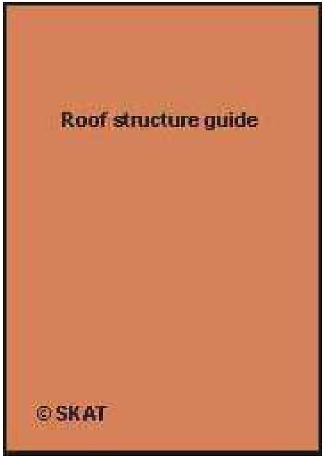

Roof Structure Guide - Basics for the Design and Construction of Leightweight Sloped Roof Structures (SKAT, 1993, 144 p.)

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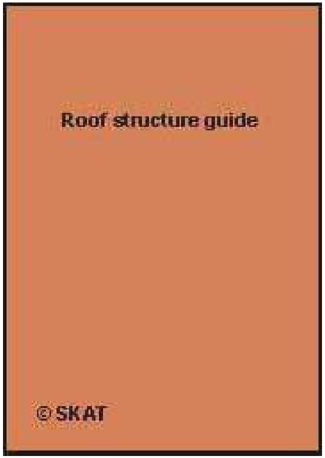

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Appendices

Basics for the Design and Construction of Lightweight Sloped Roof Structures

Paul Gut

FCR / MCR TOOLKIT

ELEMENT 24

Swiss Centre for Development Cooperation in Technology and Management
International Labour Office

Guide for the design and construction of basic roof structures for lightweight cover, with a sizing-aid for timber structures and detailing.

A co-publication of the Swiss Centre for Development Cooperation in Technology and Management (SKAT) and the International Labour Office (ILO), supported by the Swiss Development Cooperation (SDC)

FCR / MCR TOOLKIT-OVERVIEW

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4 Standards Guidelines
10 FCR/MCR Basics
11 Case Reports
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30 Business Skills Guide
31 Marketing & Selling Guide

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This guide provides information on how to design and build simple roof structures for light weight and even (non-curved) roof cover materials. Although it is part of the FCR/MCR Toolkit series, it is equally applicable in the case of other roof cover materials such as clay tiles, slates, sheets etc.

The guide explains the basic principles of building statics and structural design. Constraints determining the roof shape and earthquake and storm proof construction are discussed.

The guide deals in brief with all the commonly known materials for roof structures with special emphasis on timber technology.

The guide is addressed to architects and engineers involved in the design of buildings with FCR/MCR tile roofs, and also to builders, site engineers and overseers, who are implementing construction.

Producers of roof cover materials can use the guide as a basis for advising their costumers on the successful use of their products. The guide is also useful as a teaching aid.

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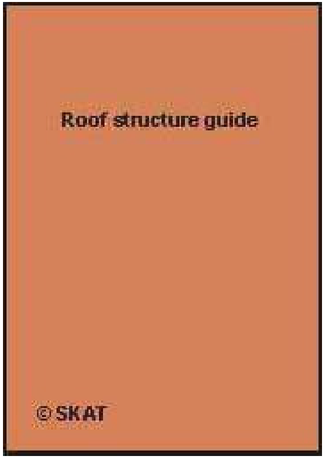

Preface

This guide is part of the FCR/MCR (Fibre Concrete Roofing/Micro Concrete Roofing) toolkit series although not restricted to these roofing materials only, but valid for other light weight roofs also.

The history of FCR/MCR

The FCR/MCR technology was developed in the 1970s based on many years of experiences made with concrete tiles and asbestos cement sheets. During the 1980s it found applications in many

countries all over the world. Today the technology is at a mature stage and experiences have shown that it offers a reliable roofing material which can compete in most cases with conventional roofing materials.

FCR/MCR Toolkit Series

The FCR/MCR Toolkit series impart the entire know-how that is required in the field of FCR/MCR technology, covering technical as well as economic, organisational, management and marketing aspects. The FCR/MCR Toolkits Overview shows the structure of its contents.

Roles of BASIN,

SKAT/RAS and ILO

SKAT and ILO are co-publishers of the FCR/MCR Toolkit Series which this guide is one element.

BASIN SKAT is a member of BASIN (Building Advisory Service and Information Network), a coordinated network of experienced

international professionals, which was established to provide qualified advice and information in the field of building materials and construction technologies.

The activities of BASIN are divided amongst four leading European, non-profit organisations in the field of appropriate technology viz. GTZ/GATE Germany, ITDG Britain, SKAT Switzerland, CRATerre France. Each of these organisations covers a separate specialised subject area, thus providing more qualified expertise with greater efficiency.

SKAT

SKAT is an information and documentation centre and a consultancy group engaged in promoting and implementing appropriate technology in partner countries worldwide.

RAS

As a member of BASIN, SKAT specialises in roofing technology, particularly FCR/MCR technology. Within BASIN, SKAT established the Roofing Advisory Service (RAS). To facilitate the promotion and

dissemination of roofing technologies, SKAT/RAS produce the "FCR/MCR Toolkit" series of which this "Roof Structure Guide" is one element.

Network of specialists

A worldwide network of specialists and specialised institutions provides technical support to new and existing producers of FCR/MCR. This helps to ensure the reliability and quality of the products in this growing market.

This FCR/MCR network is coordinated by SKAT/RAS.

ILO

A programme for the development, promotion and application of appropriate building technologies suitable for low-cost construction is currently being implemented by the Micro-enterprise and Informal Sector Section of the Entrepreneur ship and Management Development Branch of ILO.

The objectives of this programme are to minimise construction

costs, maximise the use of locally-available raw materials and generate productive employment. The program also aims at developing small and micro-enterprises in this sector and at demonstrating their commercial viability. It makes use of an innovative approach whereby some of the activities are carried out in on-going technical cooperation projects for the development of small and micro-enterprises. These projects are executed by ILO or other agencies such as UNDP, as multilateral or bilateral projects. Various approaches are used by this programme: research and development, dissemination of technological information, advisory services to governments and implementation of technical assistance projects.

Contact address

This literature, as well as further information, is available from:

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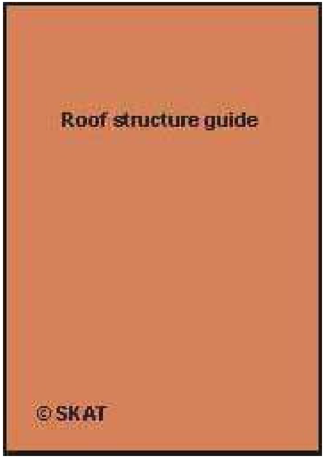
We would like to thank all the experts, technicians and producers who helped us with their valuable comments and remarks based on their wide experience. There are too many of them to name them individually.

Comments

Comments and feedback information are welcome and will help to further improve this guide. They may be sent to SKAT/RAS or ILO.



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1. Introduction

1.1 Objectives of this guide

The roof constitutes the most important part of a building and special care has to be taken in preparing it and its elements. The

best available raw materials should be used and throughout the production process it should be kept in mind that a sub-standard and ill-designed roof may not only result in a defective roof, but may also lead to severe damage of the whole building.

In order to construct a reliable roof, not only must the cover material be of a high quality, but the entire roof structure and cover must function as a coherent system which is adapted to local conditions such as climate, available skill and materials. This guide therefore aims at facilitating the design of a suitable roof shape and adequate structure. It also provides guidelines on proper attention to details and on the construction and maintenance of the roof in a sound manner.

Scope

This guide is generally valid for sloped roofs which are covered by any kind of light and even material such as tiles or sheets. Emphasis is placed on basic and simple roof forms.

Target group

The guide is addressed to architects and engineers involved in the design of buildings and to builders, site engineers and overseers implementing construction.

Producers of roof-cover materials can also use the guide as a basis for advising their customers on the successful use of their products.

This guide can also be used as a teaching aid during training.

1.2 Contents of this guide

What you will find in this guide:

This guide provides information on how to design and build simple roof structures for lightweight and even (non-curved) roof cover materials. Although it was originally compiled as part of the FCR/MCR Toolkit series only, it is equally applicable in the case of other roof cover materials such as clay tiles, slates, sheets etc.

- In a popular rather than in a scientific way the principles of basic building statics are explained, providing a general understanding of the forces which occur in buildings and their implications on the

structure.

- Various aspects that determine the design and shape of roofs are explained. These include climatic aspects and the interrelationship between the floor plan and roof shape.

- Principles of structural design are explained. A step-by-step approach explains how to develop the design of the structural elements.

Aspects of earthquake proof and storm proof construction are also included.

As timber is still a material which is widely-used in roof structures, it is dealt with in detail.

A handy method for sizing the main timber elements for simple roof structures is provided, taking into account the varying strength properties of different timber species. The method can be used where standard values are not available.

Other alternative materials for roof structures such as timber

trusses, bamboo, pole timber, metal and concrete are dealt with briefly. For detailed information specialised literature or professional advice should be consulted.

- Finally, methods and practical hints for the construction process as well as maintenance are provided.

- The appendices contain conversion factors for roof slope measures, an extensive list of timber available in different regions with their main characteristics, tables for sizing structural timber (sawn timber and pole timber), and a list of selected literature.

What you will NOT find in this guide:

The guide is not a scientifically-comprehensive textbook, but is rather designed for practical application.

It does not focus on free and complicated forms in roof design which require a greater degree of expertise, skill and practical experience.

It also does not contain

- Information on production management

- Specifications with regard to costs and profit

- Information about particular problems in specific countries

- Truss-making

- Guidelines for the production of tiles

- Guidelines for quality control of tiles and the required tests

- Information about roof cover and its detailing

For information on these aspects please refer to the other toolkit elements in this series. (See Toolkit Overview on the front page)

1.3 General remarks

Validity of data

The material presented in this guide is based on general know-how and universal practice. It is up to the readers in each particular

country to develop and apply corresponding solutions which are adapted to local practice and circumstances .

Responsibilities of the producer of roof-cover material

The reliability and functional value of the entire roof as a system as well as of its individual components such as the cover or structure, are of relevance for the house owner. The producer of cover materials should, therefore, not only be concerned about the high quality of his product, but also about the quality of the roof as a whole. If he constructs entire roofs as well as sells tiles, his responsibility is clearly defined. In the case where the roof is constructed by someone else, however, the producer should also take an interest in its design and construction. Although he can, naturally, not be held responsible for the structure and the laying of the cover, he should participate by advising and providing all necessary information.

Only if the roofs are properly functioning and long-lasting, will his products earn a good reputation and become a sustainable success.

1.4 Definition of main terms

1.4.1 Roof types

Gable roof, saddle roof or double-pitched roof

Single pitch roof or mono-pitched roof

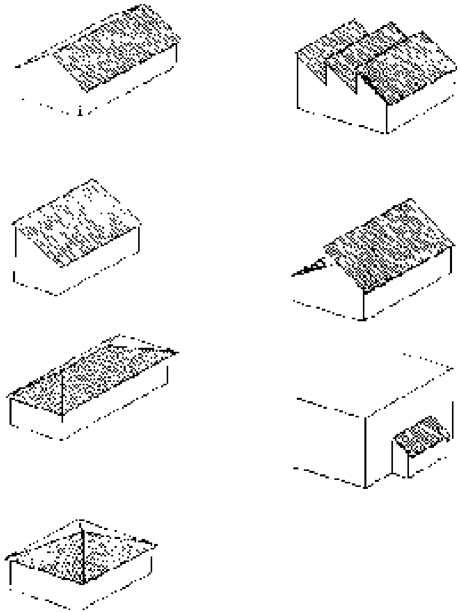
Hipped roof

Pyramid roof

Shed roof

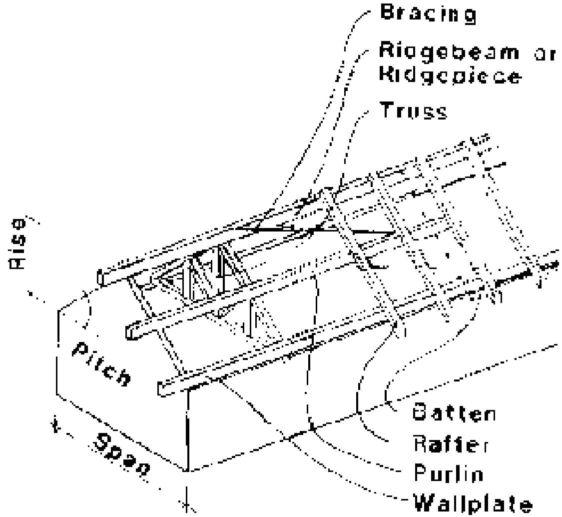
Broken pitched roof

Lean-too roof

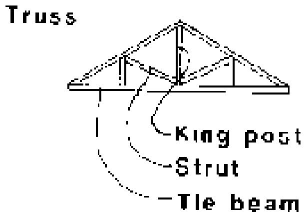


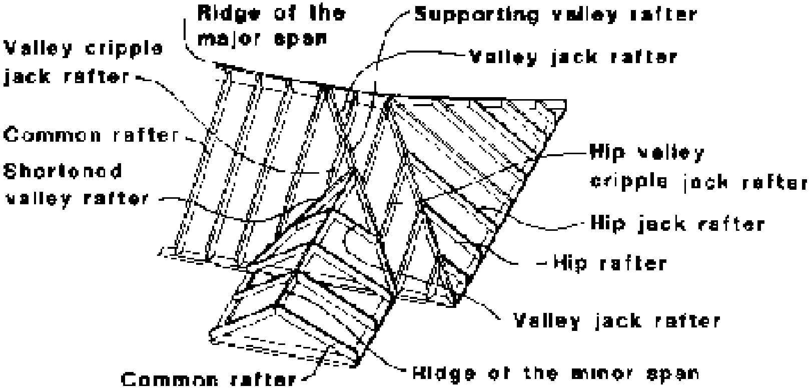
Roof types

1.4.2 Structural elements



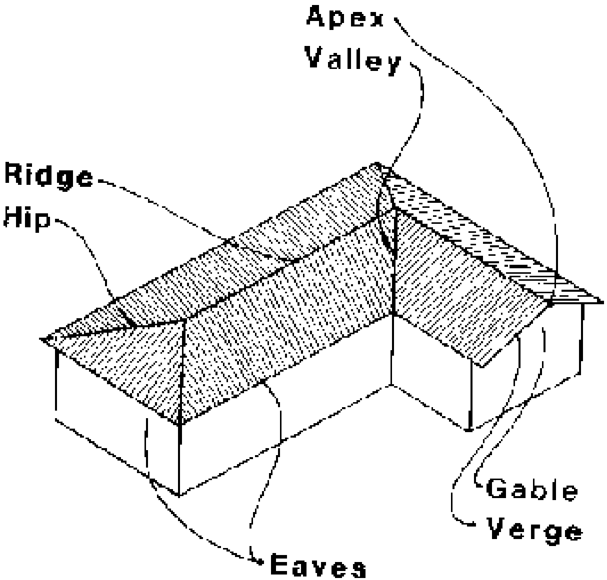
Structural elements 1





Structural elements 2

1.4.3 Roof cover related terms



Roof cover related terms

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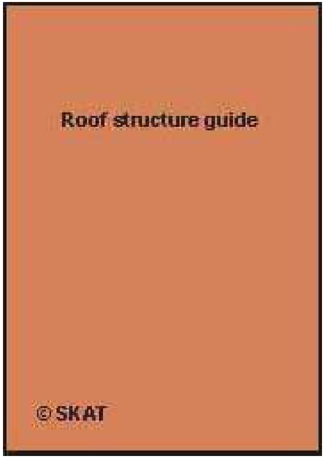

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2. Fundamentals of building statics

When designing and constructing a roof it is self-evident that it should be robust enough to withstand all the forces that act on it. The roof must be stable, must not collapse or distort. On the other hand, for economical reasons, the structure should not be oversized. It should not be as strong as possible, but as strong as necessary.

A basic knowledge of building statics enables the builder to develop a structurally correct system and to assess the appropriate dimensions of the structural components.

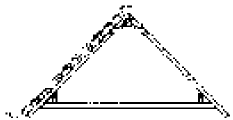
2.1 External forces

2.1.1 Acting forces

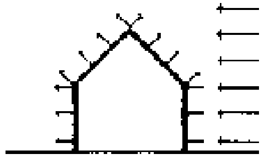
(Magnitude of forces on roofs see Chapter 2.3)

The loads that act on a roof structure come from different sources. A distinction can be made between dead load and live load.

Dead load



Live load



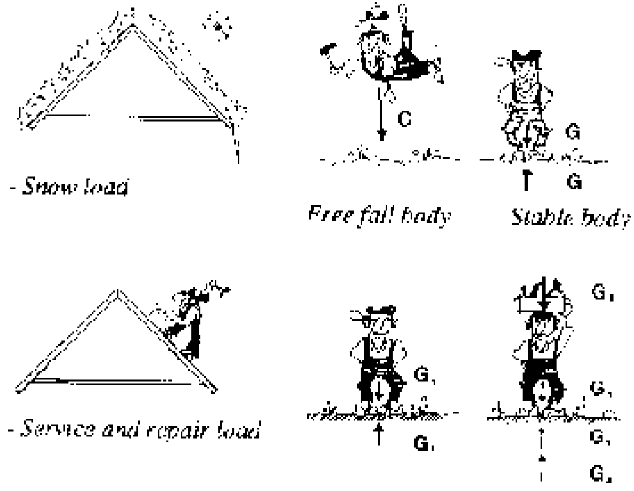
- *Example of wind load*

Dead load; Live load

The dead load consists of the weight of the structure and of the cover.

