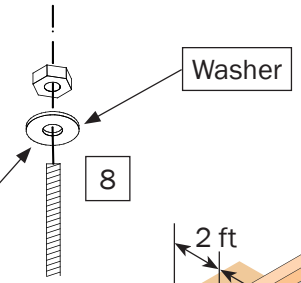
1. Depth and width:
   Foundations must be at least 2 ft deep in solid ground (except on rock) and at least 2 ft wide.
   For 2 storey buildings foundations should be at least 2'-6" wide.
2. Add a plinth of 1 ft on top of the foundation to keep the base plate away from the ground.
3. Finish the outer part of the top surface of the plinth with a slope towards outside to drain water away from the base plate.
4. 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. Place the anchor rods while preparing the foundation.
7. Keep the first anchor rods 2 ft from the corner and place the following less than 6 ft apart.
8. Use washers between timber and nuts!

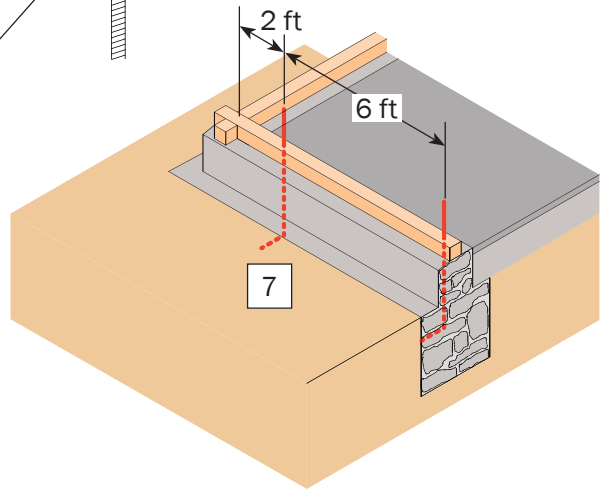


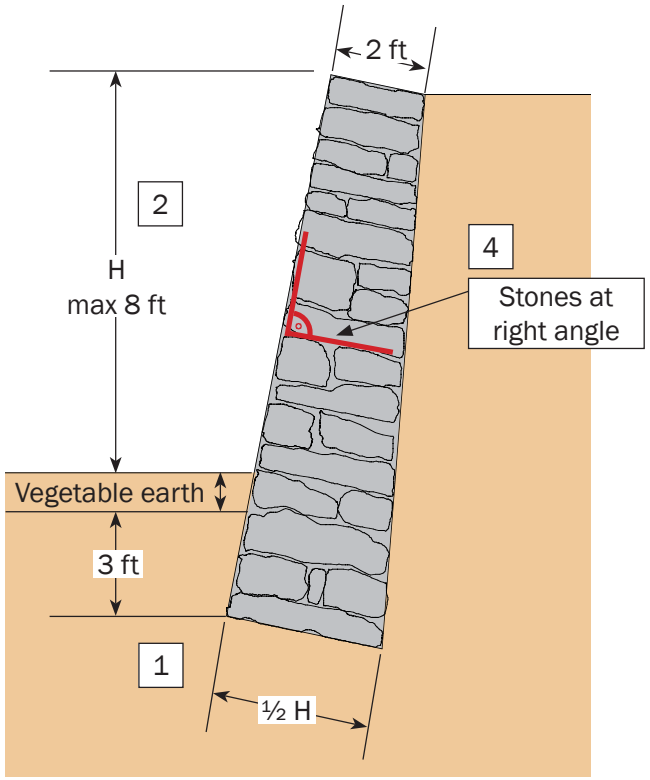


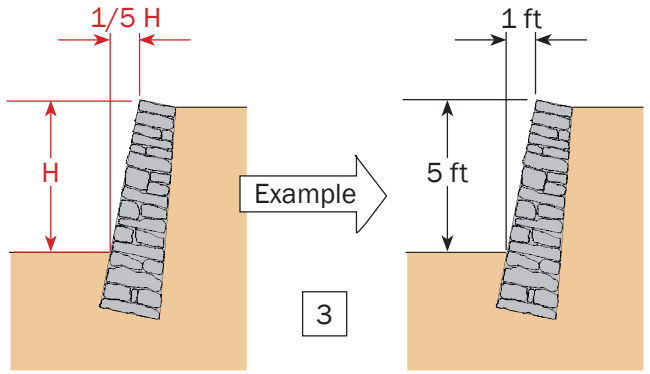




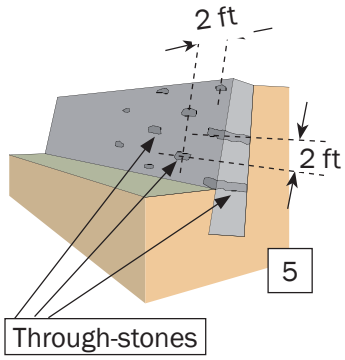


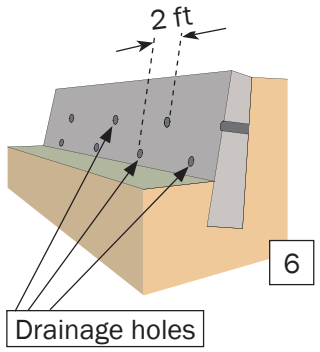


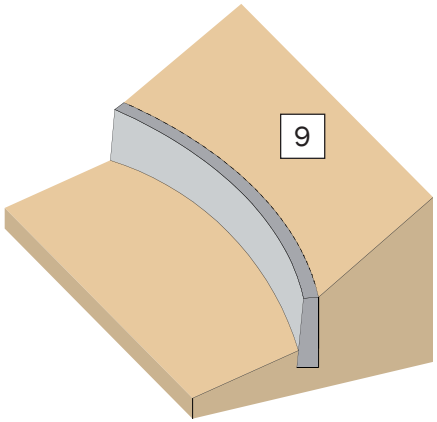


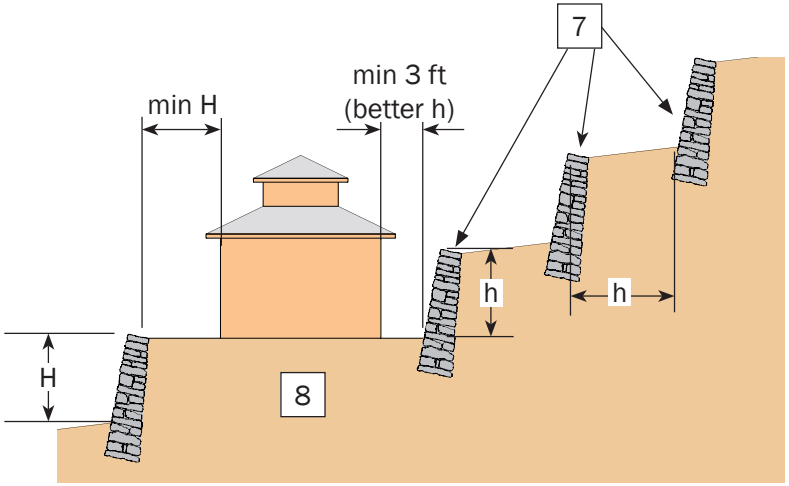


Slope of front 1/5



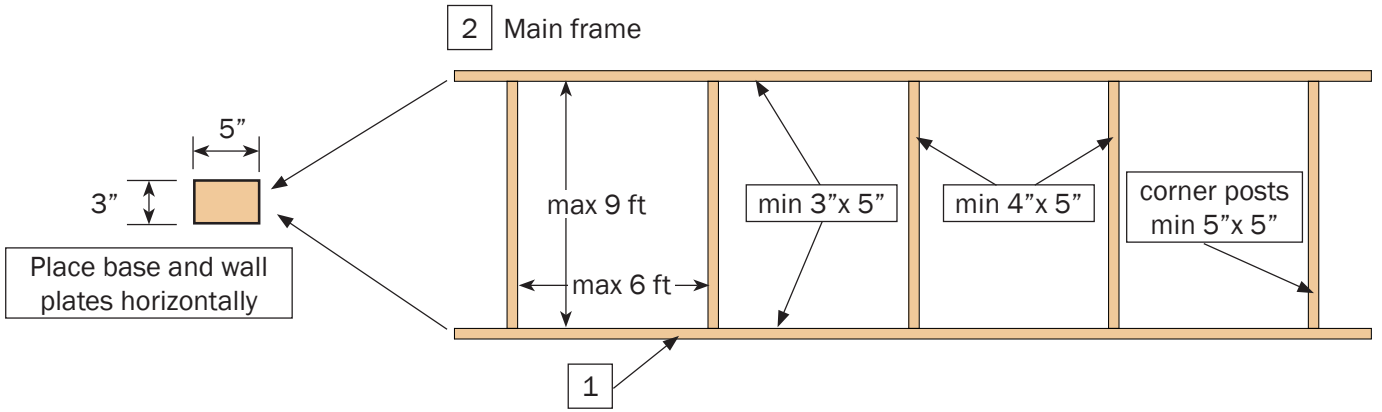


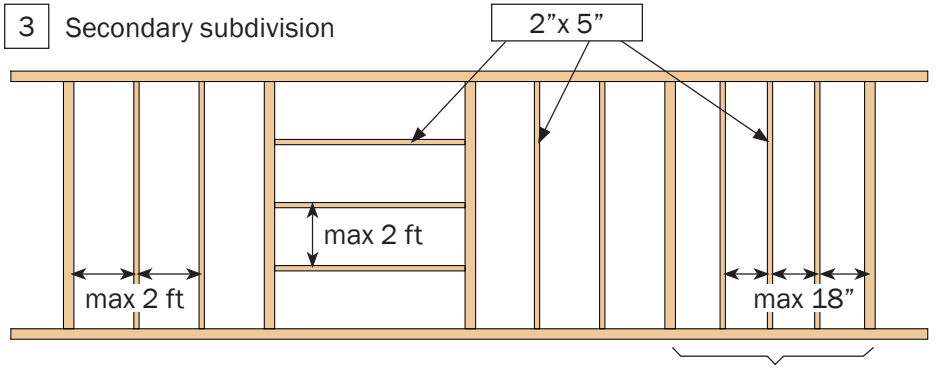


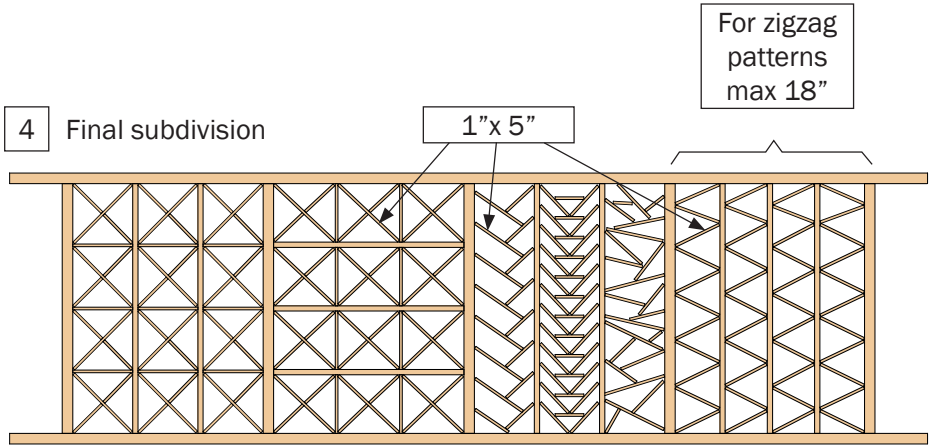


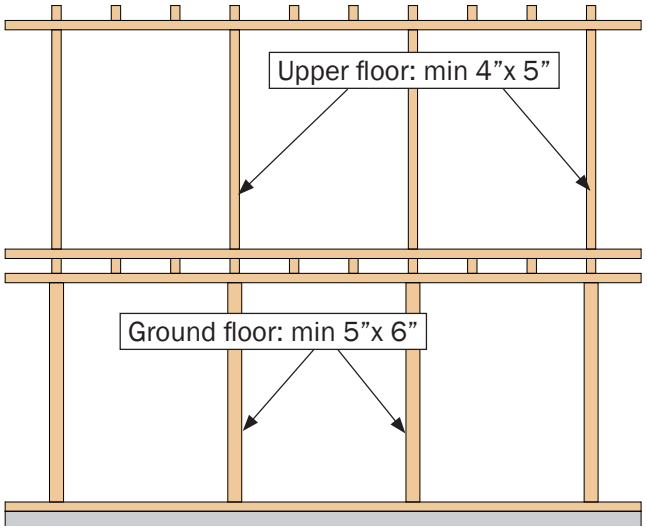
1. Start the retaining wall 3 ft below vegetable soil and prepare a basis half as wide as the finished wall is high.
2. Maximum heigth of a retaining wall should not exceed 8 ft. The lower the wall, the stronger it will be.
3. Incline the front of the wall in a ration 1:5. That is, for every 5 ft of height go 1 ft back.
4. Incline the stones in a right angle to the front.
5. Place as many ‘throuh-stones’ as possible, but at least every 2 ft of height and length.
6. 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 lower wall is high.
8. Keep the building away from the retaining walls.
   - On the lower side at least the same distance as the wall is high.
   - On the upper side at least 3 ft from the retaining wall.
9. Curved retaining walls are stronger.