- Example of wind load

Live loads consist of wind load, in some cases show load and service or repair load. In lightweight roofs such as tiles and sheets wind is often the heaviest load. Wind can also have a suction effect, causing the roof to lift.



c) Earthquakes

Snow load; Service and repair load; Free fall body; Stable body

Snow loads only occur in certain regions, depending on the climate.

Service (repair) load is of little relevance because it does not normally apply at the same time as the maximum wind or snow load.

c) Earthquakes

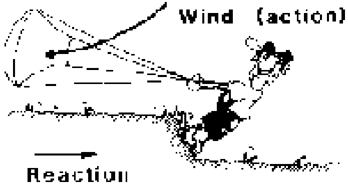
Forces resulting from earthquakes are in fact not additionally-superimposed loads. Earthquakes cause a horizontal or vertical movement that results in dynamic forces due to the dead load. For static calculations the earthquake load is taken into account in the form of an additional fraction of the normal horizontal load. Its magnitude depends on the significance of the building and on its location (risk zone).

2.1.2 Reacting forces

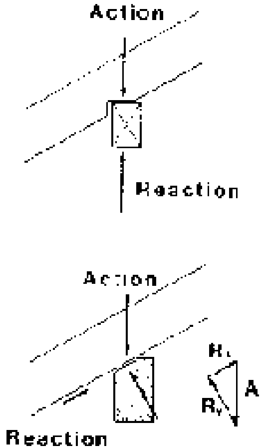
Every force acting on a body causes a corresponding reacting force; otherwise the body would not be stable.

The sum of the forces acting on a body in a state of equilibrium is always zero. For that reason for every force acting on a body (acting) there has to be a corresponding force (or sum of forces) acting in the opposite direction (reacting).

A vertical acting force (usually gravity) causes a vertical reacting force; a horizontal one (usually wind) causes a horizontal reacting force.



Example: Reacting forces at a rafter support point



Example: Reacting forces at a rafter support point

Depending on the support system, an acting force can either causes

a reacting force directly in the opposite direction or a pair of reacting forces with a resultant in the opposite direction.

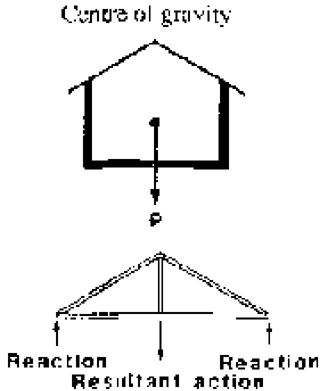
This can best be illustrated by two different designs for rafter support:

Under normal load conditions (excluding wind) the so-called “bird’s mouth cut” support causes a direct vertical reacting force.

If the wall plate or ridge beam is slanted in line with the roof slope, a pair of reacting forces results, one vertical to the rafter, the other one longitudinal to it. The resultant of the two is vertical. This support design requires additional fixing means and is in practice very difficult to implement.

2.1.3 Load distribution of external forces

In roof constructions, the centre of the acting force and the location of the bearing (reaction) points are usually not identical.



Centre of gravity

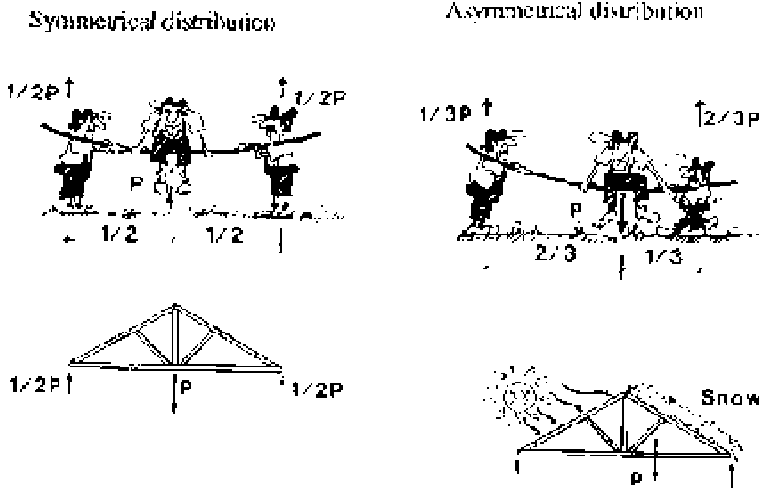
In the case of a vertical load only, the centre of the acting force is identical with the centre of gravity. For the purpose of calculating the load distribution over two bearing points it is convenient to assume that the whole weight acts through this point.

Equal distribution

In the case where the centre of the acting force lies in the middle between the bearing points, the load is distributed equally over the bearing points. This applies to most roof constructions which are symmetrical with an even load distribution.

Unequal distribution

In the case where the centre of the acting force is located asymmetrically, the bearing point which is closer receives a greater part of the load and the reacting force is bigger. The distribution of the load is in inverse proportion to the distance between acting and reacting forces. This applies to asymmetrical roofs and in the case of uneven live loads, e.g. snow on one side only.



Equal distribution; Unequal distribution

Cantilever

When the centre of the acting force lies outside the two bearing points, an additional moment of force (torque) occurs. In order to keep the system in equilibrium (static) the bearing points receive an additional load.

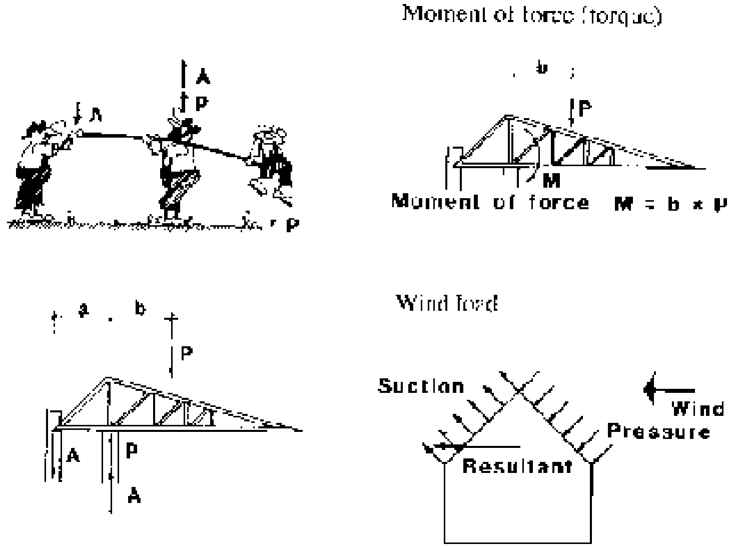
The figure opposite shows that the bearing point at the left side receives an uplift force (A), whereas the bearing point in the middle receives the entire load P plus the force A in a downward direction, thus P + A.

The same situation can occur in cases of wide overhanging roofs and other cantilever constructions.

Moment of force (torque)

To calculate the magnitude of the additional forces caused by cantilever, it is useful to apply the concept of the moment of force. It is defined as the distance between the turning point and the force multiplied by the force, the distance being at right angles to the directional line of force. If a system is in equilibrium, the sum of

all left-turning moments is equal to the sum of all right-turning moments. In the example in the figure opposite the cantilever above the force A is hence
a x A = b x P and A = |f(b x P,a)



Cantilever; Moment of force (torque); Wind load

Wind load

Wind load acts perpendicular to the surface, usually as pressure on

the windward side and as suction on the leeward side. Its resultant is usually approximately in the direction of the wind, that is, horizontal.

The reacting forces caused by wind load can be determined using the concept of moment of forces. The horizontal (resultant) wind load (W) creates an equal reacting force at the bearing point. This force multiplied by the distance between the acting and reacting forces gives a moment (a x W). This moment is balanced by a pair of forces in a vertical direction (B), creating a moment in the opposite direction (b x B). The vertical reacting force is therefore downward on one side and upward on the other side (uplift). Its magnitude is calculated as a x W = b x B, thus B = |f(a x W,b)

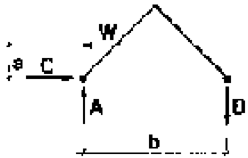
In reality the calculation is more complex because wind creates an uneven distribution of pressure and suction, and the resultant and its direction are difficult to determine.

Nevertheless, the theoretical model clearly illustrates the need for anchoring the structure.

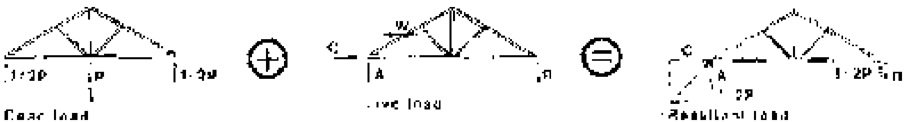
Resultant reacting forces

To determine the resultant reacting forces all the different forces that occur are added.

It is important to keep in mind that all these forces have to be taken down to the foundation. Walls and foundations must be designed and built accordingly. (See Chapter 4.2.1)



Wind load



Resultant reacting forces

Example

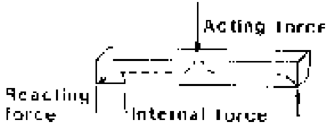
The example of a heavy weight structure illustrates how the active forces resulting from live load and dead load are take down to the foundation and create respective reacting forces.

The example of a light weight structure illustrates, how a wind load can cause uplift reacting forces in the foundation, making anchorage necessary not only in he roof structure but also in the walls and in the foundation.

Example

2.2 Internal forces

In buildings the point of application of the acting force and reacting force are not identical. It is the function of the structure to transfer the acting force. This causes internal forces within the structural elements.



Internal forces

2.2.1 Compression, tension, shear

Depending on the structural system, different internal forces can occur:

- compressive stress
- tensile stress
- shear stress

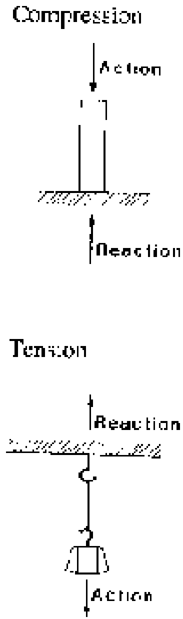
Compression

Compressive stress occurs when the acting force is directed towards the structural member, as is the case in columns.

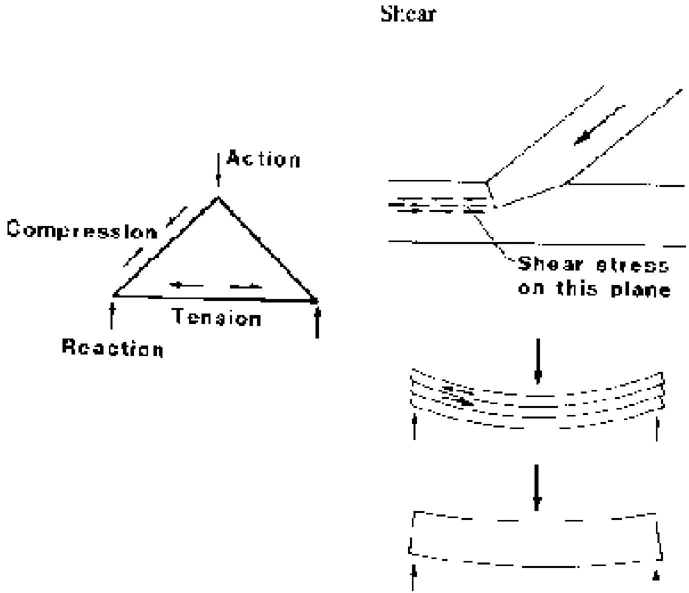
Tension

Tensile stress occurs when the acting force is directed away from the structural member, as is the case in a string when a weight is

suspended. The string is stretched.



Compression; Tension



Compressive and tensile stress typically occur in the case of trusses. Shear

Shear

Shear stress occurs when the flow of forces tends to result in sliding as found in the case of the footing point of a truss.

Shear stress also occurs in a beam which is stressed on bending. This can be understood if one compares a pile of planks with a solid beam of equal dimensions. The planks resist little to the acting force, bend strongly and may even break, whereas the beam only bends a little. This is because the beam can absorb shear stress, but the pile of planks cannot.

2.2.2 Bending moment

If a beam has to transfer a force from the point of application to the point of support it will be under a moment of force. It has to resist a bending moment of the same magnitude.

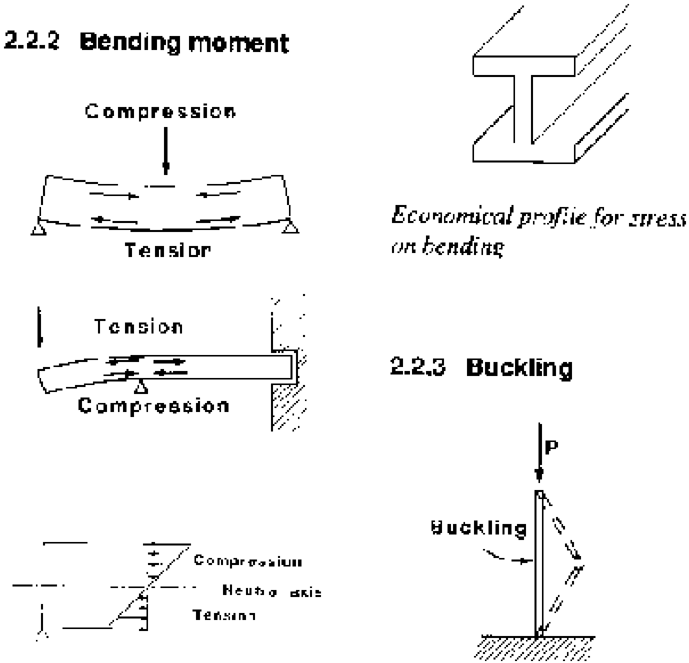
Under the load of a bending moment the fibres on one side of a beam are under tension (stretched), whereas on the other side they are compressed.

On the periphery of the beam the stress is greatest, whereas in the middle of the beam there is neither tensile nor compressive stress. This is the so-called neutral axis.

This is why in the case of bending stress beams of solid sections

are less economical than beams with a profile which is strong at the periphery and weaker near the neutral axis.

Economical profile for stress on bending



Bending moment; Buckling

2.2.3 Buckling

A column under compressive stress may be strong enough from the point of view of compression, but it may collapse due to the effect of buckling.

Effective height

The danger of buckling increases with the effective height. This is not identical with the actual height of the column but depends on the structural system.

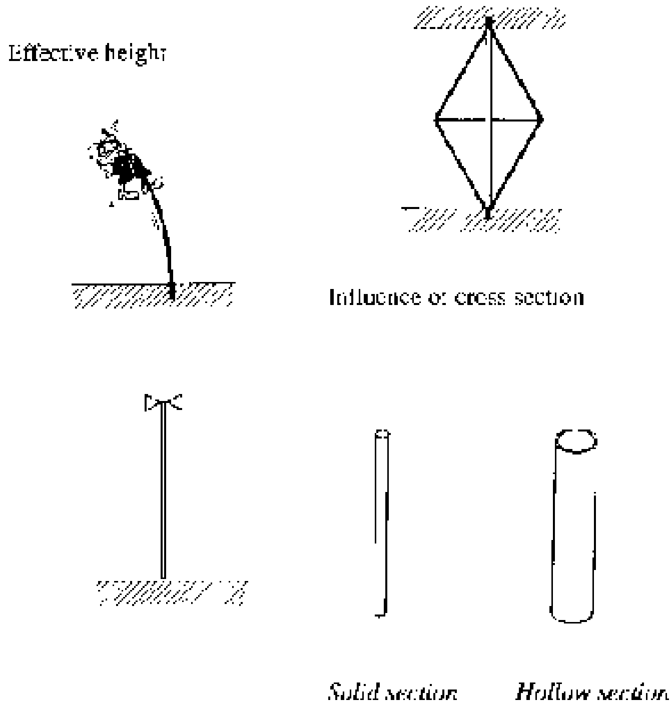
If the upper end of the column is not fixed but can move freely, the danger of buckling is greatest.

If both ends of the column are fixed, the danger of buckling is reduced.

If additionally the centre of the column is fixed, e.g. by bracing or by a truss system, the danger of buckling is further reduced.

Influence of cross section

The type of cross-section has also an influence on buckling. For instance, a pipe with a large diameter but a thin wall is by far stronger than a solid pole made of the same amount of material but with a small diameter.

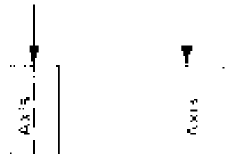


Effective height; Solid section - Hollow section

Application of force

In the case of buckling it is also important where a force is applied. The highest load can be borne when the force is applied centrally. The more eccentrically the force is applied, the less is the bearing capacity and the sooner a column buckles.

Application of force



Centrally and ... *eccentrically applied force*

Wrong *Correct*

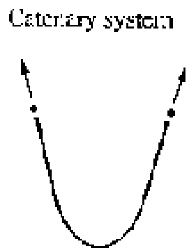
Centrally and ... eccentrically applied force

Therefore, in designing the details of a structure, care should be taken that forces act as much as possible in the axis of a structural member.

Wrong Correct

2.2.4 Distribution and magnitude of internal forces

The distribution and magnitude of internal forces depends not only on the applied external load, but also on the geometry of the structural system.



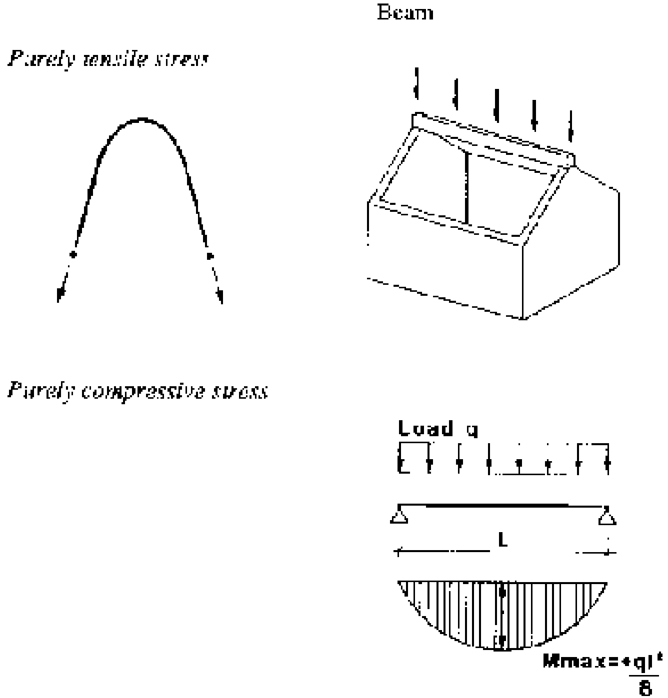
Catenary system

An ideal system with minimal internal forces is the catenary shape.

The geometry corresponds to a chain which is under a uniformly-distributed load and hangs from its ends. When hung, purely tensile stress but no bending occurs in the system. When turned upside down, purely compressive stress occurs.

The system is very useful for the construction of arches and vaults when a material with high compressive strength but with low or no tensile strength is used (brick, adobe etc.)

In the case of flat cover materials such as clay tiles and FCR/MCR, roof structure materials and systems are used which are suitable for the construction of even surfaces and which can also bear bending. Hence catenary systems are usually not applied.



Purely tensile stress, Purely compressive stress; Beam

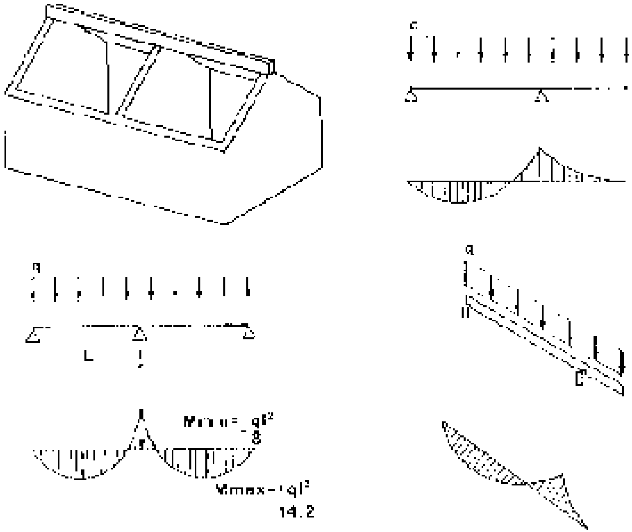
The most common structural element in roof construction is the beam. As seen in chapter 2.2.2 it is stressed on bending. The distribution of the bending moment depends on the location of the supporting points.

In the case of the beam with a supporting point at each end, the bending moment is greatest in the middle and zero at the supporting points. The magnitude of the bending moment depends on the load and on the span. In this case it is calculated using the formula |f(q $L^{2,8}$) .

The greater this bending moment, the greater are the internal tensile and compressive stresses.

In the case of a beam with three supporting points the maximum bending moment is smaller and is no longer exactly in the middle between two supporting points. At the middle supporting point a negative bending moment occurs and on both sides near this point the moment is zero. This is the best place for beams to be jointed, because neither tensile nor compressive stress occurs here.

In the case of a cantilever beam the distribution of the bending moment is analogous, but the entire cantilevered section has a negative moment.



Beam

A common situation of a cantilevered beam in roof construction is the rafter with an overhang.
For sizing of a beam, the maximum bending moment is usually the main calculation criterion.

Framed structures

Trussed and framework structures in the main consist of a

combination of tensile and compressive structural parts. The load which these parts receive depends largely on the geometrical configuration.

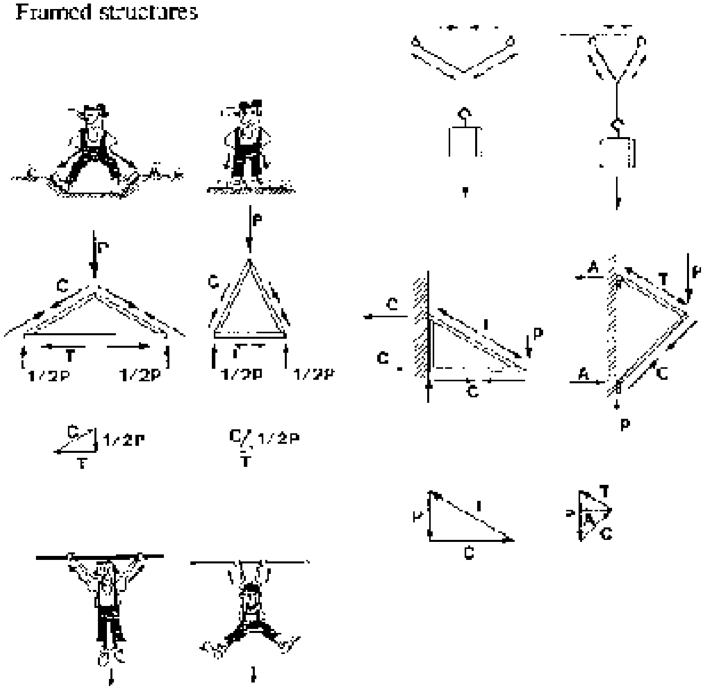
In the case of a rather flat roof, the compressive and tensile stress in the system are by far greater than in the case of a steep roof.

The magnitude of the forces can easily be worked out with the help of a triangle with sides parallel to the structural system.

The same concept also applies in the case of suspending a weight. The greater the distance between the suspending points and the flatter the direction of the tensile components, the greater is the internal force.

The internal forces that occur in a cantilever construction can be determined in the same way. Here the importance of the direction of the supporting strut becomes obvious.

If the strut is inclined, the resulting internal forces are much smaller.



Framed structures

2.3 Loads on the roof

In order to build a good, strong roof, it is necessary to take into account the forces which act on a roof. These forces are called

loads and can be divided into.

Dead loads and
Live loads
(also see Chapter 2.1.1)

2.3.1 Dead loads

The weight of the structure, the cover, the ceiling, ceiling fans etc. are called dead load.

Its magnitude depends on the size of the structural elements and the material they are made of, and on the kind of cover and ceiling. The dead load has to be calculated from case to case.

In the case of FCR/MCR, the values for average housing-type buildings are:

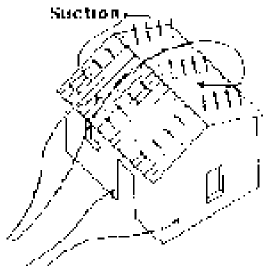
Purlins, rafters, battens	15 kg/m^2
FCR tiles (at a 30^o slope)	27 kg/m^2
FCR semi-sheets (at a 30^o slope)	39 kg/m^2

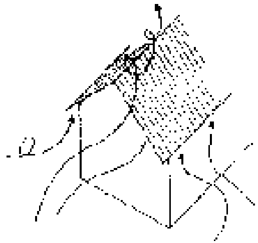
With increasing slope, the weight of the cover per m^2 (in the horizontal) increases.

2.3.2 Live load

The load which is imposed on the roof is called the live load. It consists of wind load, repair load, and in certain cases snow load etc.

Wind load





Wind load

The most dangerous load in most locations is the wind load. Strong winds or storms can cause great damage to a roof if it is not well made and securely fixed to the building.

In designing a structure, live load factors other than wind can

usually be ignored because they hardly occur at the same time as the maximum wind load. However, this does not apply for snow load.

Information on wind may be obtained from meteorological stations, local inhabitants and builders. Local building codes, if available, should be followed.

Wind forces act perpendicularly to the surface, either as pressure or as suction. Usually the maximum wind pressure is lower than the maximum wind suction, the latter resulting in considerable uplift forces, particularly on low-pitched roofs.

It should be noted that the suction forces are much higher at roof overhangs, ridges, eaves, verges and other protruding edges and corners. These must be counteracted by fixing the roof structure and covering firmly in these areas. Moreover, if a building has large openings, or in the case of an open shed, the wind forces are further increased.

The magnitude of the wind load varies greatly, depending on the wind direction and its turbulence, on the shape and orientation of

the building.

In general a maximum wind speed of 150 km/h is taken into account which is equivalent to a storm capable of uprooting trees. This results in suction forces on the roof of up to 70 kg/m^2. In the case of buildings which are open on one side, the suction can be double this figure.

On eaves, verges and ridges the suction can reach up to 160 kg/m^2.
The wind can also create pressure of up to about 30 kg/m^2 on the roof.

Repair load

Many lightweight roof covers (e.g. FCR/MCR) are not considered suitable to walk on and therefore loads caused by people are generally not taken into account. However, during construction and maintenance, workers may climb onto the roof. This is mainly of relevance for the sizing of battens. For the safety of the workers a single batten has to be able to bear the weight of a man, say 80 kg.

Snow load

Depending on climatic conditions snow can fall on the roof. Information on snowfalls may be obtained from meteorological stations, local inhabitants and builders. Local building codes, if available, should be followed.

1 cm of snow generally exerts a pressure of 3 kg/m^2.

2.3.3 Resultant load

In the design and construction of a roof, the resultant live and dead loads - that is, the worst possible combination of these forces - are to be taken into account.

Load for structures

In the design of the structure, usually the dead load plus wind pressure (plus snow load) are relevant. In certain cases the dead load plus service load may be relevant. A combination of dead load, service load and wind pressure is not necessary, because maximum wind pressure and service load hardly occur at the same time.

For FCR/MCR the recommended load factors are:

Maximum dead load	55 kg/m^2
Wind pressure	30 kg/m^2
Total	85 kg/m^2

or

Dead load	55 kg/m^2
Single load	80 kg

whichever creates the greater bending moment.

Load for anchoring the structure

To design the required anchoring against uplift, the maximum wind suction is to be considered.

For FCR/MCR the recommended load factors for closed buildings are:

Wind suction	70 kg/m^2
Minimum dead load	- 40 kg/m^2
Total	30 kg/m^2

In the case of open buildings the suction force is much bigger.

Load for anchoring the cover

When fixing the cover, the wind suction also has to be considered.

In the case of closed buildings, the recommended load factors in the middle of an FCR/MCR roof area are:

Wind suction	70 kg/m^2
Weight of the cover	- 20 kg/m^2
Total	50 kg/m^2

On eaves, verges and ridges a higher wind suction occurs. In this case, for FCR/MCR the recommended load factors are:

Wind suction	160 kg/m^2
Weight of the cover	- 20 kg/m^2
Total	140 kg/m^2

1 kg/m^2 = 0.01 kN/m^2

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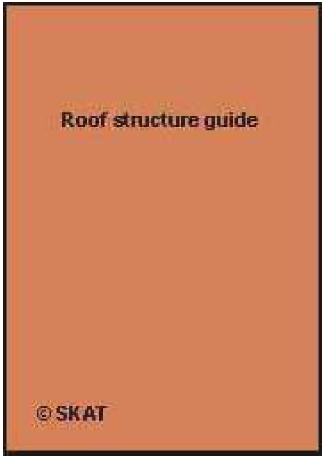


Roof Structure Guide - Basics for the Design and Construction of Leightweight Sloped Roof Structures (SKAT, 1993, 144 p.)

3. Shape of the roof

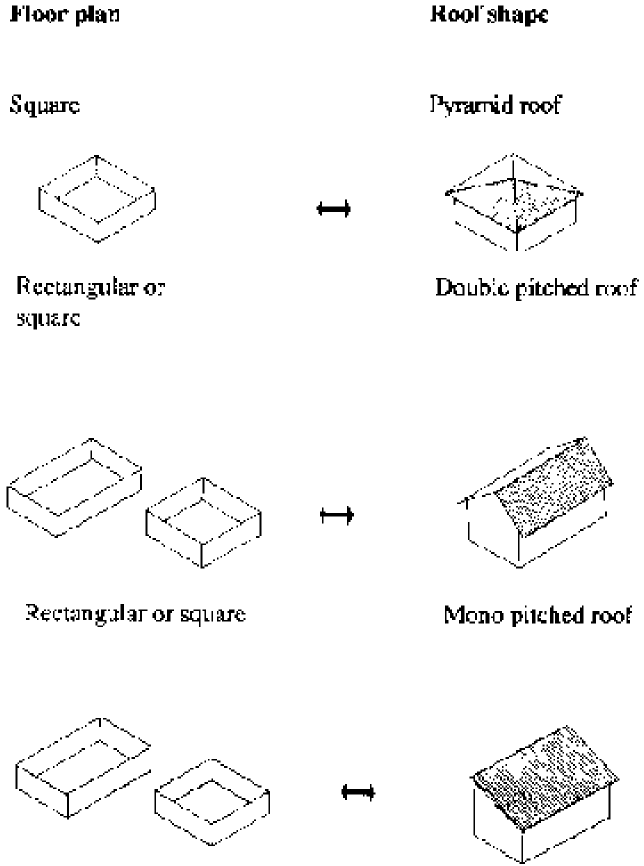
3.1 Roof forms and floor plan

The floor plan and roof shape of a building are interrelated. Not every floor plan matches a given roof shape and, the other way round, not every roof shape matches a given floor plan. Therefore, when designing a floor plan, possible roof shapes have to be

considered.

Moreover, the characteristics of the cover materials may restrict the freedom in form. For most roofing materials which consist of rectangular elements, such as tiles, corrugated iron sheets, FCR/MCR etc., roof areas of a rectangular shape are convenient, whereas free forms are difficult to roof.

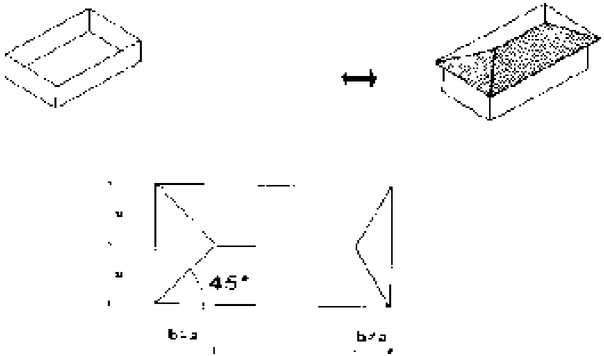
Free and complicated forms in roof design are not impossible, but the construction of such a structure and the laying of the cover involve more labour and skill, require practical experience and close supervision and also resulting in higher costs. These facts should be considered at the design stage.



Floor plan; Roof plan 1

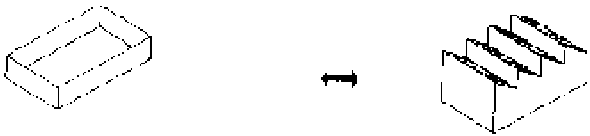
Rectangular

Hipped roof



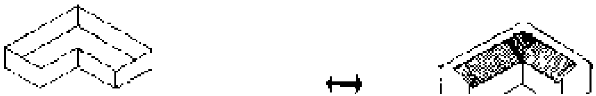
Rectangular

Shed roof

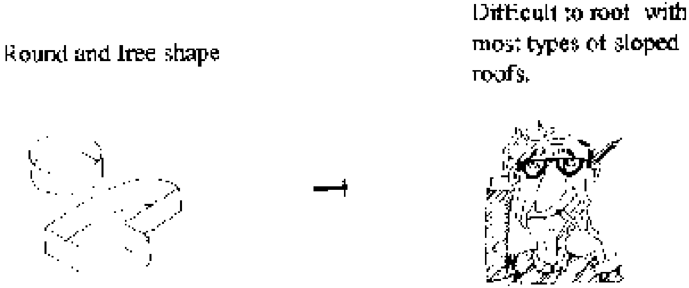


L - shape

Roof with valley



Floor plan; Roof plan 2



Floor plan; Roof plan 3

3.2 Main wind and orientation of roof

In general wind and storms can occur in any direction. Hence the roof has to be built equally strongly on all sides.