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 suggestons on pages 24-25).
2. The posts of the main frame are made of timber pieces with a minimal cross section of 4”x 5” (5”x 5” for corners).
   The base and wall plates may be made with timber pieces of 3”x 5”, placed horizontally.
3. For the secondary subdivision use timber half as thick (e.g. 2”x 5”, or 2.5”x 5”).
4. For the final subdivision use 1” boards.
5. For two storey buildings the posts on the ground floor should have a minimum cross section of 5”x6”.

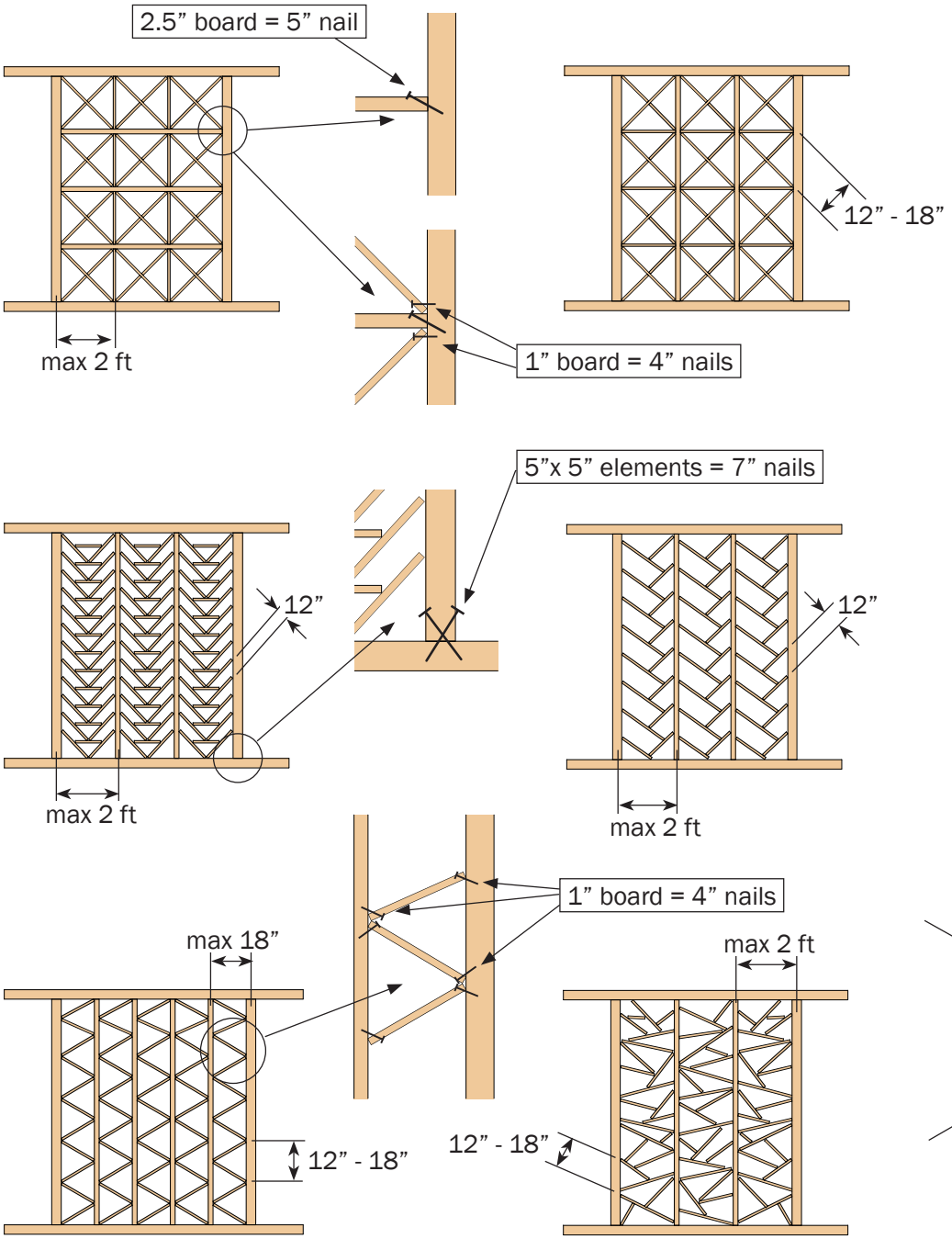




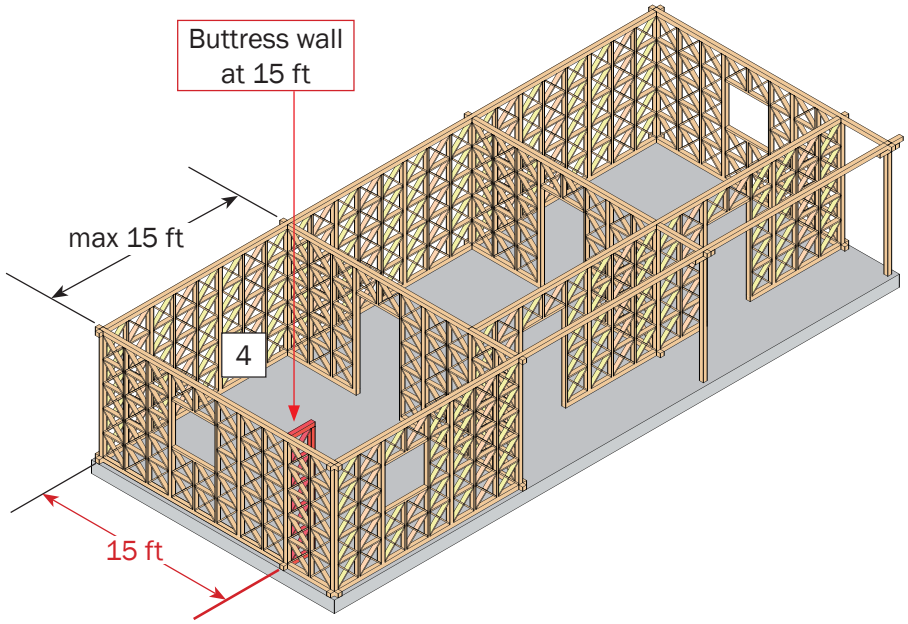




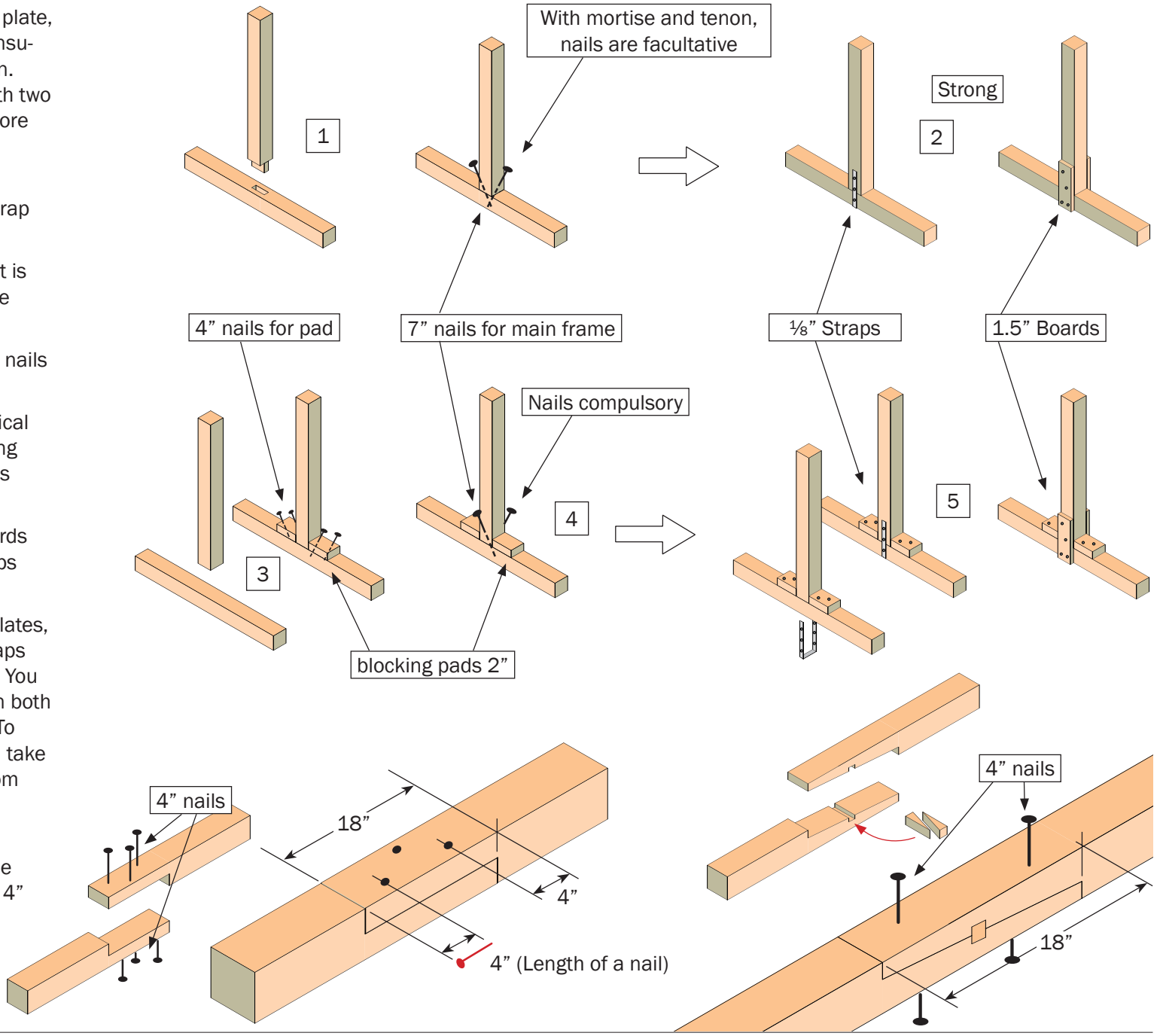
5

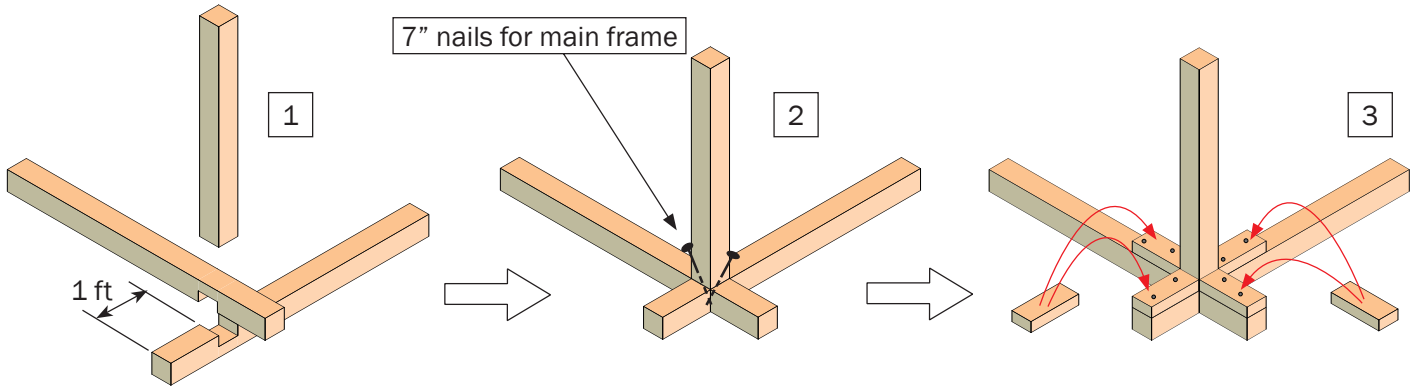


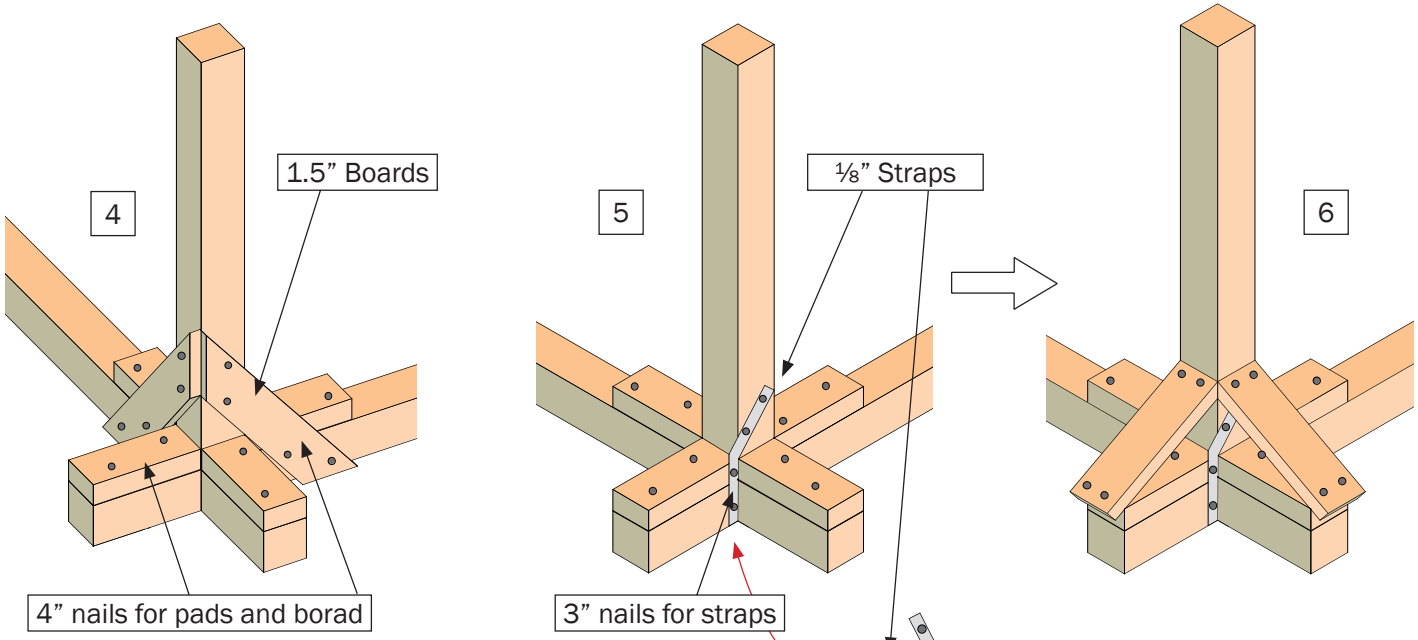
1. Walls can be subdivided in various ways. The strenght of the finished wall depends on the quality of connections and the number of bracing boards.
2. Distance between secondary studs is 2 ft except for the zigzag pattern where the distance is only 1 ft - 6”.
3. Use:
   - 7” nails to connect the the main frame elements (5”x 5”),
   - 5” nails for 2.5” boards,
   - 4” nails for 1” boards.
4. Maximum free wall length is 15ft. If a wall is longer, add a buttress wall at 15 ft.

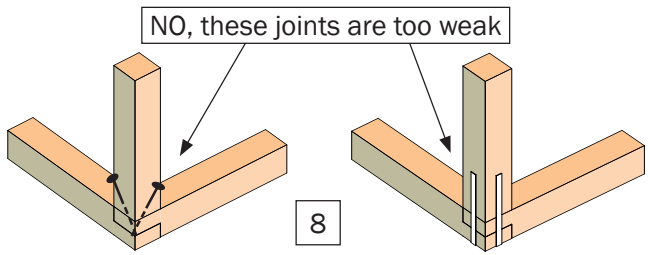


1. To fix the posts on the base plate, a mortise and tenon joint ensures the strongest connection. You may secure the joint with two 7” nails on both sides for more strength.
2. To secure the joint against vertical movement, nail a strap or boards on both sides.
3. If no mortise and tenon joint is used, blocking pads must be added on both sides.
4. Secure the joint with two 6” nails against lateral sliding.
5. Secure the joint against verical 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 you may use 3” nails.
7. To join base plates or wall plates, use a nailed lap joint. The laps should be at least 18” long. You should use three 4” nails on both the upper and lower sides. To avoid splitting of the timber, take care to keep the nails 4” from the ends.
8. You can also use a scarf (or Kashmiri) joint. It’s advisable to secure the joint with four 4” nails.

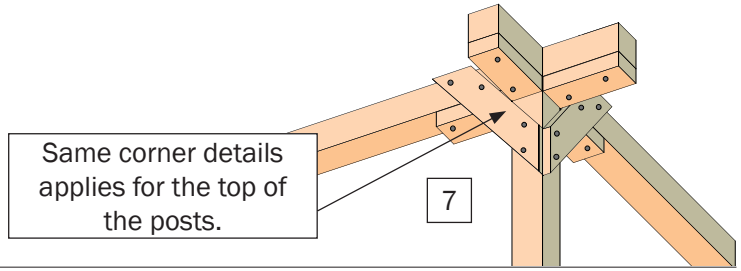




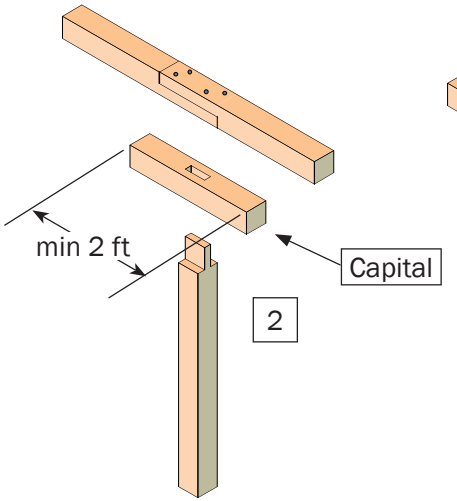


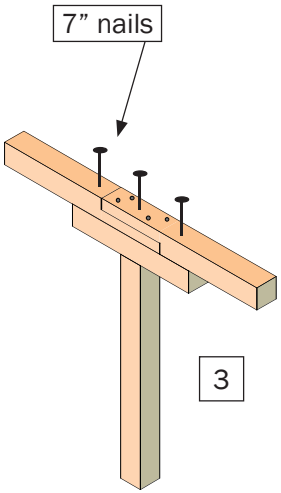


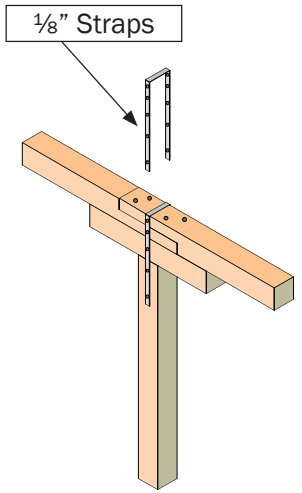
1. Corner joints must be made with greatest care, as they are particu-lalry at risk during an earthquake. Join the base plates with a cross lap joint. To ensure strength leave 1 ft of timber after the joint.
2. Secure the posts with two 6” nails driven diagonally through the joints.
3. Add blocking bads on all four sides and fix each of them on the base plate with two or three 4” nails.
4. Nail diagonal boards over the joint in order to anchor the post to the baseplate. This is a very important detail. It will make sure that the post is not pulled upwards during an earthquake.
5. You can also use a strong strap going all around the joint.
6. Protect the joint against rain with weatherboards.
7. The same details apply for the connection between posts and wall plate.
8. Never use nailed half lap joints in the corners. They are not strong enough, even with straps.

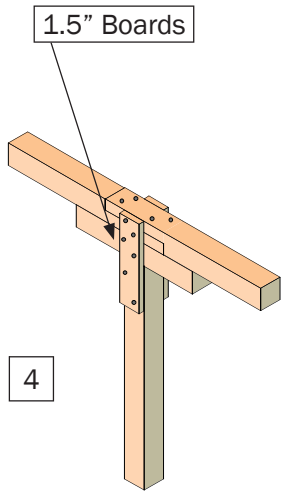


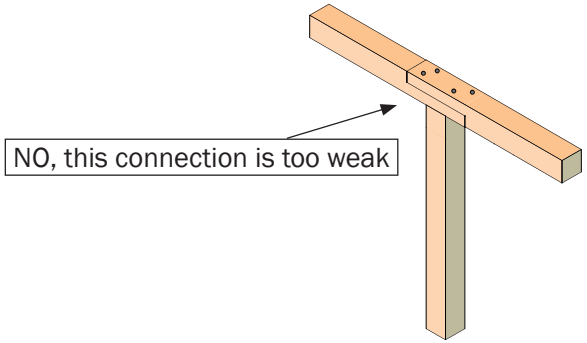
1. If a wall plate joint comes to rest on top of a post, a capital must be added.
2. The capital can be fixed to the post with a mortise and tenon (best solution). Otherwise blocking pads with nails can be used as described on the previous page
3. Fix the wall plate to the capital with 7” nails.
4. Then add a strap or boards.
5. For the footing of veranda posts, prepare a concrete block with an embedded strap anchored around two rebars of the plinth beam.
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.