However, under certain circumstances a main wind direction can be determined. This is the case in certain geographical locations with well known typical winds or where the topography or surrounding buildings and obstructions influence the wind pattern.

Where such typical wind patterns can be identified, they can be

considered while designing the roof.

In areas with heavy winds the design should aim at a minimum wind impact and thus a minimum wind load on the roof. This lowers the danger of damage to the roof and may reduce the cost of the structure and extra fixing of the cover.

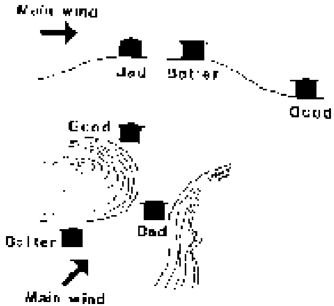
In hot areas, however, where cooling by air movement is desired, buildings should preferably be exposed to winds. This may contradict the requirements for a safe and wind-protected roof. [10]

Some considerations for a wind protected roof are:

Topography

Avoid locations such as crests which are exposed to extreme winds.

Topography



Topography

Avoid locations such as gorges and ravines where wind is funnelled.

Roof shape

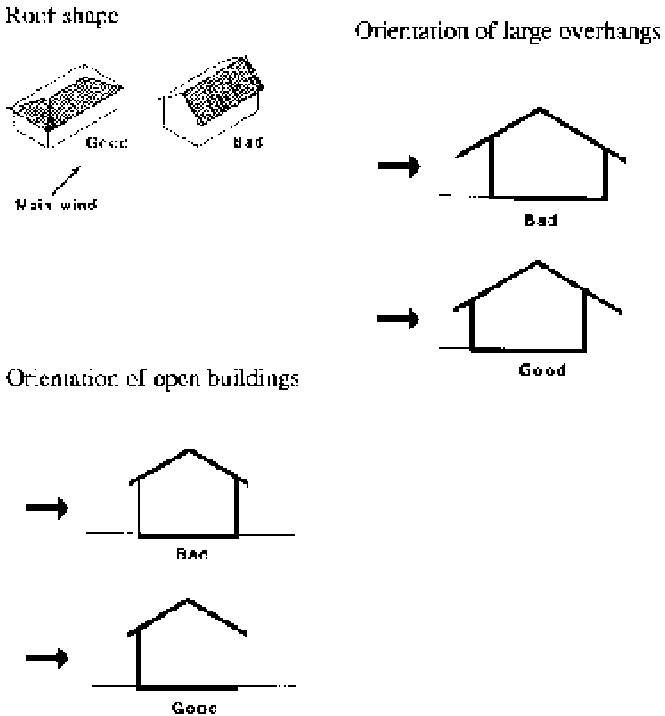
A hipped roof rather than a gable roof is preferred in heavy wind areas because the wind forces are smaller.

Orientation of open buildings

Large openings in buildings should not face the main wind direction. This would result in very high suction forces.

Orientation of large overhangs

Similarly, large overhangs should not face the main wind direction.



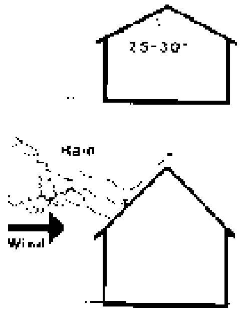
Roof shape; Orientation of open buildings; Orientation of large overhangs

3.3 Roof slope

An appropriate roof slope depends on the cover material used and on the climatic conditions.

Roof slope for FCR/MCR

For FCR/MCR, the recommended roof slope is between 25· and 30·. Steeper slopes are also possible.
The minimum roof slope is 22·. It should only be used in dry areas with little wind.



Roof slope for FCR/MCR

A steep roof of 30· and more is adequate in areas where heavy rain

occurs together with wind.

Advantages and disadvantages

low slope	
+	small surface and hence reduced cost
-	not watertight when rain coincides with wind
-	High wind suction forces
high slope	
+	waterproofing more reliable
+	less wind suction forces
-	higher cost

Conversion factors

See Appendix 1 to convert a pitch which is expressed in degrees, into pitch a percentage, or into the ratio rise: span, or the ratio rafter length: span.

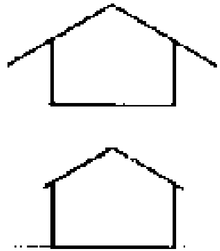
3.4 Roof overhang

The roof overhang is designed according to the specific situation and requirements of the building. Beside aesthetic preferences, the following factors determine its size:

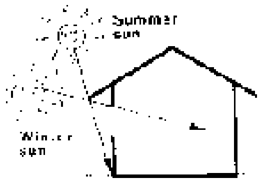
- protection of walls against rain,
- climate (solar heat gain),
- access to daylight,
- wind impact

A large roof overhang protects the wall from rain and provides shade. On the other hand, it reduces daylight in the rooms and direct solar heat gain. The roof area exposed to winds is large.

A small overhang provides little shade and protection from rain, but allows good daylight access to the rooms and solar heat gain on walls and openings. Winds have less impact.



Climatic considerations



Climatic considerations

A large overhang on a high wall provides proper protection from the high (summer) sun, but cuts off less light. It provides good access to the low (winter) sun and hence solar heat gain in winter. It is suitable in areas of temperate climates, where protection against the heat in summer and heat gain in winter are desired. [10]

Structural limits

For structural reasons the maximum size of overhangs depends on the roof span. The relation between roof span and overhang is defined in Chapter 4.3.5.

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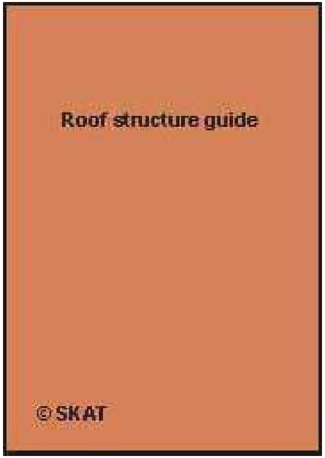

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4. Roof structure

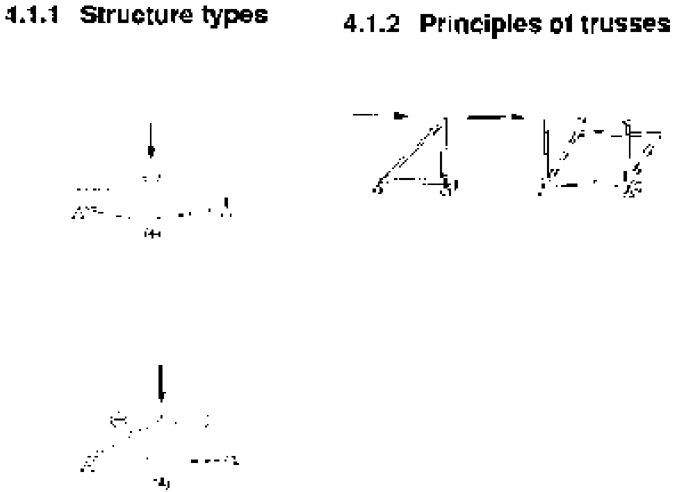
4.1 Principles of structure design

4.1.1 Structure types

Basically, two types of structure are used:

a) The beam system, where simple beams are stressed on bending. Both tensile and compressive stresses occur on the beam.

b) The system using trusses. In this case the structural members of the truss receive either tensile or compressive stress only.



Structure types; Principles of trusses

4.1.2 Principles of trusses

The basic shape of the truss is triangular, because a triangle cannot be distorted, unlike shapes with more than three angles.

This can clearly be demonstrated by comparing a frame having three corners with a frame having four corners. The triangle frame is always rigid. The rectangular frame can easily be distorted, the only resistance being the corner joints.

Perfect and imperfect structures

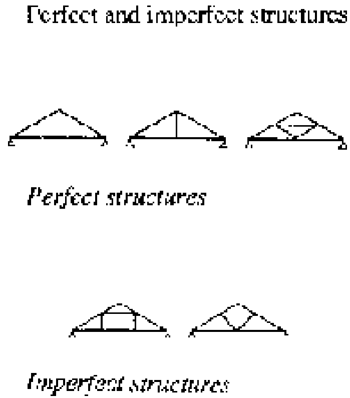
Structures consisting of triangles only are called “perfect structures”. If a structure includes elements of more than three angles, it is called an “imperfect structure”.

Perfect structures

There are many examples of “perfect structures”, e.g. bicycle frames or scaffold braces.

Imperfect structures

Trusses should be made as perfect structures, consisting of triangle-shaped elements only; rectangular or square structures should be supplemented with diagonals.

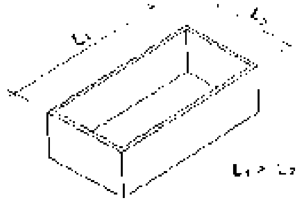


Perfect and imperfect structures

4.1.3 Structural design in a step-by-step approach

When designing the roof structure, the supporting elements required by the roof-cover material must be taken into account.

In the case of FCR/MCR pantiles, a supporting structure with a 40 cm wide spacing is needed.



Structural design in a step-by-step approach

Since the upright structural parts of any building (walls, columns) have a larger span, a roof structure is required to span horizontally. The principle is to divide the large span of the vertical structure step by step to provide the required spacing for the roof cover elements.

1. Step

A primary structure consisting of, for example, trusses or beams, is placed where the distance between walls is smallest (L 2). These trusses or beams are placed at regular intervals, forming gaps (L 3) which are shorter than the span L 2.

2. Step

A secondary, finer structure (e.g. ridge beams and purlins) is laid dividing the gaps further (L 4).
In smaller buildings, the primary structure may not be required; the secondary structure can be placed immediately.

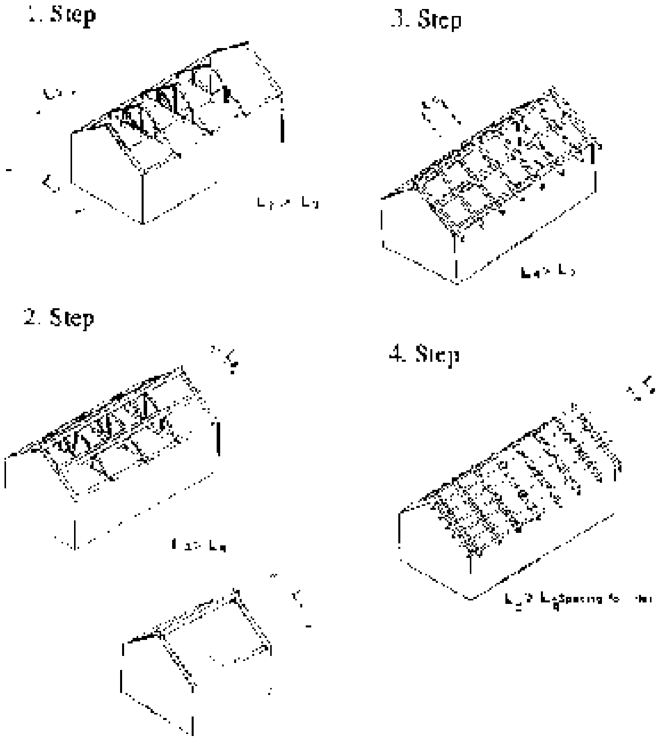
In some cases, the spacing in the primary structure (L 3) may be smaller than the span of the secondary structure (L 4), but the roof area carried by subsequent structural members become smaller and smaller.

3. Step

The system of dividing the span further can be continued by placing. rafters with the spacing L 5.

4. Step

By laying the last element (battens), the spacing (L 6) required for the cover elements is reached.
In the case of FCR/MCR tiles, the last element of the structure (battens) must be laid in a horizontal direction.



Steps

4.1.4 Detail principles

First large, then small members

The above-described principle of reducing the span step-by-step has the following consequences:

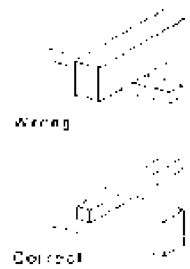
The primary structure carries the highest load and is hence the strongest, i.e. heaviest member.
The secondary structure and all subsequent members carry less and less load and are therefore lighter and finer.

Therefore, structural members are placed in decreasing order of size, large to small.

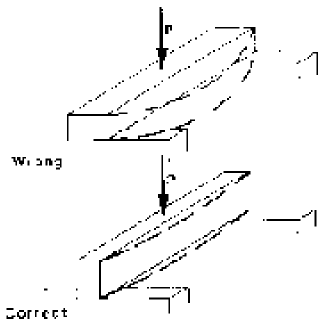
Laying of rectangular beams

Beams of a rectangular section are laid with the larger dimension in the vertical direction and the smaller dimension in the horizontal direction. In this way the load bearing capacity is greater.

First large, then small members



Laying of rectangular beams



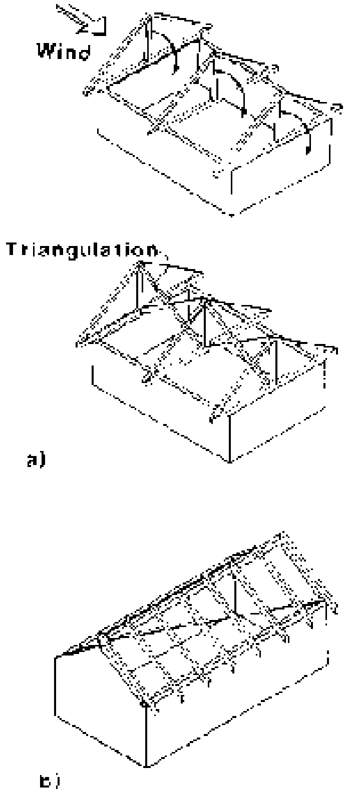
First large, then small members; Laying of rectangular beams

4.1.5 Bracing

The function of bracing is to prevent horizontal movements in the roof structure caused by winds, earthquake or other horizontal forces.

The principle of bracing is usually based on triangulation. Braces can be laid either in a vertical position between trusses (a) or in an inclined position along the rafters (b).

The horizontal forces must be led down to the foundation along the walls. Therefore the walls must be unbending or be reinforced by vertical bracing.



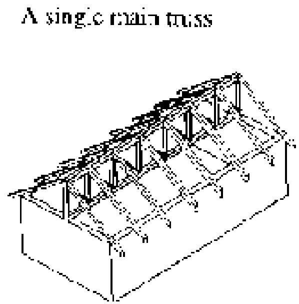
Bracing

4.1.6 Special forms of primary structure

A single main truss

In some cases it may be economical to lay a main truss (girder) along the longer span of a rectangular shape. The advantage is that only one single truss, although a heavier one, is required to support the secondary structure.

Such trusses have to be designed by a qualified engineer.



A single main truss

Frame trusses

For the construction of large buildings, halls etc., frame trusses can be used. The trusses rest directly on the foundations and provide

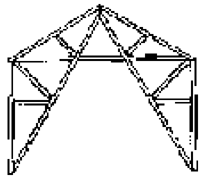
support for the roof as well as for lightweight walling systems.

Spanning in two directions

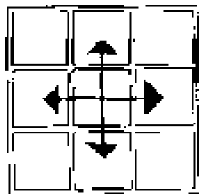
To span a space which is square or almost square, it may be appropriate to lay the primary structure in two directions. In concrete technology this system is common, when beams or slab reinforcements are laid in two directions.

Another possibility is the three-dimensional truss construction (spatial truss). In this case the crossing points of the structural members require a careful design and workmanship, especially if they are made of timber.

Frame trusses



Spanning in two directions



Frame trusses; Spanning in two directions

4.2 Structures for storms and earthquakes

(also see Chapter 2.3 and 3.2)

As described in Chapter 2.3, structures have to withstand not only live loads and dead loads, but also loads from storms and

earthquakes.

4.2.1 Storms

[see FCR News No 5] Winds with a speed of more than 75 km/h are considered storms. They cause heavy pressure and suction on the structure in a direction perpendicular to the surface.

The main storm-prone areas in the world are well known, such as Southeast Asia, Central America, where special care has to be taken.

Storms can, however, occur everywhere, although perhaps less frequently and with less intensity. Therefore structural means with which to avoid destruction of the roof are important in any location.

Structures are normally designed for a wind speed up to 150 km/h.

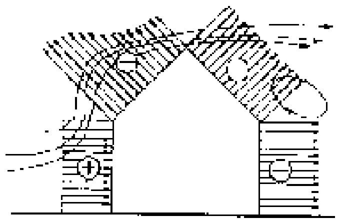
Means for avoiding storm damage:

a) Anchorage

The roof structure should be secured to the walls by bolts or rods

against uplift (see also chapter 4.3.4). These bolts are attached to the ring beam reinforcement. Where there are no ring beams, the anchorage can be built into the masonry wall. In this case the anchorage should be at least three brick courses deep.