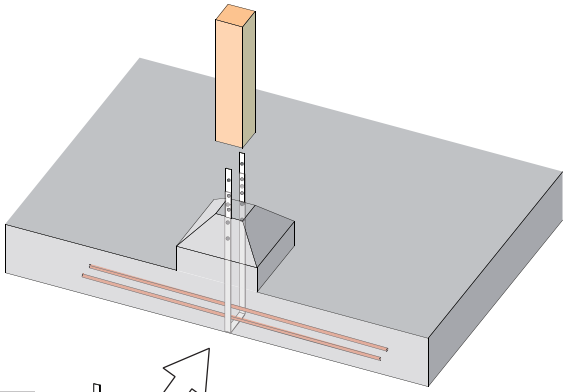


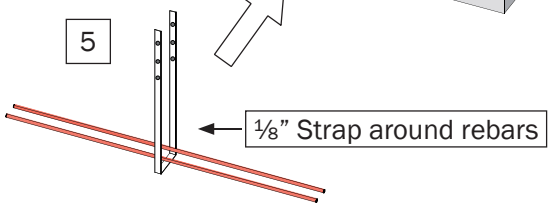


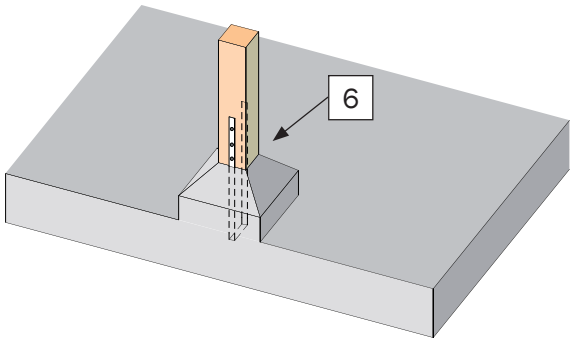


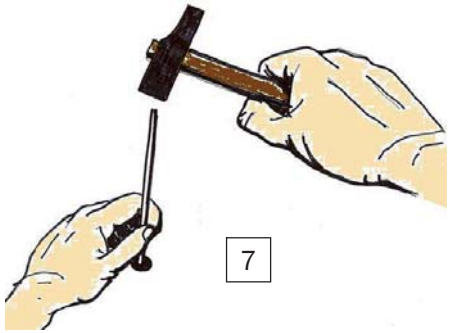


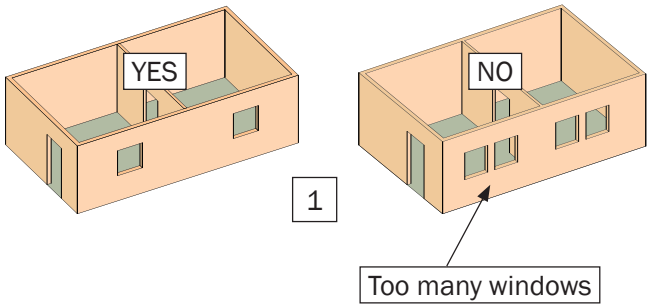


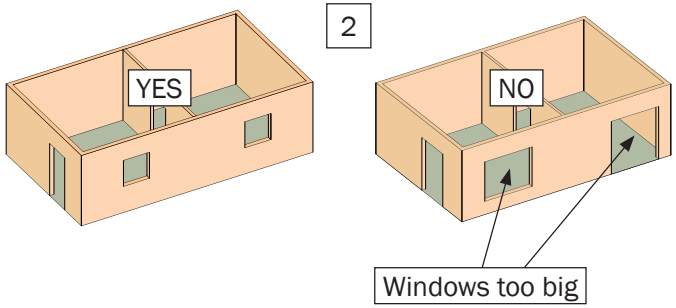


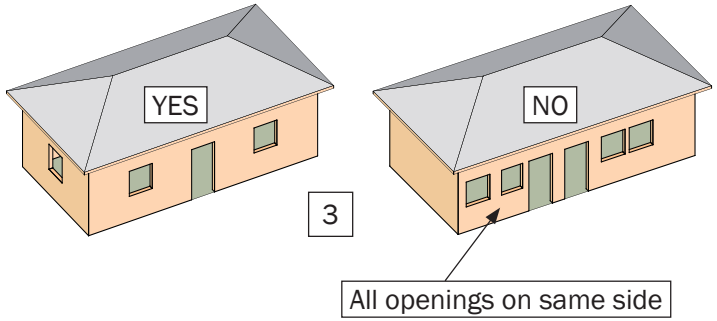


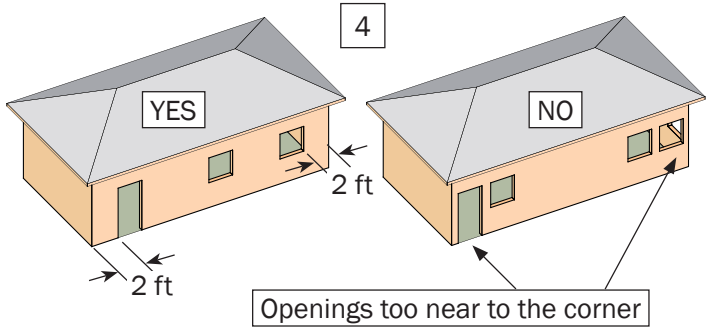


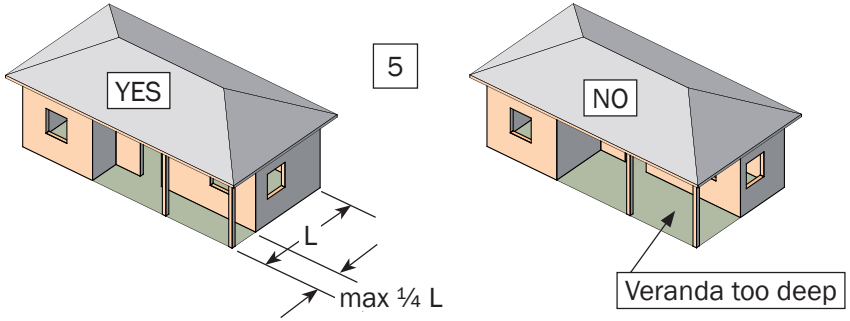


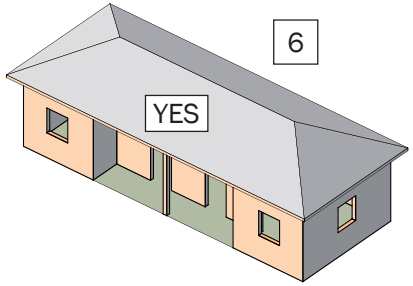




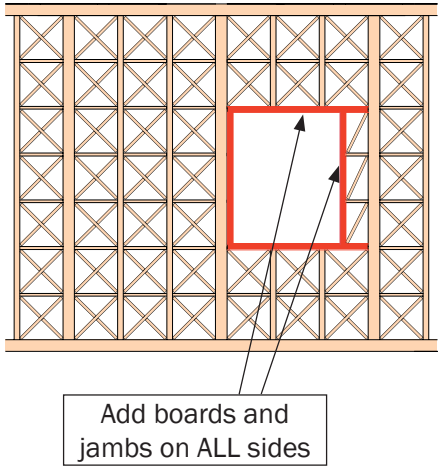




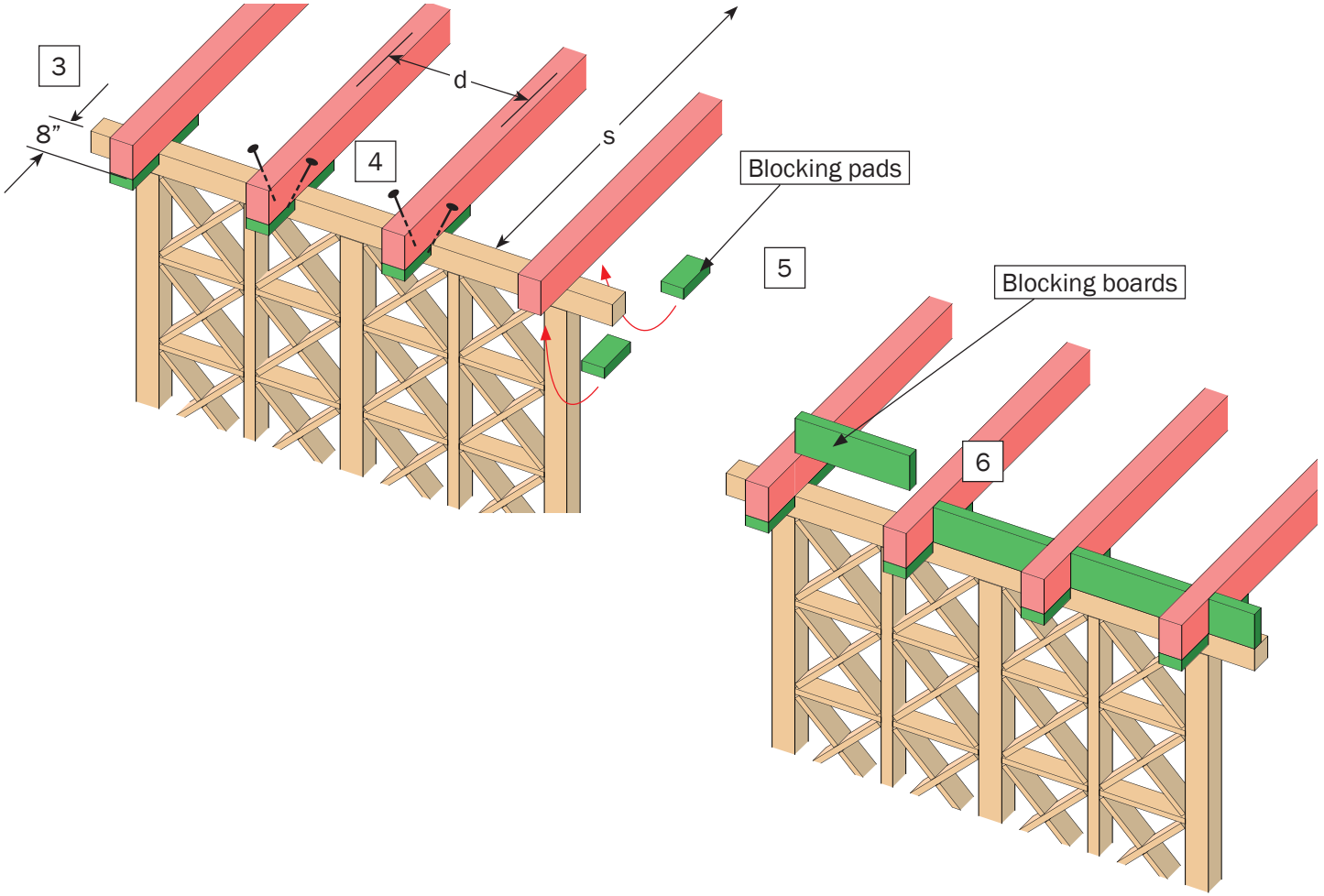


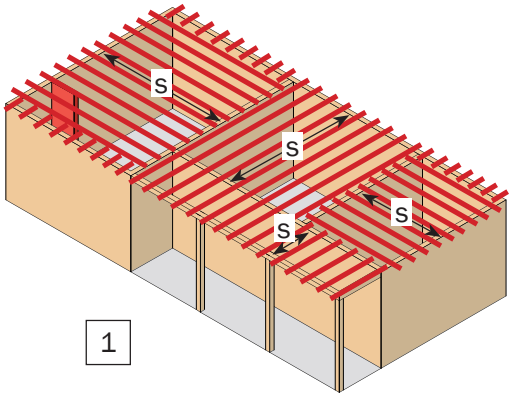


1. Windows and doors are weak points. make as few as possible.
2. Smaller windows are better than big ones.
3. Avoid putting all windos and doors on the same wall.
4. Keep windows and doors at least 2 ft from the corners. A bigger distance is even better.
5. Verandas should not be deeper than 1/4 of the depth of the building.
6. Verandas placed in the middle of the building are better.
7. To make a window, place strong sill and lintel boards from main post to main post. Then place the lateral boards on both sides. Connect all with strong nails.



1. In order to use as little timber as possible for the beams, place them in the direction of the shorter distance between walls. This distance is also called span (s).
2. With the help of the table below, choose the size of the beams according to the length of the span and the distance between the beams.
3. Place the beams on top of the wall plates, letting them stick out 8 inches on both ends.
4. Fix the beams with 7” nails.
5. For additional strength, add the blocking pads and fix them with 4” nails.
6. Add the blocking boards between the beams. These boards must fit well as they will stop the beams from moving sideways and from overturning. Fix these boards with nails.



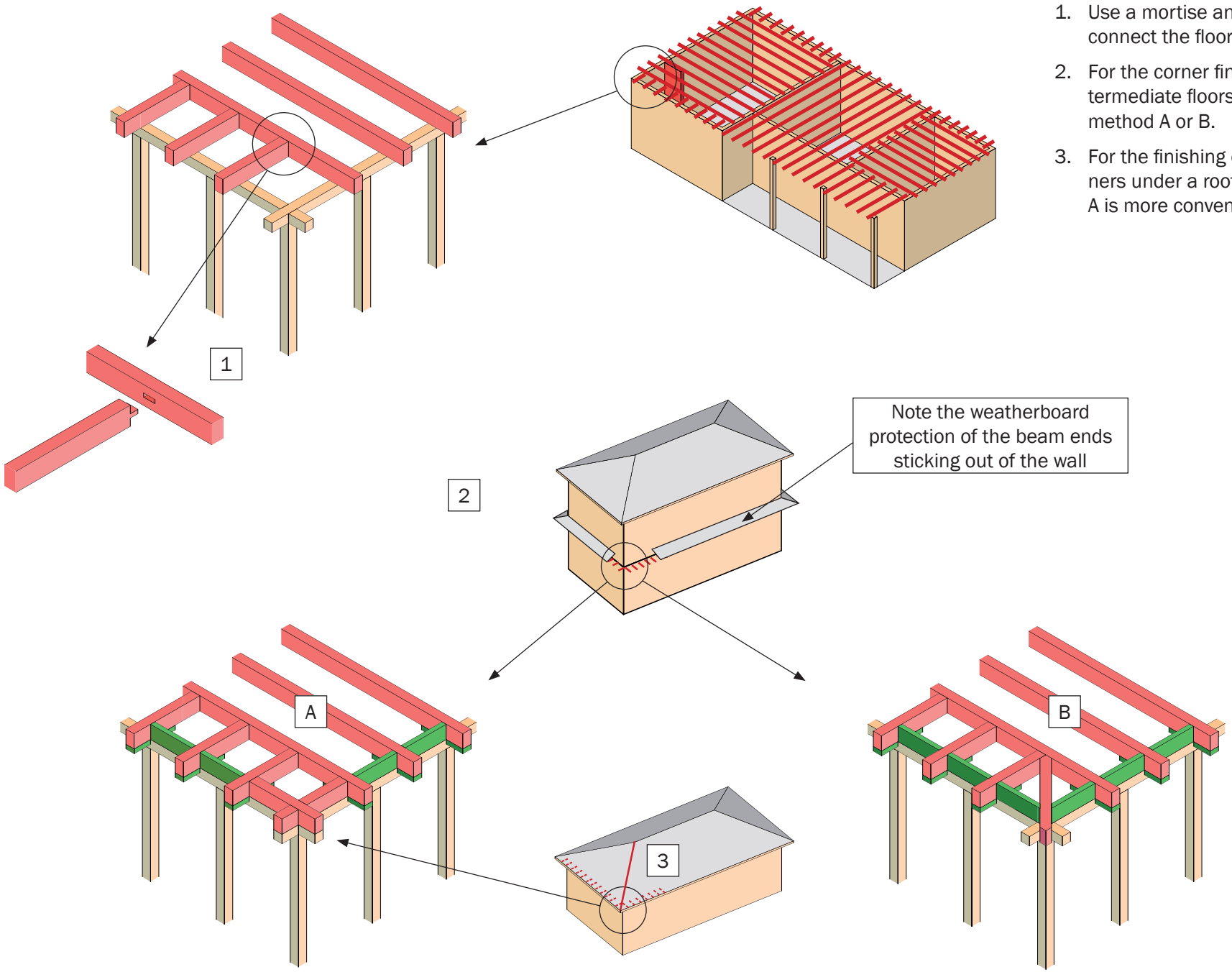


2 Table for the dimensioning of floor beams (joists)

(for the dimensioning of beams for a flat roof, use table on page 29).

(life load 40 lbs/sqft) (2.0 kN/m2)

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
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



1. Use a mortise and tenon joint to connect the floor beams.
2. For the corner finishing of intermediate floors you may use method A or B.
3. For the finishing of ceiling corners under a roof ridge, method A is more convenient.

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 to fall off during an earthquake.

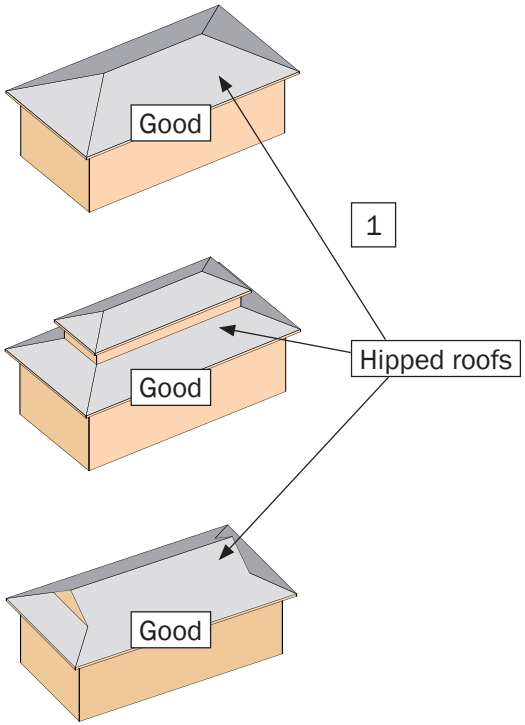
Slope:

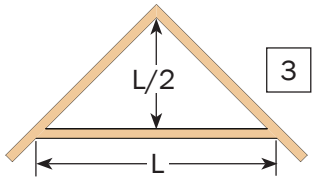
Roofs can have diferent slopes according to the climate and need:

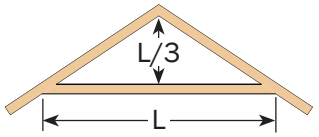
3. In snowy areas a steep roof (L/2) is better as the snow will slide off more quickly.
4. Flatter roofs (L/4) need less timber and sheeting.

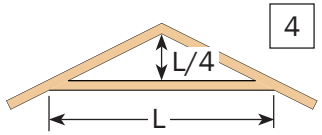
Type of structure:

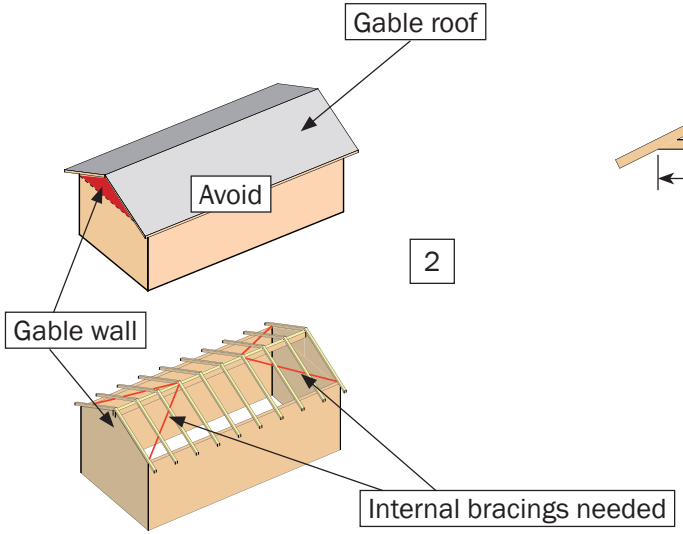
6. For spans up to 15 ft you can use a simple truss.
7. For larger houses the roof structure should be supported by post on the ground floor at a maximum distance of 15 ft.
8. This solution is not ideal as the roof posts of one side are not supported and the lower cord of the truss will bend (shown in red).

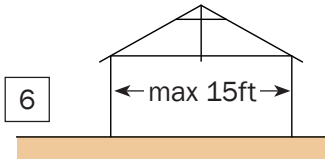


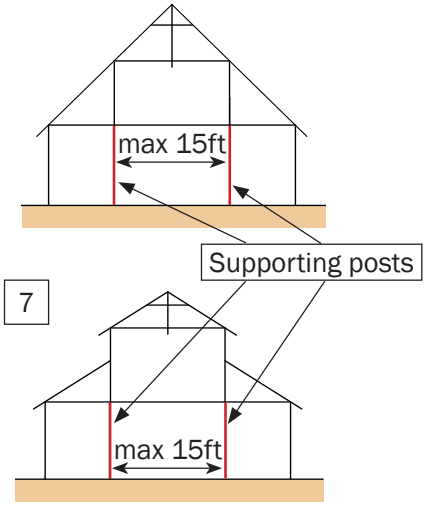


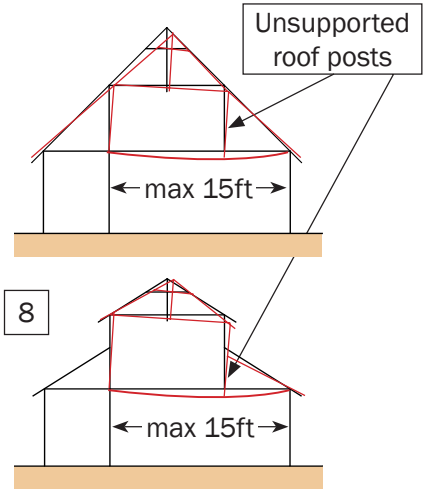


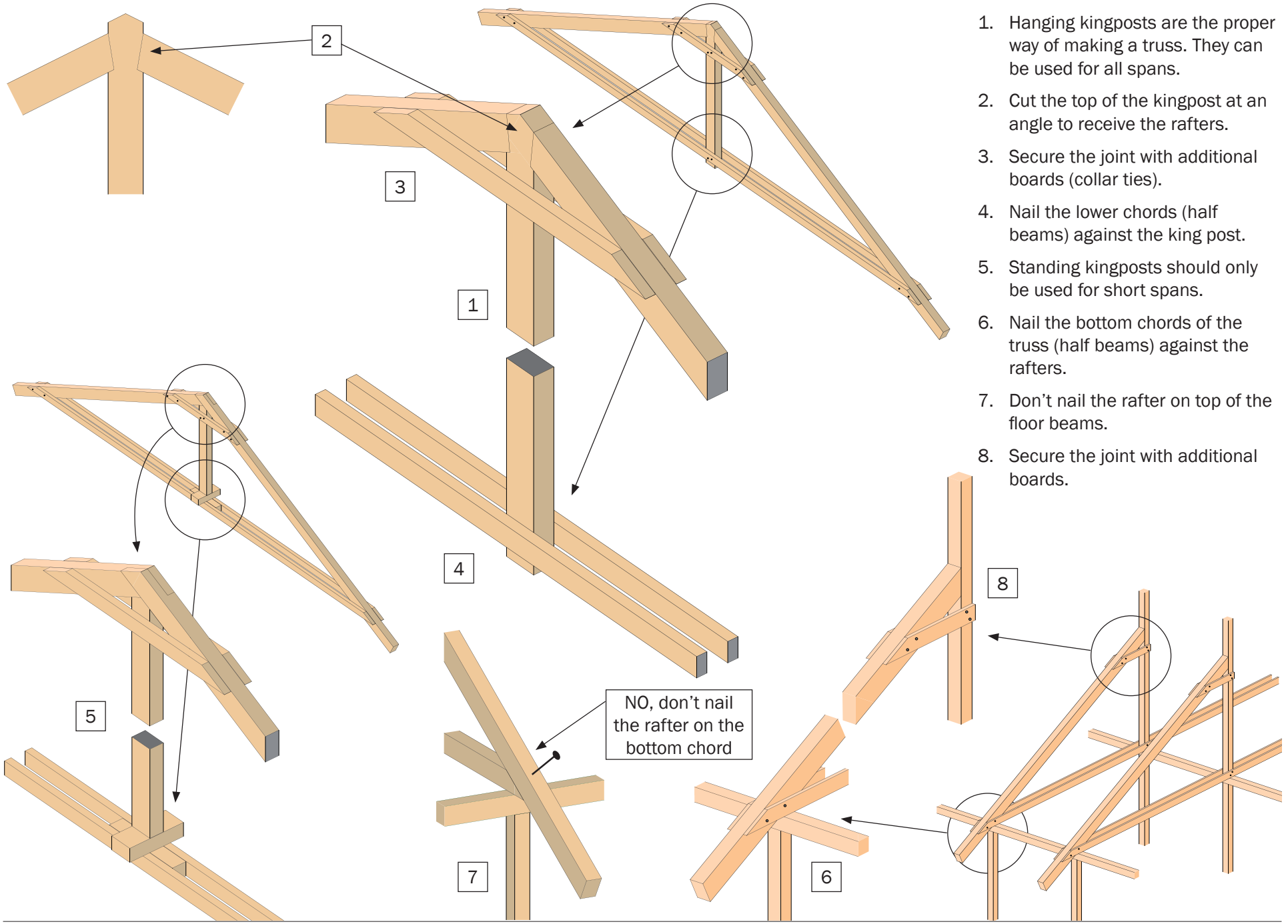






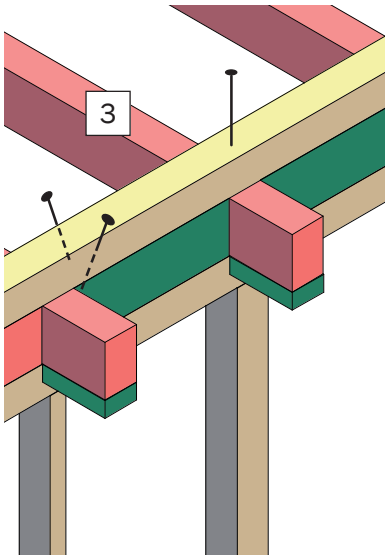


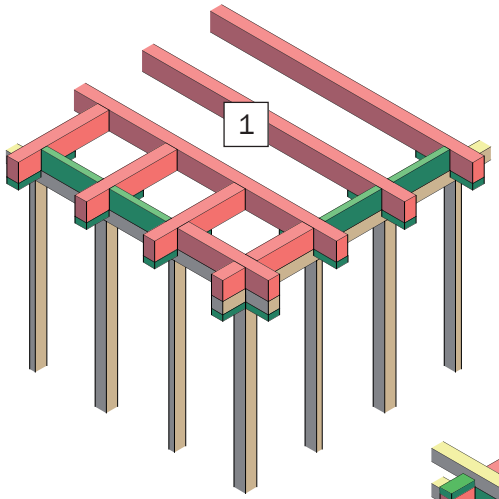


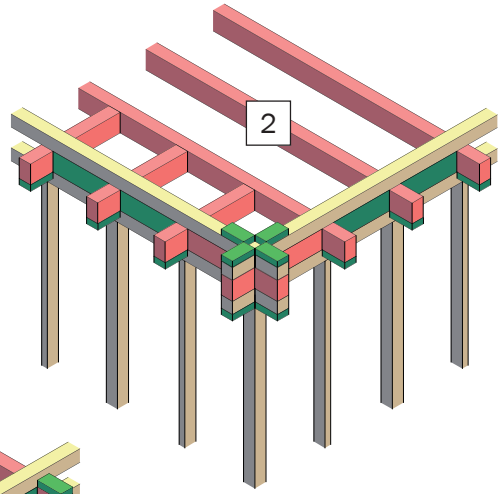


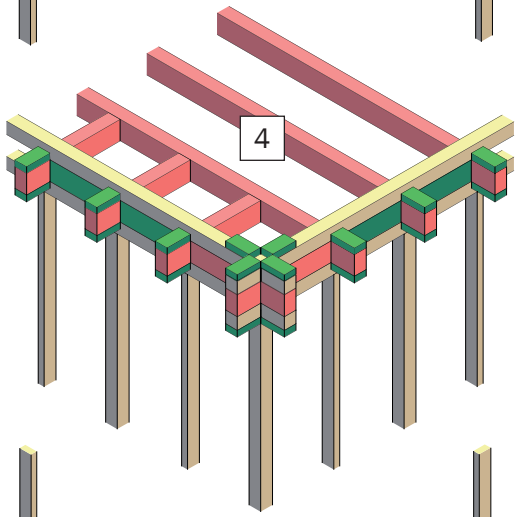
1. Hanging kingposts are the proper way of making a truss. They can be used for all spans.
2. Cut the top of the kingpost at an angle to receive the rafters.
3. Secure the joint with additional boards (collar ties).
4. Nail the lower chords (half beams) against the king post.
5. Standing kingposts should only be used for short spans.
6. Nail the bottom chords of the truss (half beams) against the rafters.
7. Don't nail the rafter on top of the floor beams.
8. Secure the joint with additional boards.

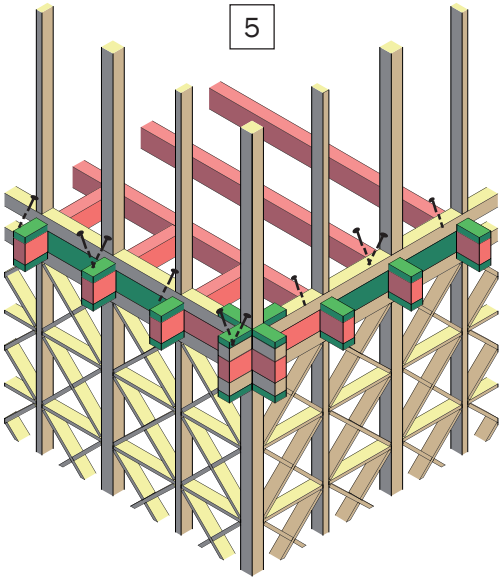
1. Prepare the floor structure as shown on pages 14 and 15.
2. Add a base plate and fix it with-nails to the beams.
3. Nail sizes:
   For vertical nailing use:
   - 8” nails for a 5” base plate.
   - 7” nails for a 4” base plate.
   For diagonal nailing use:
   - 7” nails on both sides.
4. Add blocking pads only on the outside.
5. Add the posts as on the ground floor (see pages 10 and 11).
6. Add the finer subdivisions as on pages 8 and 9.
7. Add a small weather roof (timber board or CGI sheet) to protect the beam ends.