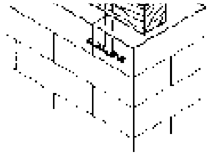
[see FCR News No 5]



Possible example of wind load distribution

Means for avoiding storm damage

a) Anchorage



Insufficient anchorage of wall plate, in top course only

Possible example of wind load distribution; Insufficient anchorage of wall plate, in top course only

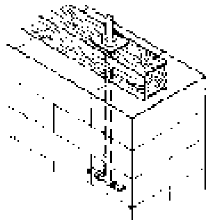
Based on the data in Chapter 2.3, the magnitude of the uplifting forces can be determined. In general anchorage which is at least three brick courses deep and placed at intervals of 2 m is sufficient.

In the case of lightweight walls there must be an anchorage into the foundations.

b) Bracing

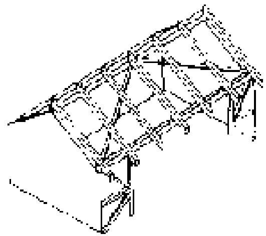
Winds naturally have a strong horizontal load component on roofs. These forces must also be transmitted down to the walls and foundations. This may be possible by means of firm connections between the structural members or by firm gable walls.

A more secure and therefore recommended method is the use of bracing.

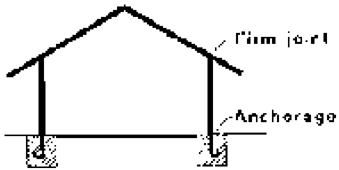


Anchorage 60 cm deep is recommended

b) Bracing



Bracing in the plane of the roof slope



Lightweight wall with anchorage in foundation

Anchorage 60 cm deep is recommended; Lightweight wall with anchorage in foundation; Bracing in the plane of the roof slope

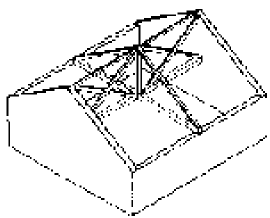
At the point where bracing is connected to the walls, concentrated forces occur. These forces must be transmitted along the walls to the foundations. This is possible either by firm walls or by additional bracing in the walls.

c) Ring beam

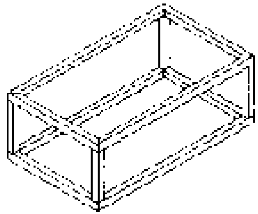
A ring beam (tie beam) is a continuous beam at the top of the wall.

It provides a solid base on which wall plates or rafters can be anchored. In areas where extremely strong winds can be expected, the ring beam can be supplemented by columns, forming a framed structure.

Such structures are usually made of reinforced concrete.



Bracing of trusses in a vertical plane



Framed structure

Bracing of trusses in a vertical plane; Framed structure

Influence of roof pitch

Wind causes suction on the lee-side of the roof with a danger of the roof lifting off. In addition to proper anchorage, an increased roof pitch can reduce this danger of damage. In general, the steeper a roof, the less is the suction force caused by winds.

Shape of the roof

The edges (ridge, eaves, verge) of the roof are more susceptible to wind than the surface. The most critical parts are the verge and the mono-pitched ridge. Therefore for wind safety the preferred roof shape is the hipped roof. Gable roofs or mono-pitched roofs are

disadvantageous.

(also see Chapter 3)

4.2.2 Earthquakes

Earthquakes occur mainly in well known zones around the globe. In these areas special precautions have to be taken.

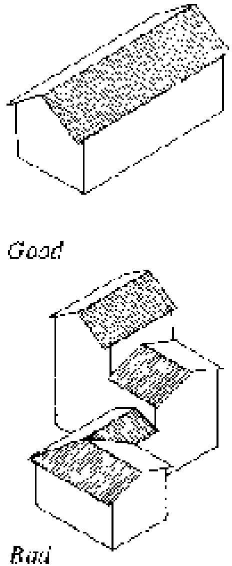
Seismic waves comprise horizontal, vertical and torsional (twisting) movements. Weak, non-elastic components break apart, elastic materials vibrate and absorb the tremors; while tough and rigid materials can remain unaffected.

Means to avoid damages by earthquakes

a) Simple building form

Simple and symmetrical buildings are safer than buildings with complicated and asymmetric shape.

Buildings of complicated shape should be divided in simple independent components which are separated by expansion joints.



Simple building form: Good - Bad

b) Light roof

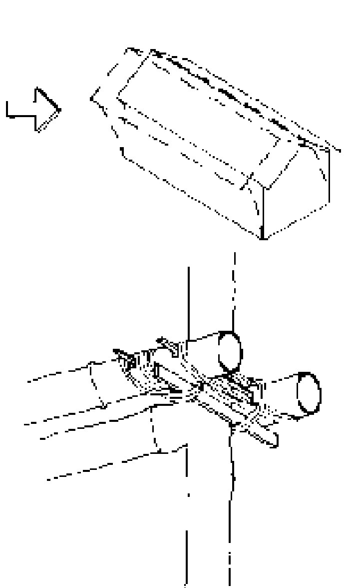
For safety reasons in earthquake areas, the centre of gravity (see Chapter 2.1.3) of the building should be as low as possible. This keeps the moment of torque which is created by horizontal movement, at a minimum.

The roof should therefore be light. FCR/MCR is an advantageous material in this respect. If the roof is properly anchored and braced for storms (see chapter 4.2.1), then it is also safe for earthquakes.

c) Flexible structure

A structure with flexible but tight joints can balance horizontal movements by giving way to them. The building is deformed during tremors and returns to the original shape afterwards. Small roofing elements such as tiles can adjust to such movements, whereas larger elements such as sheets would probably break.

Bamboo and pole timber are suitable materials for such building systems.



Flexible structure

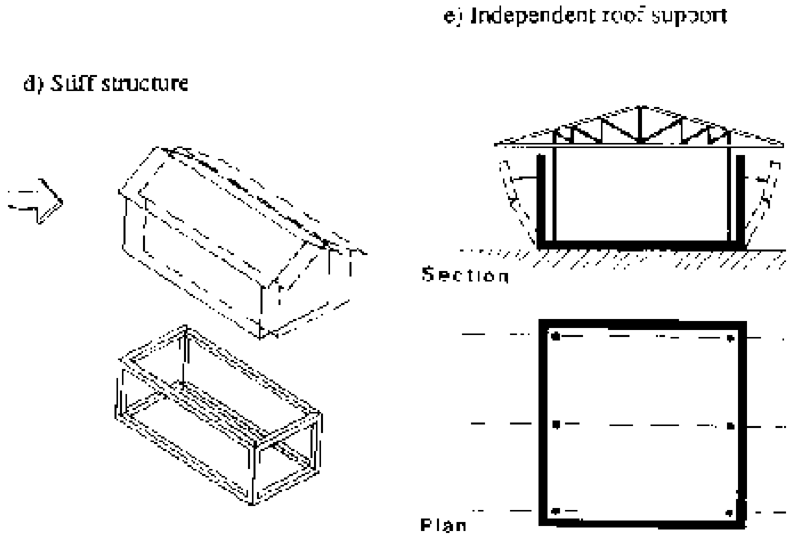
d) Stiff structure

Another approach is to build a structure with stiff joints to avoid any deformation during earthquakes. This results in dynamic forces which demand a firm construction.

Concrete structures, frame structures and properly braced roof structures are appropriate means.

e) Independent roof support

Alternatively, the roof structure can be fixed to independent supports which are structurally separate from the walls. In the case of the walls collapsing, the roof remains unaffected.



Stiff structure; Independent roof support

4.3 Timber structures

4.3.1 Materials

This chapter deals with sawn timber only. Another kind of timber, pole timber, is briefly dealt with in Chapter 4.4 "Alternative structures".

General

Timber is not only one of the oldest, but also one of the most versatile building materials. However, it is an extremely complex material, available in a great number of varieties and forms with greatly differing properties.

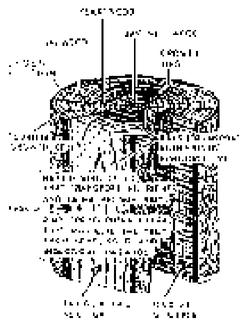
Timber is basically a renewable material. Nevertheless, there is an universal concern about the rapid depletion of forests and the great environmental, climatic and economic disaster that would follow. Although construction timber represents only a small fraction of the timber felled, it should be used thriftily and wastage should be minimised. In addition reforestation programmes should be promoted.

Growth characteristics

The cross-section of a trunk or branch reveals a number of concentric rings. The trunk diameter increases by the addition of new rings, usually one ring a year.

The early wood (spring wood) formed during the main growth period has larger cells, while in the dry season the late wood (summer wood) grows more slowly, has thicker cell walls and smaller apertures, forming a narrower, denser and darker ring, which gives the tree structural strength.

Growth characteristics



Structure of a tree trunk (hard wood and soft wood)

Structure of a tree trunk (hard wood and soft wood)

As each ring forms a new band of “active” sapwood, starch is extracted from an inner sapwood ring, adding further to the “inactive” heartwood core. Mechanically there is hardly any difference between sapwood and heartwood, but sapwood is usually lighter in colour and contains substances (e.g. starch, sugar, water) which attract fungi and certain insects.

The slower the tree grows, the narrower are the growth rings, and the denser and stronger is the timber. Its resistance to biological hazards is also usually greater.

(Timber commonly used in roof construction see Appendix 2)

Types and properties of timber

Soft and hardwood

Woods are classified as either hardwood or softwood. There are different methods of distinguishing these woods, but the most common definition is that hardwoods comes from broad-leaved

trees, i.e. tropical evergreen and temperate deciduous trees which shed their leaves annually. Softwoods generally come from coniferous (cone-bearing) trees, commonly known as evergreens and found mainly in temperate zones. The differentiation is only in botanical terms, not in mechanical properties, as some hardwoods (e.g. balsa) are much softer than most softwoods.

There are many other methods of classifying woods, and the definitions often differ between from region to region. For instance in West-Africa the terms "red wood" for hard and strong timber and "white wood" for soft and weak timber are common. In other regions this terminology is not known, or used in another sense.

Timber categories

Timber for building construction can be divided into two or more categories according to its mechanical strength. Often one distinguishes between primary and secondary timbers.

Primary timber generally comes from slow-growing, aesthetically appealing hardwoods which have considerable natural resistance to biological attack, moisture, movement and distortion. As a result, it

is expensive and in short supply.

Secondary timber comes from mainly fast-grown species with low natural durability. With appropriate seasoning and preservative treatment, however, the timber’s physical properties and durability can be greatly improved. With rising costs and diminishing supplies of primary timbers, the importance of secondary species is rapidly increasing.

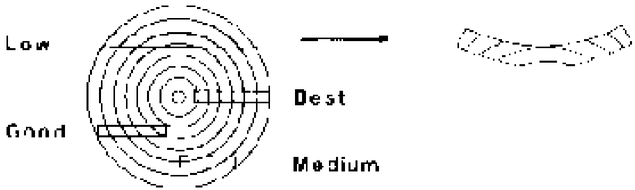
Sizing

When sizing structures, the bearing capacity of the timber being used has to be taken into account. This should be done by consulting the local norms and standards.

In remote areas, data regarding local timber are often not available. For such cases Chapter 4.3.4 provides a simple method for classifying timber without sophisticated equipment. The results may be used as a sizing aid to optimise structures of simple buildings. Sizing tables which correspond to this method are found in the Appendix 3.

Sawn timber products

Sawn timber is cut mainly from the trunks of older trees with large diameters, in rectangular sections as beams or boards. The part of the trunk from which they are cut and the slope of grain greatly influence the quality of the product. Therefore, when selecting timber, the direction of the grain has to be observed.

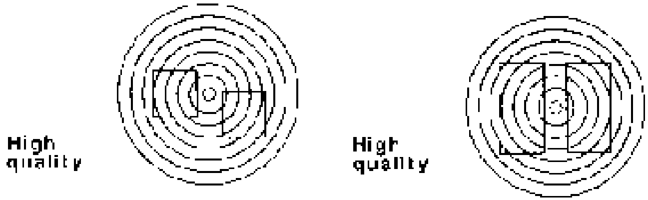


Quality of boards

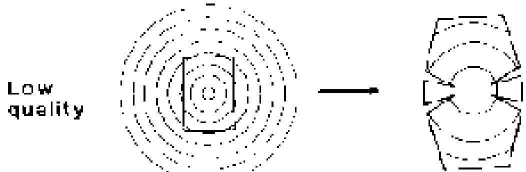
Quality of boards

High quality sawn timber is used for heavily-stressed structural members, e.g. purlins and trusses.

Low quality timber is used for wall plates etc.

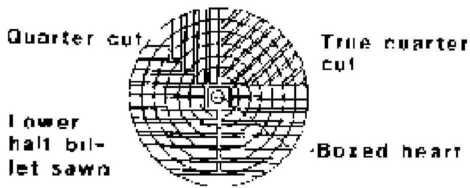


Low quality timber is used for wall plates etc.



Quality of beams

To make the best use of a trunk, the cutting method has to be considered. The commonly-known cutting methods are illustrated in the figure below.



Cutting types

Selection of timber

For structural members which are under high stress, such as purlins, rafters and trusses, the selection of suitable timber is of great importance.

Timber with cracks, knots or with grains that are not longitudinal should not be used. Such timber should only be used in positions with reduced stress, such as wall plates.

Cracks

During felling and transport cracks may occur. Such timber should be rejected.

Cracks may also occur due to shrinkage which is unavoidable. Such timber should be tolerated to a certain extent, but not used for heavily-stressed structural parts.

Hidden cracks may also occur but are very difficult to detect. This risk is taken into consideration in the safety factor in the sizing

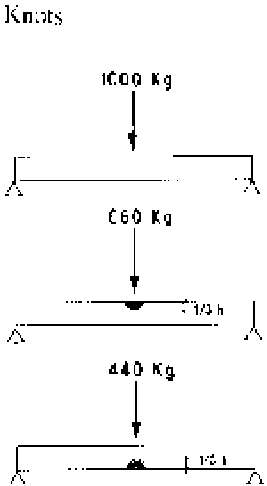
calculations.

Knots

The strength of beams can be greatly reduced by knots, especially when located in the area of the greatest bending moment and in areas with tensile stress.

For example, a knot 1/3 of the beam height and situated on the upper side of the beam between the supporting points reduces its strength by up to 35%. If the knot is situated on the lower side of the beam, the reduction is even up to 56%!

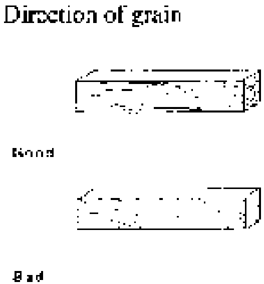
This weakening effect depends much on the growth characteristics of the knot, i.e. how well it is grown into the adjoining wood. (also see example in Chapter 4.3.4)



Knots

Direction of grain

The strength of timber also depends on the direction of the grain. It should be longitudinal. If it is not, the strength is drastically reduced.



Direction of grain

Juvenile and cambium

Timber containing juvenile and cambium parts should be used for subordinate structural members only, e.g. wall plates.

Seasoned timber

To avoid cracking and warping, only seasoned timber should be used.

Wind thrown wood

For ecological reasons it would be highly sensible to use timber from trees blown over by wind. However, because of the risk of

invisible cracks it should only be used for subordinate structures, rafters, battens etc. It should be rejected for use as heavily-stressed beams and trusses.

Such invisible cracks are difficult to detect. A simple but not very reliable method is to throw the cut beams from a height of 0.5 or 1 m. Badly-cracked timber will fall apart. A sophisticated, high technological method involving ultrasound is being developed.

4.3.2 Timber preservation and seasoning

Timber is a highly valuable and durable material. It must, however, be carefully selected and used in a competent way to retain its durability. The following aspects are important in these respects:

Timber which is cut in the non-growing time (winter) is more durable.

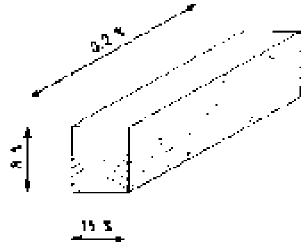
Cambium parts should not be used.
Timber should be properly seasoned before use.
Care should be given to structural details.

In certain cases chemical treatment of the timber may be necessary.

a) Seasoning

Before manufacturing timber components, the timber has to be properly seasoned. One reason is that during drying, timber shrinks. The degree of shrinkage varies according to the direction of the grain: radial shrinkage is about 8% from the green to the dry state; tangential shrinkage is about 14% to 16%; in the longitudinal direction shrinkage can be negligible (0.1% to 0.2%). The use of unseasoned timber results in cracks, warping and as a consequence uneven roofs.

If timber is to be chemically treated, this must be done only with seasoned timber. Some wood preservation methods do not allow the timber to dry properly. The moisture is trapped because the chemicals hermetically seal the timber surface. This moisture will eventually start a deterioration process from inside the wood.