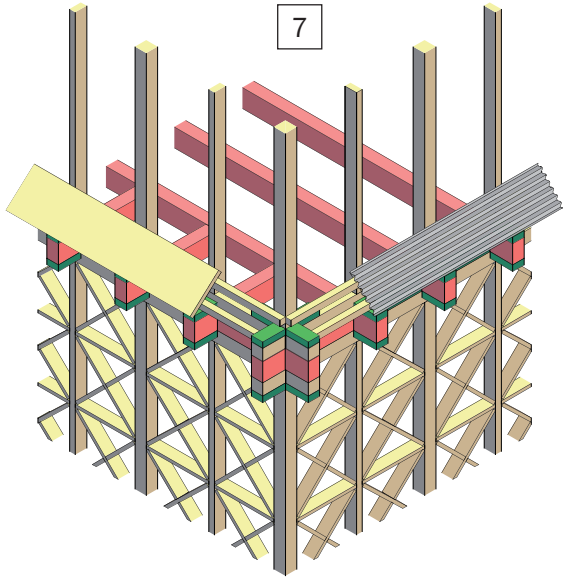


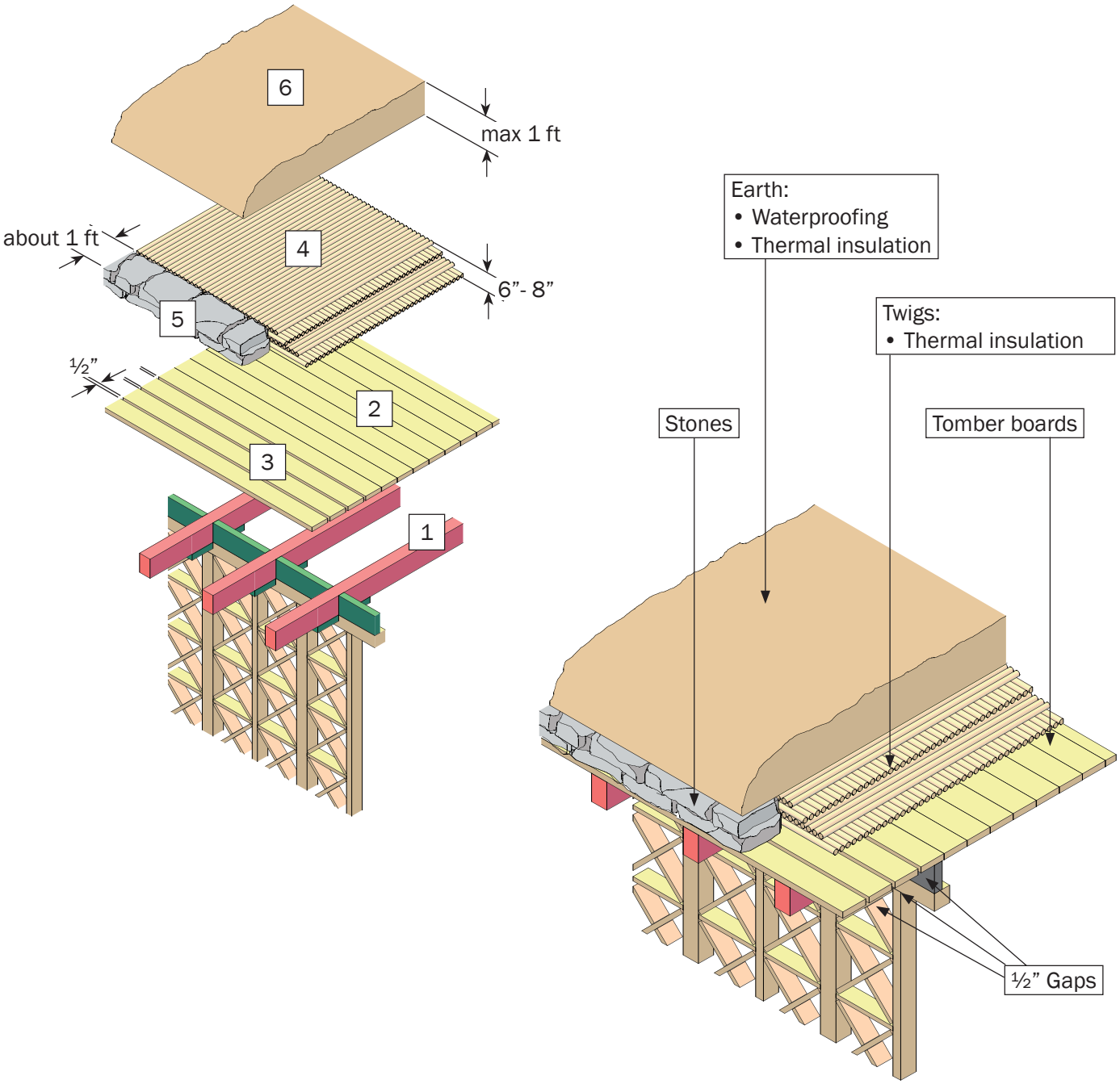












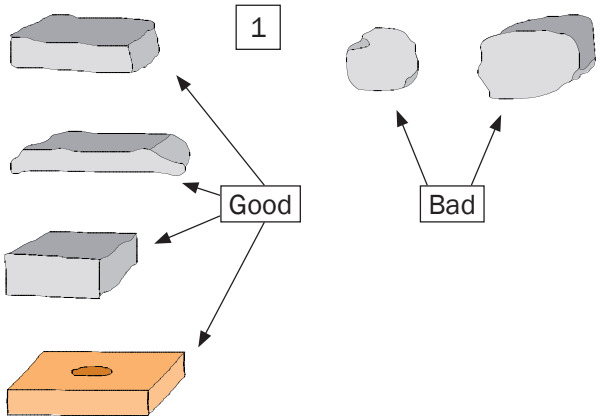
Hipped or pitched light weight roofs are preferable in earthquake areas. However, local habits and needs might require flat roofs.

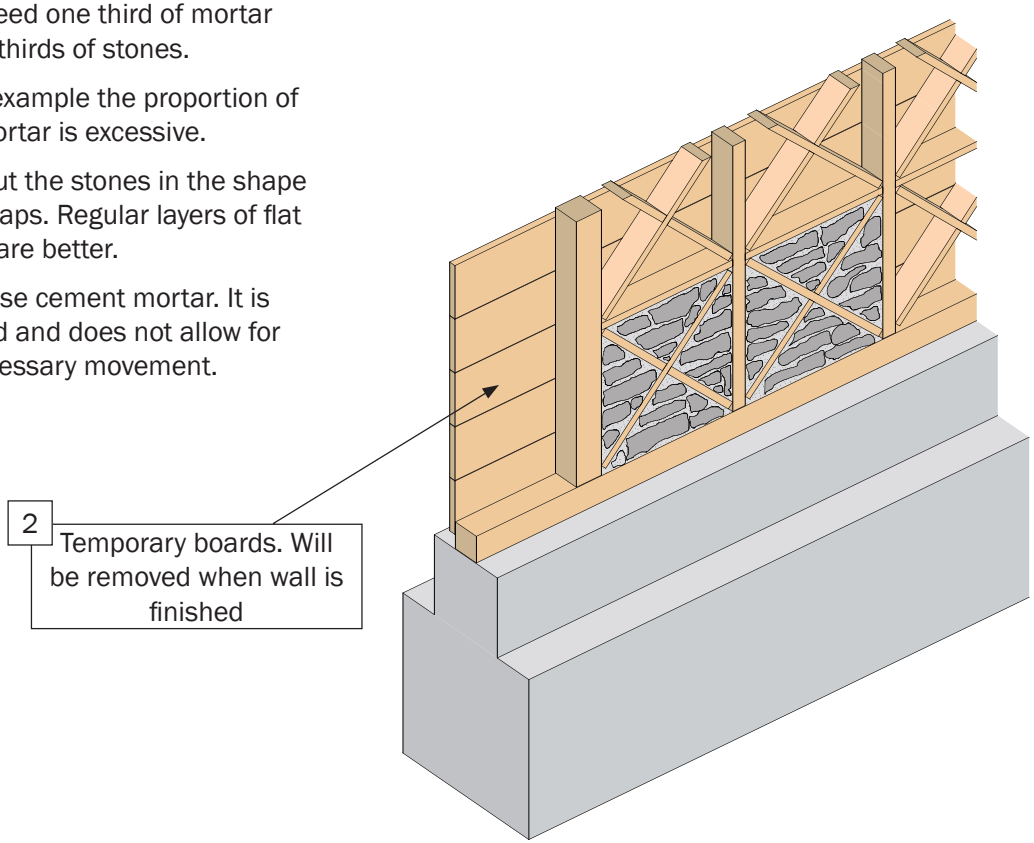
Also, flat roof as shown on this page have a better thermal insulation thanks to the layer of reeds or twigs, and the top layer of mud.

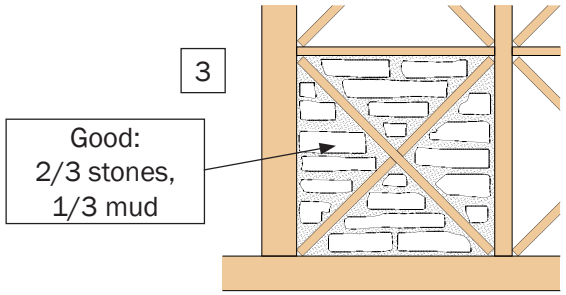
For the ideal thickness of the various layers, the best material and the proper way to use it, look for local experience. Keep in mind however that the mud layer should be kept to a minimum to increae earthquake safety.

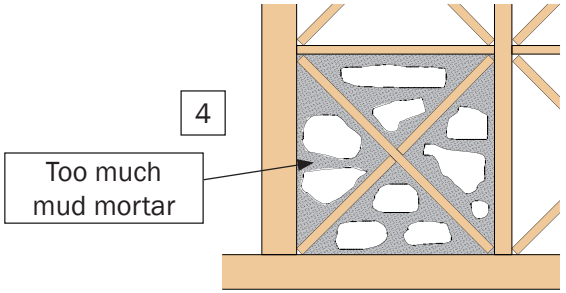
1. Flat roofs with earth on top are heavy. For the correct dimensioning of the floor beams use the table on page 29.
2. Place a layer of timber boards over the beam structure.
3. Keep 1/2” gaps between the boards placed on the external sides of the outer walls to allow possible water infiltration to run off.
4. Add a closely packed layer of twigs or reeds 6” to 8” thick. This layer will ensure a better thermal insulation.
5. Add a stone barrier on the outer edge of the roof to contain the layer of twigs.
6. Add a final layer of earth which must not be thicker than 1ft.

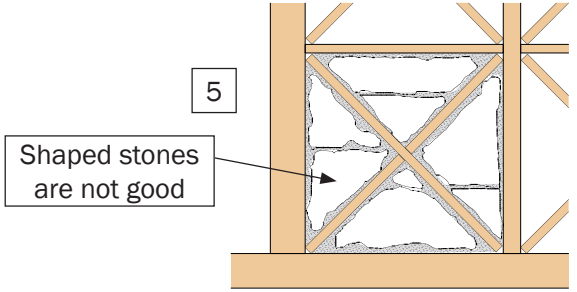
1. For the infills, use flat stones or bricks. Never use round stones as they will fall out quickly.
2. Fix boards on one side of the wall. They will help you to place the infill more easily. These boards will be removed once all gaps are filled with stones and mud.
3. Pack the stones neatly into the gaps without using too much mud mortar. The mortar layers should be between ½" and 1" thick and the proportion should not exceed one third of mortar for two thirds of stones.
4. In this example the proportion of mud mortar is excessive.
5. Don't cut the stones in the shape of the gaps. Regular layers of flat stones are better.
6. Don's use cement mortar. It is too hard and does not allow for the necessary movement.