Seasoning

By proper seasoning the moisture content of timber is reduced to its equilibrium moisture content (between 8% and 20% by weight, depending on the timber species and climatic conditions). This process, which takes from a few weeks to several months (depending on timber species and age, time of felling, climate, method of seasoning, etc.), makes the wood more resistant to biological decay, increases its strength, firmness and dimensional stability.

Seasoning methods

Basically there are three different methods for seasoning:

Air seasoning is done by stacking timber so that air can circulate around every piece. Protection from rain and avoiding contact with

the ground are essential.

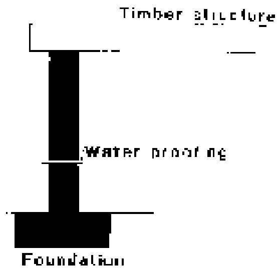
Forced air drying is principally the same as air seasoning, but the rate of drying is controlled by stacking the timber in an enclosed shed and using fans.

Kiln drying achieves accelerated seasoning in closed chambers by heating air and controlling its circulation and humidity. This reduces the seasoning time by 50% to 75%, but incurs higher costs. An economic alternative is to use solar-heated kilns.

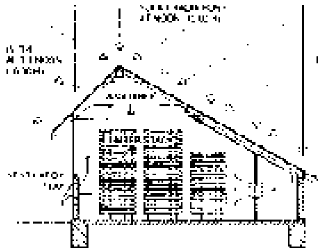
The time requirement for seasoning is greatly reduced if the timber is felled in the non-growing season (winter), when the moisture content of the tree is low.

Seasoning methods

b) Structural means



Protection from moisture



Seasoning methods; Structural means

b) Structural means

The most important aspect in preserving timber is to use it correctly in an appropriate building concept and detailing.

This includes:

Protection from moisture

Access to circulating air

Avoiding of contact with ground

Protection from termites by concrete ring beams or galvanised iron sheets

Protection from moisture

Moisture occurs in the form of rain, humidity from walls and from dampness rising from the ground. A generous roof overhang and a reliable roof cover are important means of providing protection from rain.

Where timber parts come into contact with walls , they should be separated by a bituminous felt.
Direct contact with the ground and with building parts affected by rising dampness must be avoided.

Access to circulating air

Where air cannot circulate or is excluded, a humid atmosphere forms. This promotes the development of fungus. Therefore timber should never be entirely enclosed with airtight materials and cavities should be ventilated.

Avoiding of contact with ground

The ground usually contains moisture which rises along any hygroscopic material such as timber, masonry etc. that is in direct contact with it. It also harbours different kinds of insects such as termites that can quickly destroy timber. Timber must therefore not come into contact with the ground.

c) Choice of material

Whenever available, timber should be used which is resistant to fungal and insect decay. Appendix 2 provides information in this respect.

d) Preservative treatment

When considering preservative treatment of timber, it should be remembered that timber is the "healthiest" of all building materials and it is paradoxical to "poison" it. This applies particularly when other methods could be used to protect it; for instance, a good building design (excluding moisture, good ventilation, accessibility for periodical checks and maintenance, avoiding contact with the ground, etc.) and a careful selection of the timber.

However, in the case of extreme climatic conditions and heavy fungal and insect attack, seasoning and structural means alone may not be sufficient to protect timber, particularly from species which are less resistant. Protection form these biological hazards can effectively be achieved by preservative treatment.

When preservative treatment is required, non-chemical and non-poisonous methods should be given priority.

Non-chemical methods

Stacks of timber can be smoked above fire places or in special chambers, destroying the starch and making the surface unpalatable to insects. However, cracks can occur which eventually

facilitate insect attack.

Immersion of timber in (preferably flowing) water for 4 to 12 weeks removes starch and sugar which attract borer beetles. Large stones are needed to keep the timber submerged.

Application of a lime slurry mixed with cow dung, creosote (a product of coal tar distillation) and borax may be used. This must not be done indoors, because of the strong odours.

Chemical treatment

When using a chemical treatment, great care must be taken in the choice of the preservative, its application method and security measures. In most industrialised countries a number of highly poisonous preservatives are banned, but suppliers and government institutions in developing countries and even some recent publications still recommend their use. No chemical preservative should be used without the full knowledge of its composition. Those containing DDT (dichlor-diphenyl-trichlorethane), PCP (pentachlorphenol), lindane (gamma-hexa-chloro-cyclohexane), arsenic, quicksilver, lead, fluorine and cadmium should be avoided.

Research on non-poisonous preservatives is still underway and full clarity on the toxicity of the recommended and currently available chemicals has not yet been attained. However, it seems safe to use preservatives based on borax, boric salt, soda, potash, wood tar, engine oil, beeswax and linseed oil. Their resistance to biological agents is less than that of the poisonous chemicals mentioned above, but can be equally effective in conjunction with a good building design.

There are several methods of applying chemical treatment to timber. Some examples are:

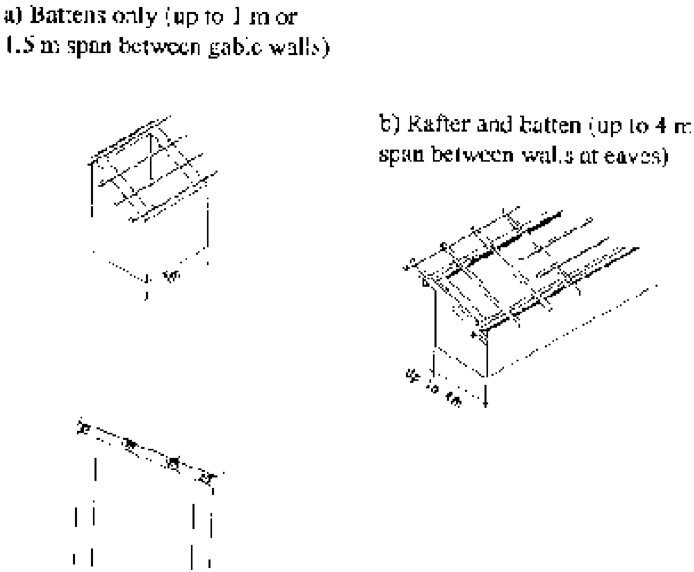
Brushing
Pump-spraying
Immersing in a preservative solution

4.3.3 Timber structure types

The design of timber roof structures depends mainly on the span which is to be covered and on the properties of the timber. The procedures described in Chapter 4.1.3 can be analogously applied.

a) Battens only (up to 1 m or 1.5 m span between gable walls)

The simplest structure is spanning battens from gable wall to gable wall. This is possible for very small buildings, e.g. toilets or small annexes like porches.



Battens only; Rafter and batten

b) Rafter and batten (up to 4 m span between walls at eaves)

For small buildings with a span of up to approx. 4 m, the use of rafters placed directly from wall to wall is possible. This results in a mono-pitched roof.

The span between gable walls is arbitrary. The maximum spacing between rafters is 1 m - 1.5 m.

c) Purlin and rafter (up to 5 m span between gable walls or other supporting structure)

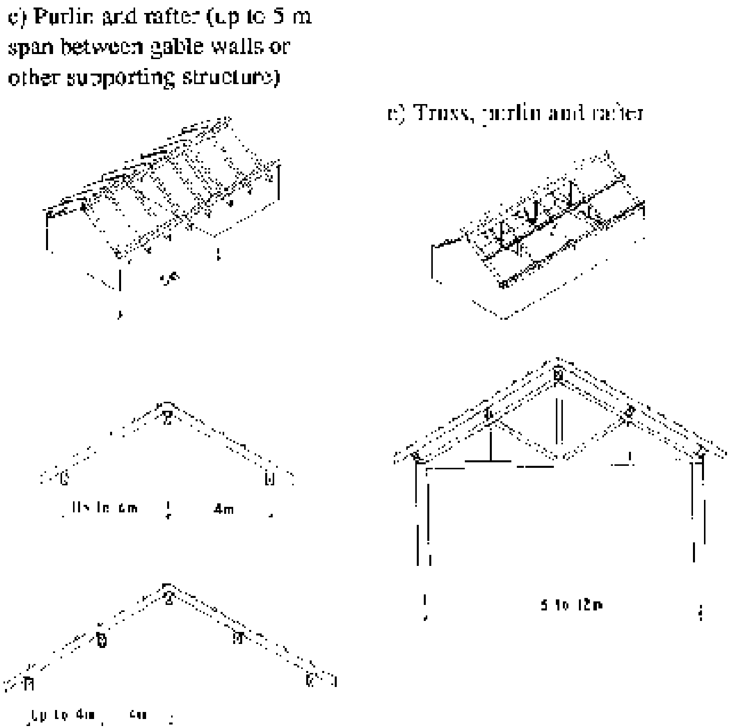
For medium-sized buildings purlins can be used to support the rafters. This allows a free span between gable walls of up to 5 m.

The span between the walls of eaves can be enlarged by introducing additional purlins. This, however, leads to very high ridges.

e) Truss, purlin and rafter

Large buildings can be roofed with conventional trussed structures. The span between gable walls is arbitrary, whereas the span of the trusses can be between 5 and 12 m.

Special truss design allows even larger spans. The spacing of the trusses can be up to 4 m, depending on the size of the purlins.



Purlin and rafter; Truss, purlin and rafter

f) Trussed rafters

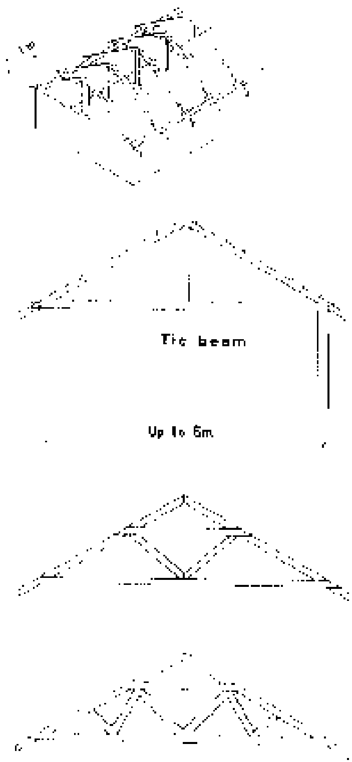
Instead of using a truss-purlin-rafter construction, each pair of rafters is tied together with a horizontal tie beam and acts similarly as a truss.

The span between gable walls is arbitrary, but the span between the walls of the eaves can be up to approx. 6 m. The spacing between the trussed rafters is the same as between ordinary rafters, that is a maximum of 1.5 m.

For larger spans more braces must be used.

Many different forms and systems of truss construction are possible, using various levels of technology (see specialised literature [20]).

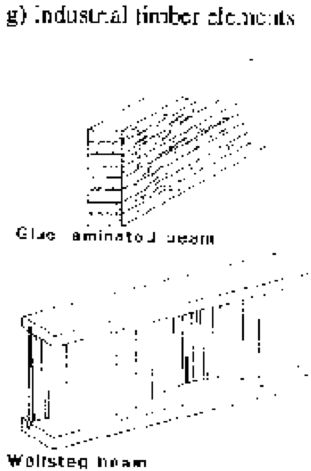
f) Trussed rafters



Trussed rafters

g) Industrial timber elements

A number of systems are used which widen the scope of timber as a construction material. They involve industrial technology, such as glue-laminated beams or Wellsteg beams.



Industrial timber elements

4.3.4 Sizing of timber structures

In consultation with LIGNUM, Zrich, and P. Hsler, Bubikon, Switzerland

Scope

The sizing of timber structures is usually a complex engineering task and requires expertise. The main factors that have to be considered are

properties of the timber,
loads on the structure and
the structural system.

Situation in practice

All over the world, hundreds of different types and qualities of timber are used for construction, all with highly varying load-bearing capacity. The bearing capacity of the same kind of timber can also vary, depending on the climatic and soil conditions of the area where the tree has grown.

Often the properties of the available timber are not known to the user, and standards are often either not available or do not exist. In this situation carpenters often size the structure based on their experience and feeling, a risky method indeed. Structures may be

oversized which involves high costs, or more often, undersized with the risk of damage or even a collapsing roof.

Sizing aid

To overcome this dangerous situation this chapter provides a relatively simple method of sizing timber structures when the properties of the timber are not known.

The method consists of two steps:

The timber has to be tested and classified accordingly . The test can only be omitted if the timber species is unmistakably known and can be classified according to Appendix 2 (Timber commonly used in roof construction).

Once the timber has been classified and the structural system (span) is known, the correct size can be established with the help of the tables in Appendix 3.

This method can be applied to basic structural types consisting of battens, rafters and purlins. For trusses and other more complex

structures it is not applicable and a competent engineer has to be consulted.

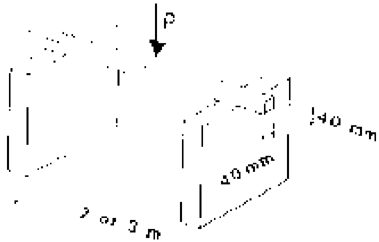
Limitation

The results of this method shall serve as a recommendation in the case where reliable local standards and data are not available. The results are not to be considered as a binding standard, and neither the author nor the publisher can take responsibility for damages.

1. Step: Testing Using a simple test, the breaking load is established.

A piece of timber, 40 x 40 mm, is placed over supports which are at a distance of either 2 m or 3 m. In the centre a load is applied and increased until the timber breaks. This breaking load determines the classification.

Where laboratory facilities are not available, this test can be done with simple improvised methods. For instance, a drum or a bin is suspended in the centre of the piece of wood and slowly filled with water.



Testing

An example of an improvised test method is illustrated below.

A wheelbarrow is suspended from the timber being tested and filled with any kind of weight. The wheelbarrow and the weight are weighed by a spring balance.

Test: A timber beam is spanned over 2 m or 3 m, then a load is applied in the centre and increased until the timber breaks.

At least 6 tests have to be carried out with timber from different trees of the same species because the properties can vary greatly.

Test results with Swiss pine

To classify the tested timber, the relevant breaking load is

calculated as follows:

Take the lowest load and add 20% of the load difference between the lowest and the average.

The formula to calculate the relevant load is thus:

P1 + 0.2 |f (P1+P2+P3+P4+P5+P6,6) - P1

Thus for the above example:

134+0.2 |f(134+140+148+148+168+180,6) -134 = 138 kg

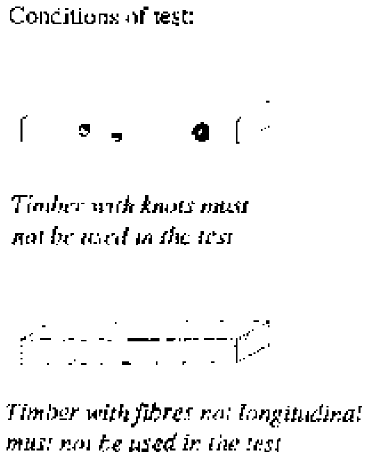
Classification of timber according to test result

	Test span		**Classification**
	2m	3m	
Breaking load	above 261 kg	above 174 kg	Category A
	211 - 260 kg	141 - 173 kg	Category B
	130 - 210 kg	87 - 140 kg	Category C

(For classification of commonly used timber species also see Appendix 3)

Conditions of test:

The timber being tested must be free of knots at least in the area near the centre where the load is applied.



Timber with knots not to be used for test; Timber with fibres not longitudinal must not be used in the test

The fibres of the timber being tested must be in the longitudinal

direction only.

The test timber must be free from fungi and insect attack.
The test timber must be free from cracks.

The humidity of the test timber must be the same as that of the timber used for construction. Extra seasoning of the test timber would result in values which are too high.

The load must be applied within 5 minutes. A long testing period would give false results.

Unknown timber

Whenever a new, unknown type of timber with questionable properties is used, the test should be repeated.

2. Step: Sizing When the timber has been tested and classified, sizing with the help of the tables in Appendix 3 can be done. Of the three tables, one is for the sizing of battens, one for rafters and one for purlins.

How to read the tables

To read the tables, the free span (L) of the beam has to be determined. Then the spacing (c) between the beams (centre to centre) has to be defined. Entering these two values and the respective timber category in the table gives the required timber dimensions.

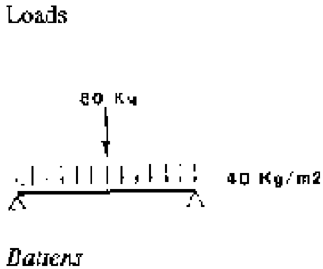
If the dimensions of the available timber are smaller than required, the span and/or the spacing have to be reduced, and vice versa.

Basis of the tables in Appendix 3
Loads

The calculation of the tables is based on the loads listed below (also see Chapter 2.3.3). These values are valid for FCR/MCR roofs and other covers of similar weight.

Battens:

Dead load	40 kg/m2 (0.4 kN/m^2)
Service load	80 kg (0.8 kN) in the centre or at the end of a cantilever



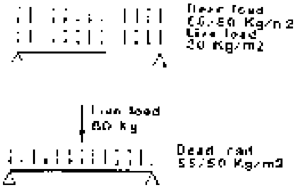
Battens

Rafters:

Dead load	50 kg/m2 (0.5 kN/m^2)
Wind load	30 kg/m2 (0.3 kN/m^2)
or	
Dead load	50 kg/m2 (0.5 kN/m^2)
Service load	80 kg (0.8 kN) in the centre or at the end of a cantilever whichever creates the bigger bending moment

Purlins:

Dead load	55 kg/m2 (0.55 kN/m^2)
Wind load	30 kg/m2 (0.3 kN/m^2)



Dead, live load

or	
Dead load	55 kg/m2 (0.55 kN/m^2)
Service load	80 kg (0.8 kN) in the centre or at the end of a cantilever whichever creates the bigger bending moment.

Rafters and purlins

A wind of 150 km/hr can cause a wind pressure of 30 kg/m^2 in a

closed buildings. In completely open buildings the pressure can be much higher. Suction can reach up to 70 kg/m^2, but it is not taken into consideration because the resultant is reduced by the dead load. However, appropriate anchoring of the roof must be provided. (Also see Chapter 2.3.2)

Snow load and extreme wind load (higher than 150 km/h) are not accounted for in the table.

Deflection

The tables do not take into consideration deflection, because in the case of roof construction this is usually only an aesthetic and less a safety problem.

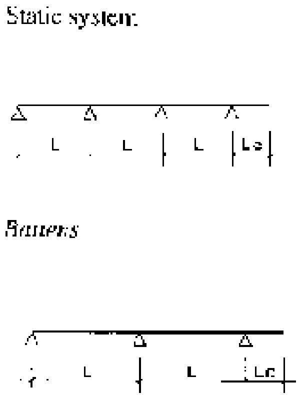
Static system

The tables are based on the following static system:

Battens:

Variable number of supports with the span L, cantilever maximum

0.30 L.



Battens

Rafters

2 or 3 supports with the span L

Cantilever (Lc) maximum 0.35 L.

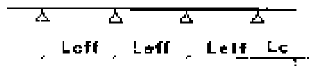
In the case of more than 3 supports the effective span (L_{eff}).can be reduced by 15% when reading the table.

Purlins

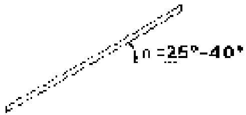
2 or 3 supports with the span L

Cantilever (Lc) maximum 0.40 L.

In the case of more than 3 supports the effective span (L_{eff}).can be reduced by 15% when reading the table.



Rafters and purlins



Roof slope

Rafters and purlins; Roof slope

A roof slope between 25^{o} and 40^{o} is considered.

Safety factor

The tables in Appendix 3 provide timber sizes that take into account the natural irregularities of timber, such as varying density, humidity, direction of growth rings and fibres, and irregularities in the structure of the timber, by applying an appropriate security factor.

The smaller the safety factor that is applied, the less timber is needed and the lower are the construction cost; the risk of damage, however, is greater.

The tables therefore provide two levels of security:

In general a normal security factor is used. These values are printed in bold in the table. These values should normally be used.

In subordinate structures a reduced security factor may be used. These values are shaded in the table. If these values are applied, savings can be made in the timber used. They may be used for stables, sheds and stores with roofs at low level above the ground, but not for structures of greater value, or in buildings in which

people live.

Warning

The safety factors do not take cracks and large knots into account. They can greatly reduce the strength of the timber. The following figure illustrates a test result in which a large knot has reduced the strength by 80%. Compare this to well selected timber as shown before under “1. step: Testing”.

The use of such faulty timber is highly dangerous for the roof structure and even for the life of the workers.

Test with faulty timber and the result: The strength is only 20% of that of well selected timber.

4.3.5 Timber structure details

Overview

This chapter describes common detailing for the basic elements of simple timber structures. The main elements are:

Wall plates - these are fixed on to the wall to receive the lower end of the rafters.

Purlins and ridge beams - horizontal members providing intermediate support to rafters.

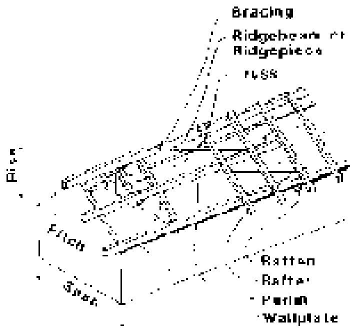
Rafters - similar to beams but inclined.

Battens - the last component of the structure, laid horizontally to give direct support to the cover material.

Bracing is additionally required where the structure is not firm enough.

For larger spans additional trusses are required to support the roof.

Overview



Overview

Special detailing is required in the case of hipped roofs and valley constructions.

Wall plates

Function

Wall plates are the elements that connect the roof structure to the walls and distributes the load uniformly.

They are supported throughout by the wall and do not span a large

distance. If there is no supporting wall but only columns, it is called purlin.

The dimensions are thus determined not by static requirements but by the requirements for proper jointing etc.

Fixing

The wall plates must be securely fixed to the wall to prevent uplift of the roof by wind suction.

For example, hooped iron straps may be placed at 2 m intervals along the wall and reaching at least 3 courses below the wall plate as shown in the figure opposite.

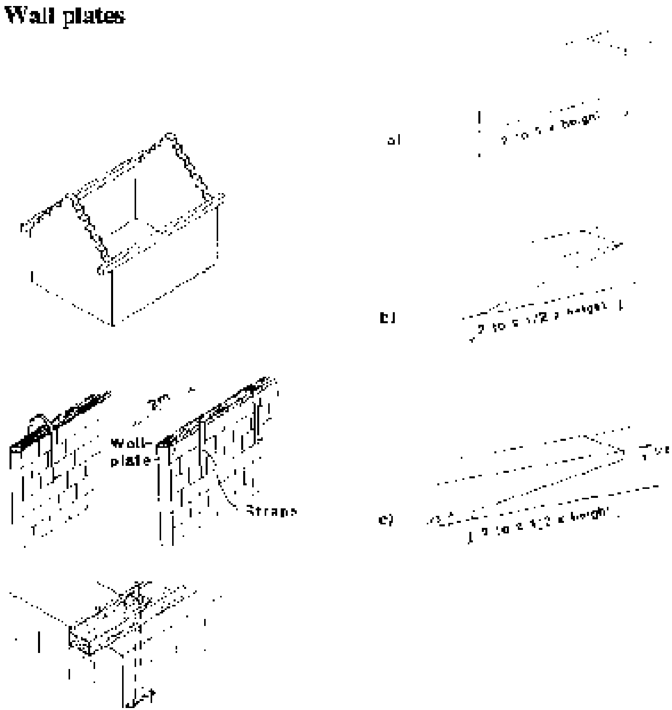
Joints

Simple lengthening joints can be used for wall plates. Possibilities are:

a) Halving joint

b) Common scarf

c) Stopped scarf



Wall plates

Wall plates as tie beam

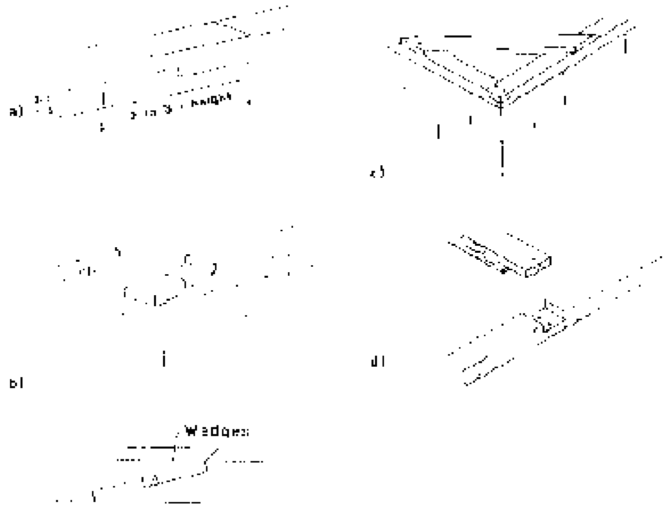
For smaller buildings, wall plates may also serve as a tie beam when a concrete tie beam is not required. In this case the joints have to be firm and built in a way that horizontal stress can be borne.

Possibilities are:

a) Hook halving joint

b) Stopped hook scarf

The wall plate, if it functions as a tie beam, must run all around the building and have strong corner joints (c). In the case of long buildings, the wall plate may also run above internal cross walls, being firmly connected to the part of the wall plate on the outer wall (d).



Wall plates as tie beam

Fish joints

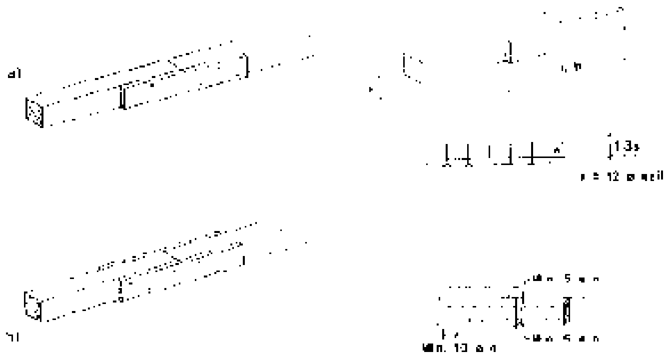
Joints can be strengthened by fish plates; enabling them to take care also for shear stress.

a) One-nailed fish plate

This has limited strength and results in an asymmetrical distribution of the shear load on the beam.

b) Two-nailed fish plate

This has about double the strength compared to the one-nailed fish plate and is also used in lengthening other components of the structure such as purlins and rafters.



Fish joints and rules

Rules for fish joints

a) The length of the fish plates should be at least 5 times the height of the joint member.

b) The nails should be as long as to enter 3/4 of the thickness of

the joint member and 12 times the diameter () of the nail.

c) Nails should be evenly distributed over the entire fish plate, normally in a staggered manner.

d) The spacing between the nails, and between the nails and the edge of the fish plate depends on the diameter () of the nails:

Along the grain of the timber, the distance between the nails should be 10 times the diameter () of the nail.

The distance between the nail and the edge of the fish plate should be:
along the grain 10 times the diameter of the nail,
across the grain 5 times the diameter of the nail.

Purlins and ridge beams

Function

Purlins and ridge beams form the primary structure (also see Chapter 4.1) of the roof, spanning horizontally to support the rafters.

Fixing

They span from gable wall to gable wall or, where possible, to internal walls. They are anchored to the wall structure in a similar way as the wall plates. A safe method to anchor them is to join them firmly to the tie beam.

Joints

A joint is always a weak point in the beam. In purlins and ridge beams, therefore, jointing should be avoided wherever possible.

If a joint is unavoidable, its position should be carefully chosen. It should be placed in a position where the bending moment is small.

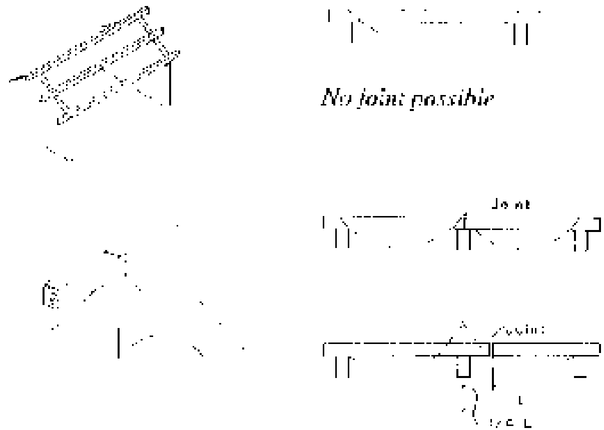
Rules for joints

a) Never use joints in purlins with only 2 bearing supports.

b) Purlins with 3 or more supports can be jointed at the bearing points.

c) Purlins with 3 or more supports can also be jointed near the

point where there is no bending moment. This method takes advantage of the static system of a continuous spanned beam which has a reduced maximum bending moment compared to a single spanned beam.



Purlins and ridge beams; No joint possible

Design of joints

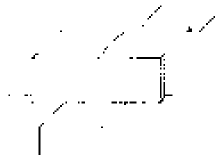
If the joint is at the place of the support, vertical halving joints (a) or scarf joints (b) can be used. Horizontal halving joints (c) must be avoided. Fish plate joints (d) are possible if the supporting wall

is thick enough.

a) Vertical halving joint
b) Vertical scarf
c) Horizontal halving joint, to be avoided
d) Fish plate joint

If the joint is not at the place of the support, but where the bending moment is small, horizontal halving joints with bolts are used. The shear load must be transmitted by the bolt and not by the timber notch.

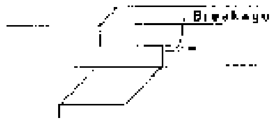
a) Vertical halving joint



d) Fish plate joint

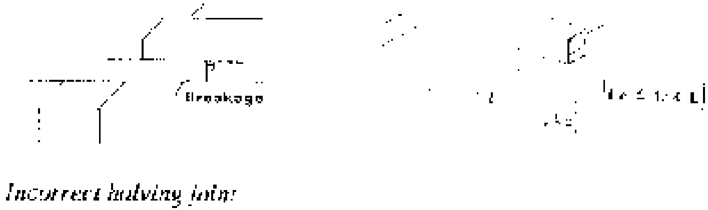
b) Vertical scarf

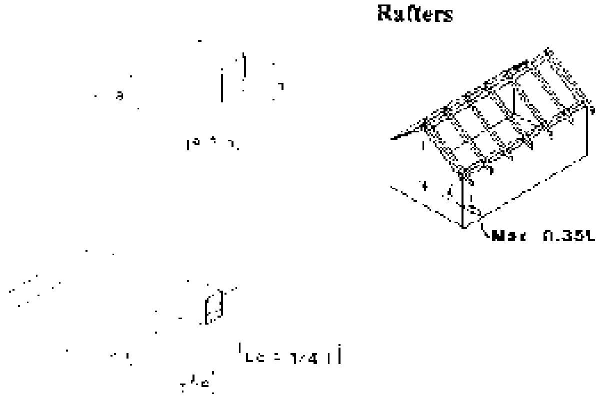
Correct halving joint



c) Horizontal halving joint, to be avoided

Design of joints; Correct halving joint





Correct and Incorrect halving joint; Rafters

Bearing area

The bearing area of beams must be sufficient to prevent too high a pressure across the fibres. The width (a) must be at least the same

as the height of the beam (h).

Cantilever

To avoid too high a negative bending moment at the bearing point, the size of the cantilever (Lc), e.g. at verges, should not exceed 25% of the normal span (L).

Rafters Function

Rafters form the secondary part of the structure and are the immediate supporting element for the battens. They are inclined in the direction of the roof slope.

Cantilever
To avoid too high a negative bending moment at the bearing point the size of the cantilever (at roof overhangs) should not exceed 35% of the normal span (L).

Fixing

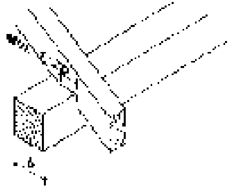
Rafters are jointed to plates, ridge beam and purlins with the bird's mouth cut. To ensure a proper fixing, the width of the bird's mouth

cut should be half the width of the supporting beam.

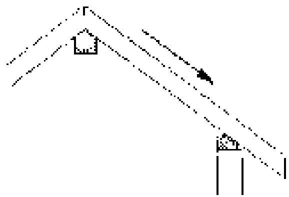
The edges of purlins and wall plates should not be shaped because the rafters then would tend to slide down.

Bird's mouth cut; Do not shape the corners of purlins

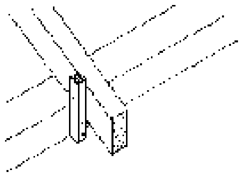
Rafters also have to be secured against uplift by wind. They are therefore fixed, to the under-structure either by proper nailing or with cleats.



Bird's mouth cut



Do not shape the corners of purlins



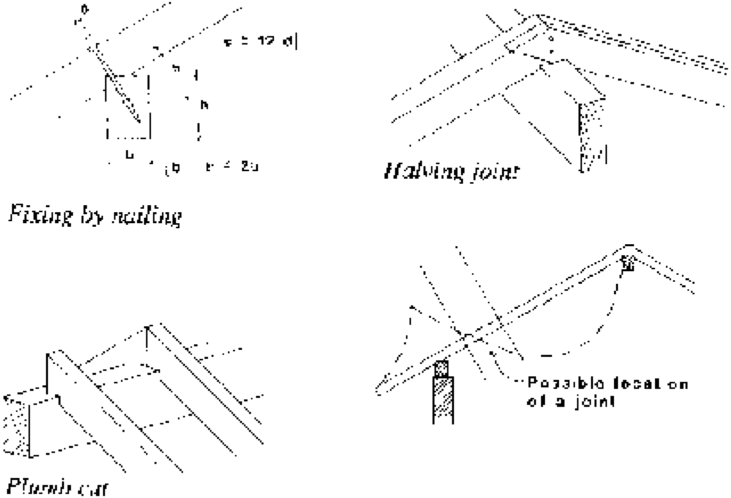
Fixing with cleats

Bird’s mouth cut; Do not shape the corners of purlins; Fixing with cleats

Nails for fixing must be long enough. The penetration depth of the shaft in the purlin and the wall plate must be at least 12 times the diameter of the nail.