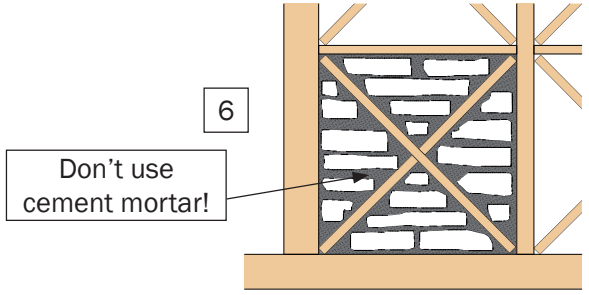


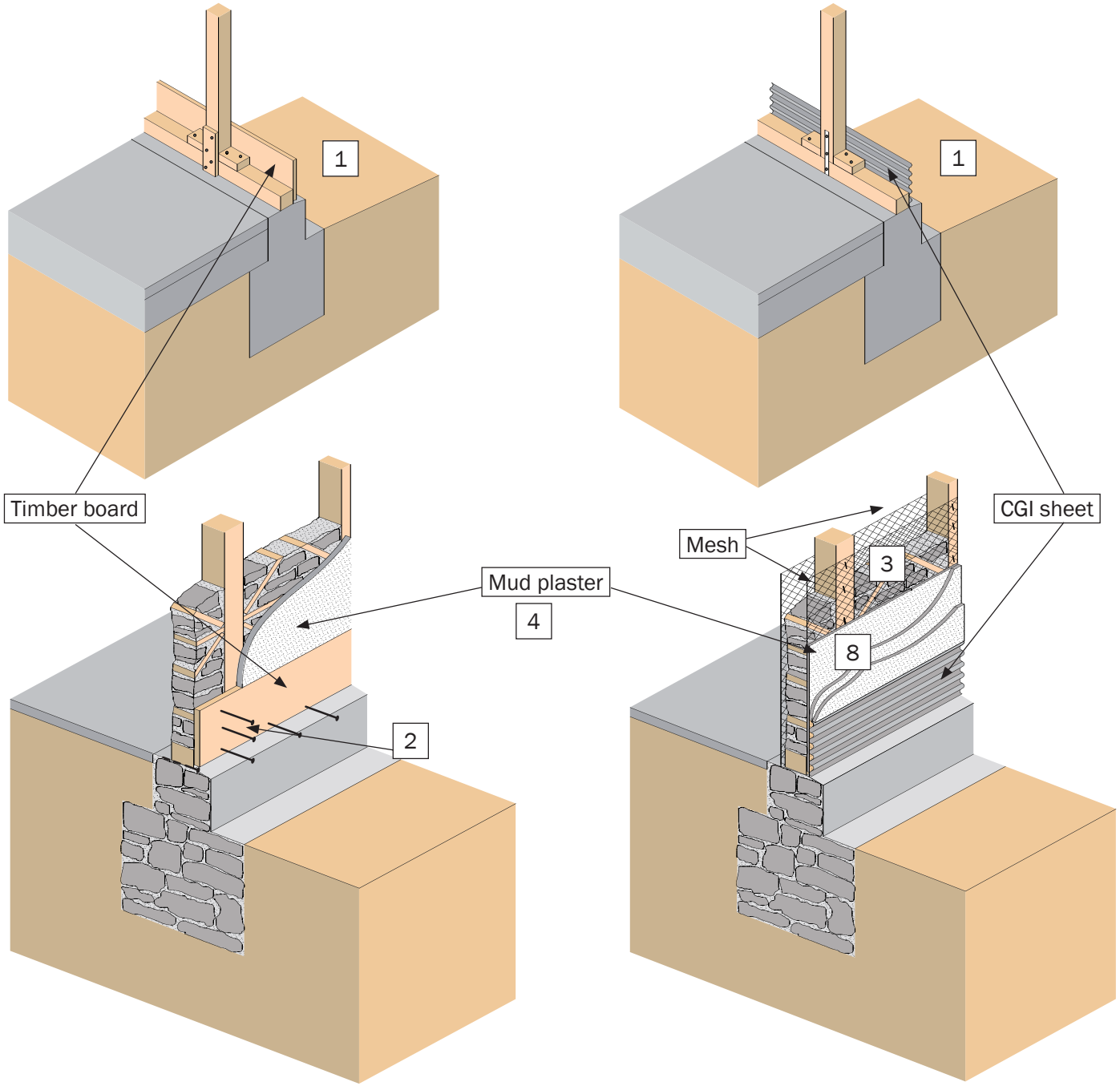






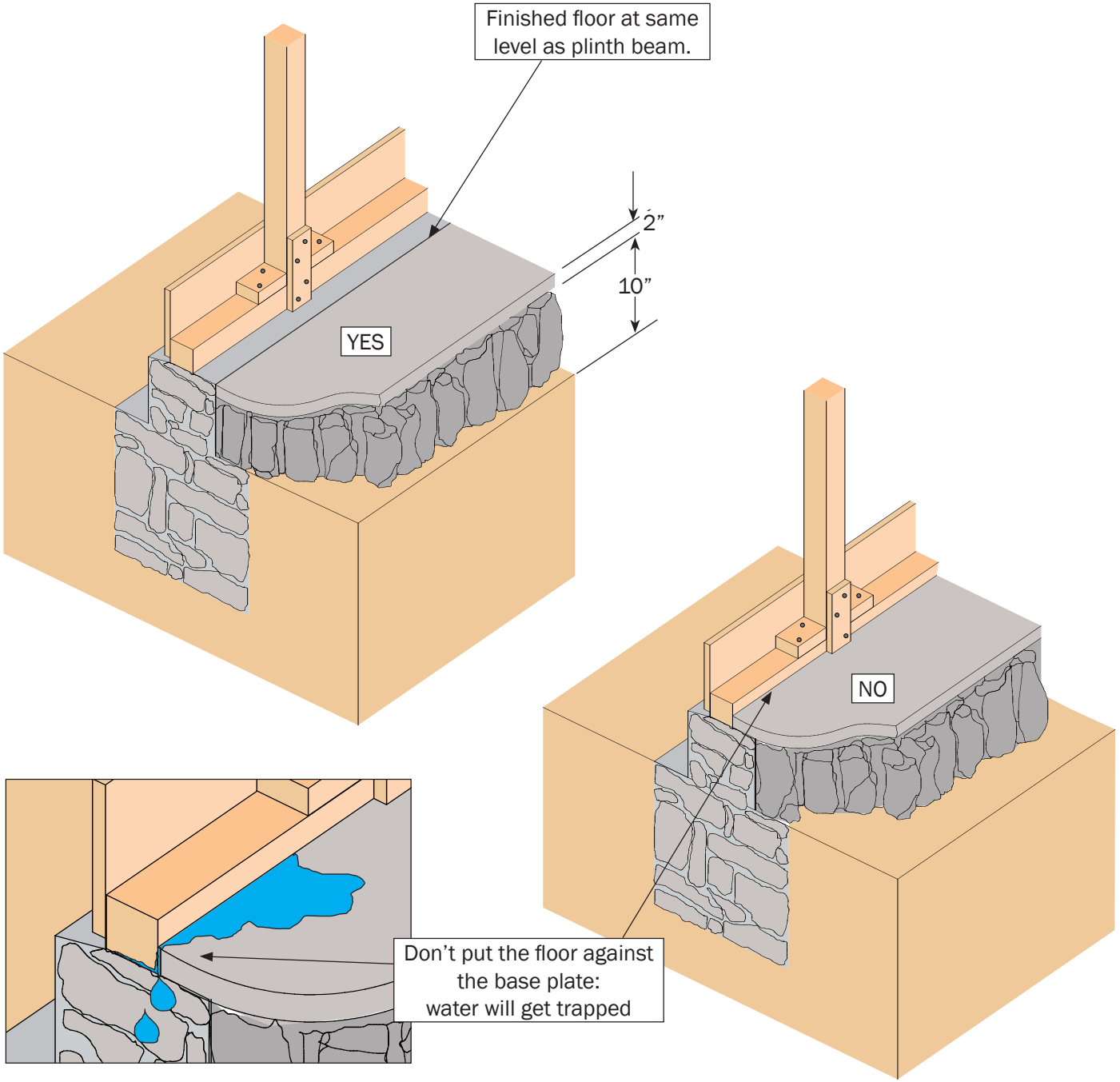






1. To protect the wall against splashing rain, nail a timber board or a CGI sheet against the lower part of the wall structure.
2. If you use a timber board, nail it against the base plate as well as againt the posts. It will help to hold the structure together.
3. For increased strength and to secure the stones against falling out, you may add a chicken wire or polypropylene (PP) mesh on both sides of the wall.
4. Use mud plaster, even for the outside. Don't use cement-sand plaster: It is too stiff and will break away.
5. Mix the mud with straw or pine needles.
6. A good plaster mix is made of one third of clay, two thirds of sand and 2 lbs of pine needles per cubic foot of mud. Look also for local experience.
7. Clean the stones and timber before plastering to ensure good adherence.
8. Apply the plaster in several layers not exceeding ½" each. If you make the layers too thick, they will crack.
9. For paint use white wash (lime). Don't use synthetic paint, it will peel off on mud plaster.

1. To fight off humidity 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.



Soil:

1. Soil must not contain any vegetable earth.
2. Make sure that the soil containes no particles bigger that 1/16” (2mm).
3. Earth should be a mix of 1 part of clay and 2 to 3 parts of sand.
4. To know the correct proportion 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. One may use horse urine 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.

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.

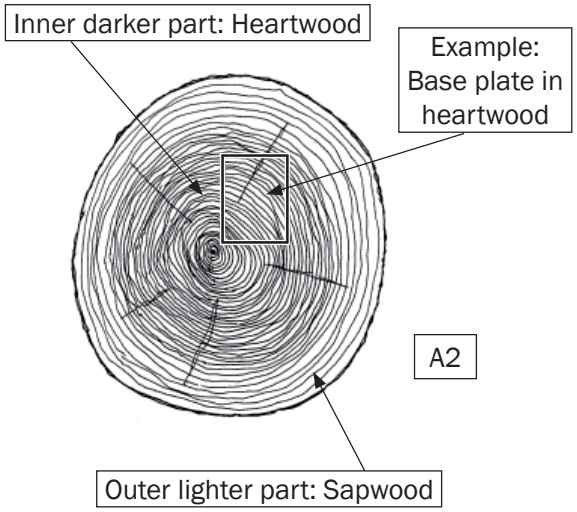
Cut-back based stabilisation

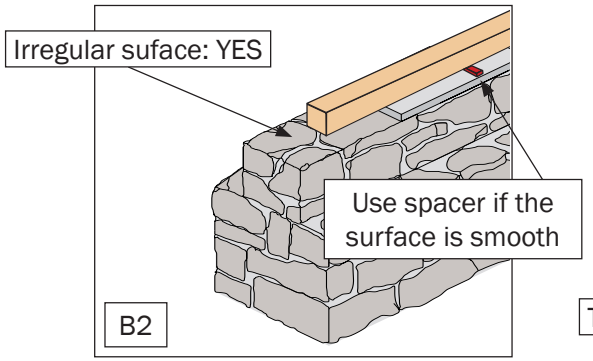
1. For soil which contains neither too much sand nor clay and has been prepared in a powder form.
2. Proportion: 2% to 6% of cut-back.
3. You might have to warm the cut-back to make it more liquid (max. 100°C).
4. Add cut-back only 2 to 3 hours before use.

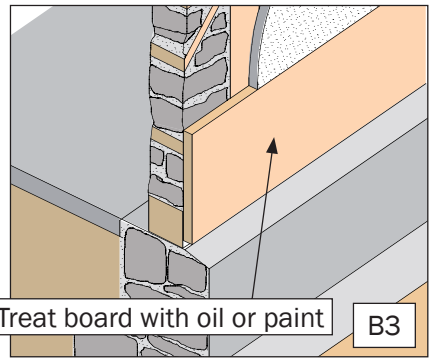
Mud plaster is composed of:

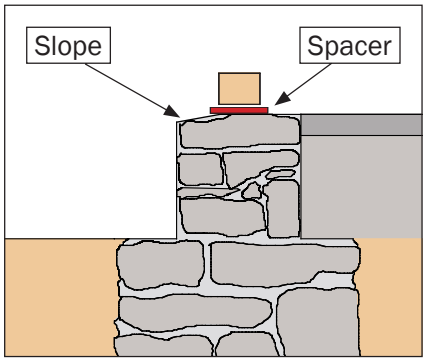
- **Soil,**
- **Water,**
- **Fibres,**
- **Stabilisation (recommended)**

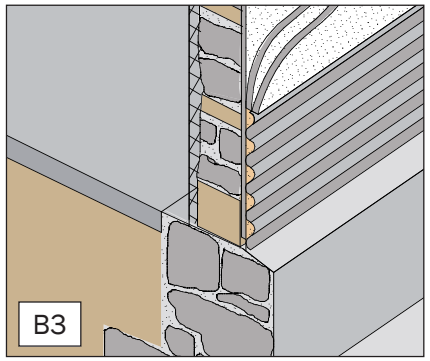
For good adherence, plaster should always be applied on well cleaned stone and timber surfaces or on a mesh (see page 19).











To increase its longevity timber employed in construction must be

A: properly selected,

B: protected,

C: treated.

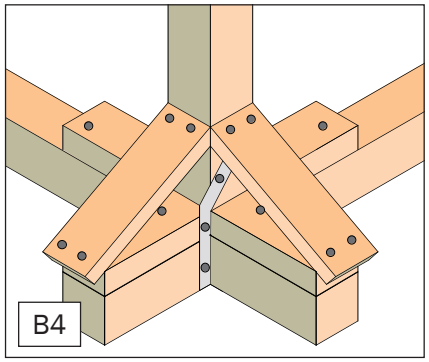
This is particularly important for elements which are often getting wet, such as the **base plate** and the **posts**.

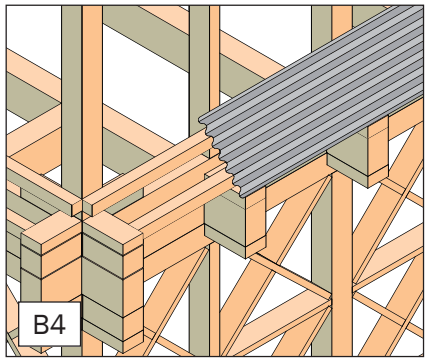
A: Selection:

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, ruining your work.

B: Protection:

1. Timber must not be in contact with earth or water.
2. Base plates must rest on an irregular surface so that water can run off or evaporate. Avoid placing the base plate on a perfect concrete surface, otherwise place ½" hardwood spacers under the baseplate to keep it away from the concrete surface.
3. Protect the base plate with a





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 disolved.
4. Add a final 2.5 litres of water and stir.
5. Use this mixture within 24 hours. Apply one application 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, under any circumstance, 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 lants, root systems and surrounding soil with plastic to avoid contamination.
8. This amount will be sufficient for 500 sqft of timber surface.

painted or oil treated weather-board or CGI sheet.

4. Protect beam ends sticking out of walls with a weatherbord or a small CGI roof.
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. The recipes shown here are for relatively harmless chemical solutions.

1. Apply old engine oil to all timber parts exposed to water. You won't be able to apply any paint on timber treated with oil.
2. Or: Apply a proper wood preservative. You can prepare it yourself according to the above given recipes.
3. The wood preservative solutions proposed here are NOT water-resistant and will be washed out if the treated timber is exposed to rain. It therefore needs an additional protection against water.
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 when treating the timber.
6. Apply treatment before construction!
7. If borates solutions are used, you can paint the timber for further protection.

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 some hourse to some 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, 3, 4 or 5).

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

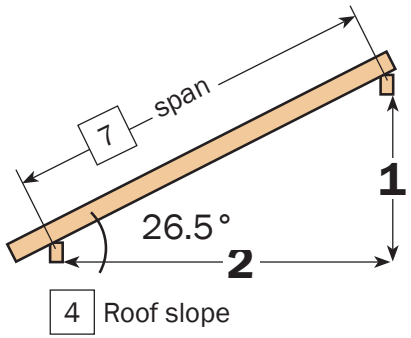
2

3

Table to be completed

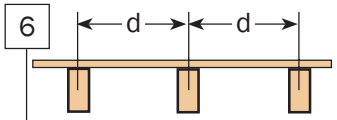
Table 2: Timber profiles for 1:2 roof slopes (26.5°)

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	3x4	3x4	3x5	3x5	3x6	3x6	3x6	4x7	4x7
	2'-6"	2x4	2x4	2x4	2x4	3x4	3x4	3x5	3x5	3x6	3x6	3x6	4x6	4x7	4x7
	3'	2x4	2x4	2x4	3x4	3x4	3x5	3x5	3x6	3x6	4x6	4x6	4x7	4x7	5x7
	4'	2x4	2x4	2x4	3x5	3x5	3x5	3x6	4x6	4x6	4x7	4x7	4x7	5x7	5x7
	5'	2x4	2x4	2x4	3x5	3x5	3x6	3x6	4x7	4x7	4x7	4x7	5x7	5x8	5x8
40 psf	2'	2x4	2x4	2x4	3x4	3x5	3x5	3x5	3x6	4x6	4x6	4x7	4x7	4x7	4x7
	2'-6"	2x4	2x4	2x4	3x5	3x5	3x5	3x6	4x6	4x6	4x7	4x7	4x7	5x7	5x7
	3'	2x4	2x4	2x4	3x5	3x5	3x6	3x6	4x7	4x7	4x7	4x7	5x7	5x8	5x8
	4'	2x4	2x4	3x4	3x6	3x6	4x6	4x7	4x7	4x7	5x7	5x8	5x8	5x9	6x9
	5'	2x4	3x4	3x5	3x6	4x6	4x7	4x7	5x7	5x7	5x8	5x8	5x9	6x9	6x10
60 psf	2'	2x4	2x4	2x4	3x5	3x5	3x6	3x6	4x6	4x7	4x7	4x7	4x7	5x7	5x8
	2'-6"	2x4	3x4	3x4	3x5	3x6	3x6	4x6	4x7	4x7	4x7	5x7	5x7	5x8	5x9
	3'	2x4	3x4	3x5	3x6	3x6	4x6	4x7	4x7	5x7	5x8	5x8	5x8	5x9	6x9
	4'	3x4	3x5	3x5	4x6	4x7	4x7	4x7	5x7	5x8	5x9	5x9	6x9	6x10	6x11
	5'	3x4	3x5	3x6	4x7	4x7	4x7	5x7	5x8	5x8	6x9	6x9	6x10	6x11	7x11



4 Roof slope

5. Select the rows corresponding to your snow load.
6. Select the row corresponding to the distance between your roof rafters or beams.
7. Select the column with the length of the beam or rafter you need.
8. Pick the corresponding profile for your beams or rafters.



5

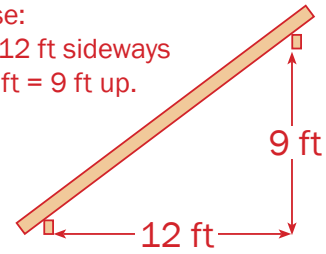
Table to be completed

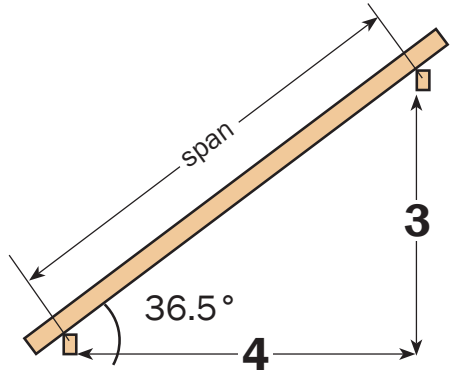
Table 3: Timber profiles for 3:4 roof slopes (36.5°)

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	3x4	3x4	3x5	3x5	3x6	3x6	3x6	4x6
	2'-6"	2x4	2x4	2x4	2x4	2x4	3x4	3x4	3x5	3x5	3x6	3x6	3x6	4x6	4x7
	3'	2x4	2x4	2x4	2x4	2x4	3x4	3x4	3x5	3x6	3x6	3x6	4x6	4x7	4x7
	4'	2x4	2x4	2x4	2x4	3x4	3x5	3x5	3x6	3x6	4x6	4x7	4x7	4x7	4x7
	5'	2x4	2x4	2x4	3x4	3x5	3x5	3x6	4x6	4x6	4x7	4x7	4x7	4x7	5x7
30 psf	2'	2x4	2x4	2x4	2x4	2x4	3x4	3x4	3x5	3x5	3x6	3x6	3x6	4x6	4x7
	2'-6"	2x4	2x4	2x4	2x4	3x4	3x4	3x5	3x5	3x6	3x6	4x6	4x6	4x7	4x7
	3'	2x4	2x4	2x4	2x4	3x4	3x5	3x5	3x6	3x6	4x6	4x6	4x7	4x7	4x7
	4'	2x4	2x4	2x4	3x4	3x5	3x5	3x6	4x6	4x7	4x7	4x7	4x7	5x7	5x7
	5'	2x4	2x4	3x4	3x5	3x6	3x6	4x6	4x7	4x7	4x7	4x7	5x7	5x8	5x8
50 psf	2'	2x4	2x4	2x4	2x4	3x4	3x5	3x5	3x6	3x6	4x6	4x7	4x7	4x7	4x7
	2'-6"	2x4	2x4	2x4	3x4	3x5	3x5	3x6	4x6	4x6	4x7	4x7	4x7	4x7	5x7
	3'	2x4	2x4	2x4	3x5	3x5	3x6	3x6	4x6	4x7	4x7	4x7	4x8	5x7	5x8
	4'	2x4	2x4	3x4	3x6	3x6	4x6	4x7	4x7	4x7	5x7	5x7	5x8	5x9	5x9
	5'	2x4	3x4	3x5	3x6	4x6	4x7	4x7	5x7	5x7	5x8	5x8	5x8	6x9	6x10

7

Example of roof slope:
For every 4 feet sideways,
go 3 feet up.
In this case:
3 x 4 ft = 12 ft sideways
and 3 x 3 ft = 9 ft up.





4 Roof slope

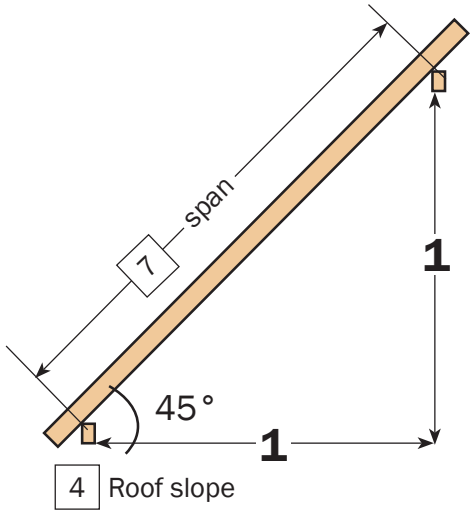


Table 4: Timber profiles for 1:1 roof slopes (45°)

Table to be completed

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	3x5	3x5
	2'-6"	2x4	2x4	2x4	2x4	2x4	2x4	2x4	3x4	3x5	3x5	3x5	3x5	3x6	3x6
	3'	2x4	2x4	2x4	2x4	2x4	2x4	3x4	3x5	3x5	3x5	3x5	3x6	3x6	4x6
	4'	2x4	2x4	2x4	2x4	3x4	3x4	3x5	3x5	3x6	3x6	3x6	4x6	4x7	4x7
	5'	2x4	2x4	2x4	3x4	3x4	3x5	3x5	3x6	3x6	4x6	4x6	4x7	4x7	4x7
30 psf	2'	2x4	2x4	2x4	2x4	2x4	2x4	2x4	3x4	3x5	3x5	3x5	3x6	3x6	3x6
	2'-6"	2x4	2x4	2x4	2x4	2x4	3x4	3x4	3x5	3x5	3x6	3x6	3x6	4x6	4x6
	3'	2x4	2x4	2x4	2x4	3x4	3x4	3x5	3x5	3x6	3x6	3x6	4x6	4x7	4x7
	4'	2x4	2x4	2x4	3x4	3x4	3x5	3x5	3x6	3x6	4x6	4x6	4x7	4x7	4x7
	5'	2x4	2x4	2x4	3x4	3x5	3x5	3x6	4x6	4x6	4x7	4x7	4x7	5x7	5x7

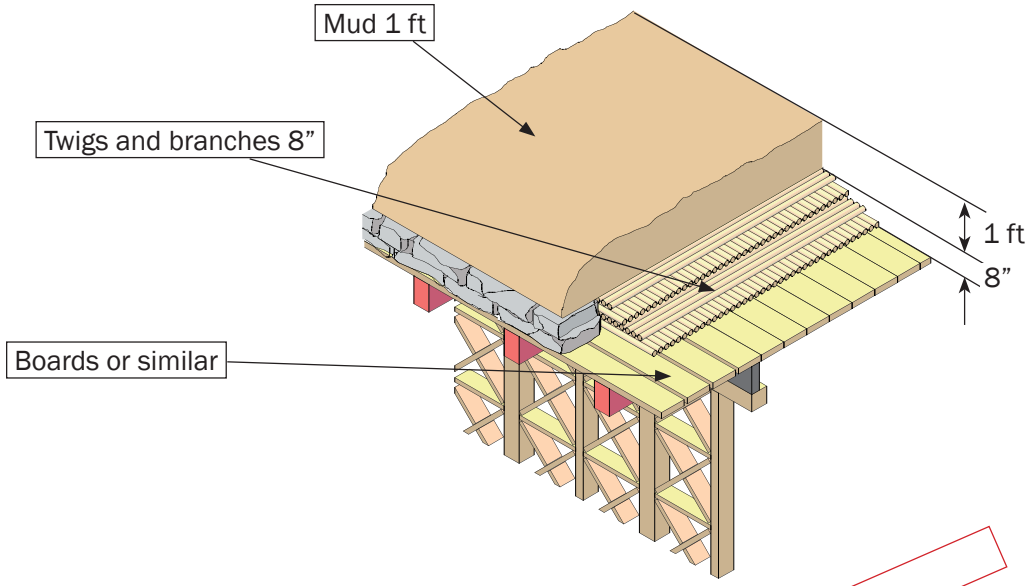


Table 5: Flat roof with mud cover

Table to be completed

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	6x9	6x10	6x10	6x11	7x11	7x11	7x12
	2'-6"	3x6	4x6	4x7	5x7	5x8	5x9	5x9	6x10	6x11	7x11	7x11	7x11	7x12	7x13
	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	6x10	6x10	6x11	7x11	7x11	7x12	7x12
	2'-6"	3x6	4x6	4x7	5x7	5x8	5x9	6x9	6x11	7x11	7x11	7x11	7x12	7x13	7x13
	3'	4x6	4x7	4x7	5x8	5x9	6x9	6x10	7x11	7x11	7x12	7x12	7x13	7x14	8x13
60 psf	2'	3x6	4x6	4x7	5x7	5x8	5x8	5x9	6x10	6x11	7x11	7x11	7x11	7x12	7x13
	2'-6"	3x6	4x7	4x7	5x8	5x9	6x9	6x10	6x11	7x11	7x11	7x12	7x12	7x13	7x14
	3'	4x6	4x7	4x8	5x9	6x9	5x10	6x11	7x11	7x12	7x12	7x12	7x13	8x14	8x15

On timber construction:

Götz K-H. et al (1983): *Construire en bois*, Presses polytechniques romandes, Lausanne

LIGNUM (1946): *Normalisation du bois équarri*, Section du bois de l'Office fédérale de guerre pour l'insustrie et le travail, Union suisse en faveur du bois, Suisse

LIGNUM (1960): *Documentation bois, projets et execution, Tome 2: assemblages et éléments de construction*, Lignum, Le Mont sur Lausanne,

LIGNUM (2005): *Table pour la construction en bois TCB 1, Manuel pour le dimensionnement*, Lignum-Cedotec, Le Mont sur Lausanne,

On wood preservation:

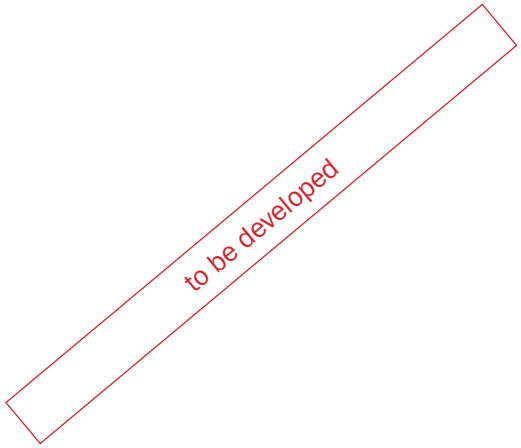
Alsnetbiz (?): *Borate wood preservatives: commercial and home-brewn*, Al's Home Improvement Centre, http://alsnetbiz.com/homeimprovement/homemade.html

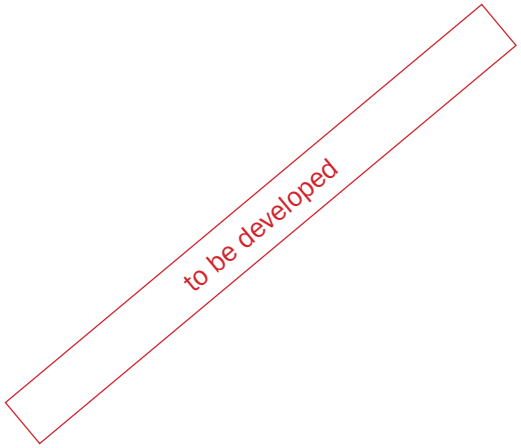
Bearfortlodge (2006): *Making home brew wood preservative,* www.bearfortlodge.com/bearfort_lodge/2006/12/log-home-repair-restoration-replacing-chinking-and-fixing-logs-part-vi-home-brew-wood-and-log-preservative/#more-93

USDA (2006): *Human Health and Ecological Risk Assessment for Borax, Final Report*, US Department of Agriculture, Forest Service, Arlington, USA

On earth construction:

Houben H. and Guillaud H. (2006): *Traité de construction en terre*, CRATerre, Editions Parenthèses, Marseille





ABOUT THIS MANUAL

ABOUT THE AUTHORS