Joints

At the ridge, rafters are jointed either by means of a plumb cut or a halving joint.



Fixing by nailing; Plumb cut; Halving joint

Lengthening joints should be avoided wherever possible. Where this is not possible, they should be near the point with the smallest bending moment. Fish plate joints are appropriate.

Battens

Function

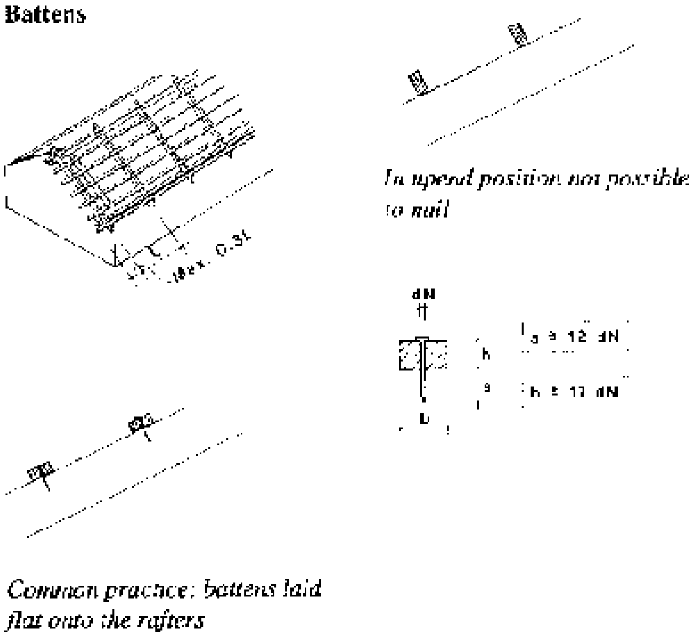
Battens are the last component of the structure. They directly

support the tiles. They run horizontally and are fixed to the rafters by nails.

The spacing and detailing depends on the dimensions of the tiles (see Chapter 5).

The overhang over the last support at the verges should not exceed 30% of the rafter's spacing.

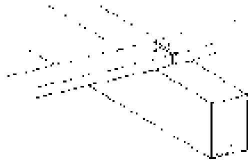
The battens are laid flat on the rafters and not in upend position. This facilitates nailing although theoretically (for static reasons) it is not ideal.



Common practice: battens laid flat onto the rafters; In upend position not possible to nail

The nails have to be long enough. The penetration depth must be at least 12 times the diameter of the nail.

Joints are placed above the rafters, by means of a plumb cut.



Trusses

In upend position not possible to nail

Trusses In truss structures great stress can occur, which cannot easily be determined with simple methods. The design of trusses, the sizing of their components and joints requires expertise, and their construction demands great care and professional workmanship.

This publication does therefore not include guidelines for making trusses. Specialist literature should be consulted.

4.4 Alternative structural materials

4.4.1 Bamboo structures

Genera- Bamboo, as well as timber, is one of the oldest building

materials and still used widely in many countries today. Its main area of distribution is the tropics. Some robust species are also found in subtropical and temperate latitudes.

Growth characteristics

Bamboo is a perennial grass. Well over 1000 species of some 50 genera are known. The largest number occurs in Southern Asia and on the islands between Japan and Java.

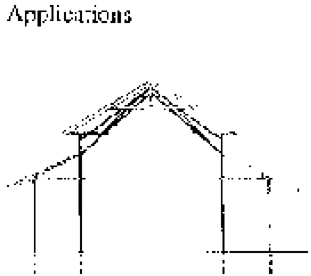
Bamboo differ from grasses in the long life span of their culms (hollow stalk) and in their branching and lignification (development of woody tissues). Like leaf-bearing trees, they shed their leaves annually and grow new branches, increasing their crown every year.

Bamboo is the fastest growing plant and has been reported to grow more than one metre in a single day. Bamboo culms can reach their full height (giant species grow up to 35 metres or more) within the first six months of growth, but it takes about 3 years to develop the strength required for construction; full maturity is generally reached after 5 or 6 years.

In many countries bamboo is a most important building material. Often it is not only available through commercial channels, but is also cultivated and used on a level of subsistence farming.

Applications

In roof construction bamboo can be used in the form of whole culms for building frame structures, trusses, beams, purlins, rafters; half culms as battens; and split bamboo strips for matting and woven panels, e.g. as ceilings.



Applications

With bamboo structures a completely even structure cannot easily be achieved. Therefore, in the case of FCR/MCR, only pantiles should be used and not Roman tiles or semi-sheets. A bamboo

structure is also rather flexible which means that there is a risk that semi-sheets could break.

Advantages

In many regions bamboo is abundantly available, cheap and is quickly replaced after harvesting, without the serious consequences known from the excessive use of timber (environmentally acceptable!). The annual yield by weight per unit area can reach 25 times the yield of forests in which building timber is grown.

Handling during felling, treatment, transportation, storage and construction work is possible with simple manual methods and traditional tools.

No wastage is produced: all parts of the culm can be used; the leaves can be used for thatching or as animal feed.

The pleasant smooth, round surface requires no surface treatment.

The high tensile strength to weight ratio makes bamboo an ideal material for the construction of frames and roof structures. With a

proper design and workmanship, entire buildings can be made of bamboo.

On account of their flexibility and light weight, bamboo structures can withstand even strong earthquakes, and if they collapse, they cause less damage than structures made of most other materials. Reconstruction is possible within a short time and at a low cost.

Problems

Bamboo has a relatively low durability, especially in moist conditions, as it is easily attacked by biological agents, such as insects and fungi.

Bamboo catches fire easily.

The low compressive strength and impact resistance limit its application in construction. Wrong handling, bad workmanship and incorrect design of bamboo structures can lead to cracking and splitting which weaken the material and make it more vulnerable to attack by insects and fungi. Nails cause splitting.

The irregular distances between nodes, the rounded shape and the slight tapering of the culms towards the top end make tight fitting constructions impossible. Bamboo can therefore not replace timber in many applications.

Bamboo causes greater tool wear than timber.

Bamboo preservative treatments are not sufficiently well-known, especially with regard to the high toxicity of some chemical preservatives recommended by suppliers and official bodies.

Remedies

Certain bamboo species have a natural resistance to biological attack, hence their cultivation and use should be encouraged.

Only mature and properly treated culms should be used. Bamboo should not be stored too long (if at all, then without contact with the ground), and carefully handled (avoiding cracks or damage of the hard outer surface). It should be used n carefully-designed structures (ensuring dry conditions, good ventilation of all components, accessibility for inspection, maintenance and

replacement of damaged members).

Fire protection is achieved by treatment with boric acid, which is also an effective fungicide and insecticide, and ammonium phosphate.

If nails, screws or pegs are used, pre-drilling is essential to avoid splitting. Fastening of joints by means of lashing is more appropriate for bamboo constructions.

Bamboo should not be used where tight fitting components are required. Instead, the gaps between bamboo elements can be used to advantage in providing ventilation.

Recommendations for preservative treatments with chemicals should not be followed blindly. Different opinions of experts should be sought. Irrespective of the type of preservative used, care should be taken to protect the skin and eyes from coming into contact with it. The need for thorough safety precautions cannot be over-stressed.

Preservation

Untreated bamboo deteriorates within 2 or 3 years, but with correct harvesting and preservative treatment, its life expectancy can increase about 4 times.

Priority should be given to non-chemical preservation methods such as correct harvesting and correct structural application.

a) Harvesting methods

Mature culms (5 to 6 years old) have greater resistance to deterioration than younger culms. Since fungal and insect attack increase with moisture content, bamboo should be harvested when the moisture content is lowest, that is, in the dry season in the tropics, and autumn or winter in cooler zones.

The freshly-cut culms, complete with branches and leaves, should be left standing for a few days (avoiding contact between the cut surface and the soil), allowing the leaves to transpire and reduce the starch content of the culm. This method, called "clump curing", reduces attacks by borer beetles, but has no effect on termites or fungi.

b) Structural means

Similarly to timber structures (also see chapter 4.3.2), bamboo should be used correctly with respect to protection from moisture; access to circulating air; and avoiding contact with the ground.

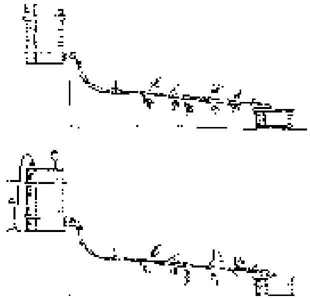
c) Chemical treatment

Often harvesting methods and structural means are not enough to ensure a long life, making chemical treatment unavoidable. In this case attention should be paid to the same hints and warnings as for timber (see Chapter 4.3.2).

The chemical treatment of bamboo is more complicated than of timber because the outer skin of the culm is impenetrable. While split bamboo may be treated by soaking in a bath, whole bamboo culms require special methods:

Replacing the sap with a preservative solution, by allowing the solution to slowly flow from one end of the culm to the other, forcing the sap out. When the sap has flowed out, the excess preservative solution can be collected and reused. The process

(called the "Boucherie" method) takes 5 days, but can be reduced to a few hours by pressure treatment.



Boucherie method, without or with pressure

Steeping

Boucherie method, without or with pressure; Steeping

Immersing the lower portion of freshly cut culms (which with their

leaves), in a preservative solution which is drawn up the capillary vessels by the transpiration of the leaves. This method (called "steeping") only works with fairly short culms, as the liquid may not rise to the top of long culms.

Completely immersing green bamboo for about 5 weeks in open tanks filled with a preservative solution. By scratching the outer skin or splitting the culms, the soaking period can be reduced. Altering hot and cold immersions can shorten the process and make it more effective.

4.4.2 Pole timber structures

[12]

General

Pole timber is unprocessed round wood in the form of poles. It is one of the oldest and most valuable building materials. Timber poles are made from young trees (generally 5 - 7 years) with the barks peeled off, seasoned and treated as required (also see Chapter 4.3.2). The cost and wastage incurred by sawing is

eliminated and 100% of the timber's strength is used. A timber pole is stronger than sawn timber of an equal cross-sectional area, because the fibres flow smoothly around natural defects and do not end as sloping grain at cut surfaces. Poles can bear great tensile stress around their perimeters resulting in high resistance during bending and compression.

Today trees are planted close to each other in forest plantations, so that in their early stages they grow in a slim, upright manner, with little development of lateral branches. These plantations are thinned out at regular intervals and as the cut trees are often of a suitable size, they can be used as pole timber.

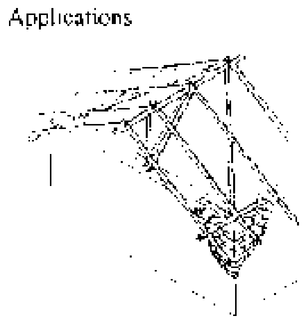
Most common species of trees provide poles which can be used for roof structures. The more perishable species can be preserved to make them more durable. Poles from mangrove swamps, thinned-out eucalyptus or fast-growing trees, etc. are suitable.

Applications

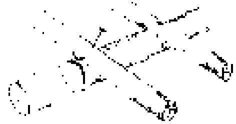
Pole timber can be used for conventional roof structures consisting of purlins, rafters, ridge piece, wall plates etc.

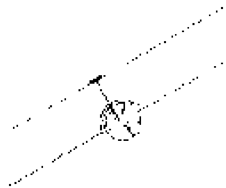
It can also be used for the construction of trusses and space frame construction.

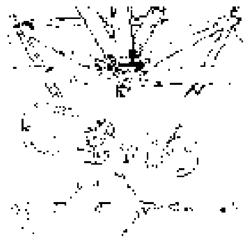
Pole timber structures are usually not absolutely even, similarly to bamboo structures. Therefore, in the case of FCR/MCR they are suitable for pantile covers; but not for Roman tiles and not at all for semi-sheet covers.



Applications 1







Applications 2

Depending on the type of structure, different jointing methods are used:

Simple structures can be jointed by cutting notches and nailing or bolting.

Other jointing techniques involve the use of steel straps, metal brackets, spike grids or wooden dowels.

Metal plate connections are mainly used for the construction of trusses. They are either simply wrapped around the joints and firmly nailed onto the timber, or are inserted into longitudinal saw cuts in the timber poles and connected to them by nails (flitch plate connection).

For frame structures a system based on special space frame connectors can be used, comprising a cross-component of welded steel, and tail end connectors with screws, washers and nuts.

Advantages

A timber pole is stronger than sawn timber of an equal cross-sectional area.

A round pole possesses a very high proportion of the basic strength of its species because knots have less effect on the strength of naturally-round timbers, compared to sawn sections. The cost and wastage of sawing are eliminated. Above all, the design of any pole structure can be simple enough for unskilled persons to construct.

Pole construction makes use of less valuable timber such as young trees obtained from thinning out forest plantations. In this sense the technology is not harmful to the environment.

Problems

Pole timber structures are usually not absolutely even and are therefore suitable only for covers which are flexible, e.g. FCR/MCR pantiles, but not Roman tiles, semi-sheets and sheets.

Pole timber has a low-prestige image.

If pole timber is obtained by clearing young forests, this has a serious negative impact on the environment.

Sizing

For testing the load bearing capacity of timber and sizing of basic elements of pole timber structures see Chapter 4.3.4 and Appendix 3.

4.4.3 Metal structures

General

Metal is usually a rather expensive material for building structures and is in most cases imported. Building with metal requires special tools and equipment. Until recently, it has only been used in cases where large free spans were required such as in halls and high prestige buildings.

Today, with the increasing scarcity of good quality timber, metal structures are becoming more and more a competitive alternative in roof construction.

Metals used in construction are divided into two main groups:
Ferrous metals: irons and steels

Non-ferrous metals: aluminium (Al), cadmium (Cd), chromium (Cr),

copper (Cu), lead (Pb), nickel (Ni), tin (Sn) and zinc (Zn).

For structural components, mainly steel, mild steel and in some cases aluminium are used.

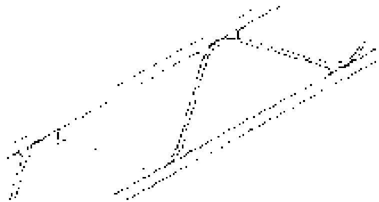
Steels are all alloys of iron with a carbon content of between 0.05 and 1.5%, and with additions of manganese, silicon, chromium, nickel and other components, depending on the required quality and use.

Mild steels, with 0.15 to 0.25% carbon, are the most widely used and versatile of all metals. They are strong, ductile and suitable for rolling and welding, but not for casting.

Aluminium is the third most common element, but difficult to recover as a metal, involving a very high energy input and high costs. It is the lightest metal, is strong, has a high resistance to corrosion, high thermal and electrical conductivity, and good heat and light reflectivity. Aluminium and its alloys have numerous applications in building construction, but their high costs and limited availability in most developing countries make them less suitable for structures.

Applications

Structural steel, mild steel and aluminium are available in hollow forms (round, square or rectangular shaped pipes), rolled profiles and as sheets. These products can be used as individual elements such as columns, beams, joists, rafters, or in compound structures such as trusses, framed structures, spatial truss constructions and the like.



Applications

A combination of a steel structure and timber rafters and battens may be a possible alternative to save costs.

Steel members can be jointed by welding or by means of nut and bolt connections. Rivet connection is a technology which is no longer used in structures.

Corrosion is a typical problem of steel structures. An anti-rust paint is required, also on the welded joints. Parts that are exposed to moisture need periodical painting.

Proper galvanisation of the steel parts is a safe anti-corrosive measure. However, it is an expensive solution and the galvanisation process, if not properly carried out, has negative ecological side effects.

Galvanisation of welded structures is difficult in practice, because it should be done after welding and the galvanisation tanks are limited in size.

Aluminium does not require protection against corrosion. Welding aluminium is difficult, requires special equipment and skill. Therefore nut and bolt connections are usually used.

Advantages

Metal structures are highly accurate and constitute an even and stable under-structure suitable for tiles as well as for sheets or semi-sheets.

Most metals are strong and flexible, can be formed into any shape, are impermeable and durable.

Prefabricated framed construction systems made of steel or aluminium are assembled extremely quickly. With strong connections, such systems can be very resistant to earthquake and hurricane destruction.

Problems

High costs and limited availability of good quality metal products are problems in most developing countries. As a result, inferior products are supplied, e.g. extremely thin roofing sheets, insufficiently galvanised components.

Metal structures lose strength at high temperatures and tend to collapse during a fire, sooner than timber, although they are non-combustible. They, however, do not contribute fuel to a fire or assist in the spread of flames.

Most metals corrode. Ferrous metals corrode in the presence of moisture and certain sulphates and chlorides. Aluminium corrodes

in an alkaline environments, and copper is corroded by mineral acids and ammonia. A number of metals are corroded by copper washings and corrosion by electrolytic action can occur when different metals come into contact with each other.

Some metals have toxic side effects, for instance: lead poisoning through lead water pipes or paints containing lead; toxicity caused by fumes when metals are welded which are coated with or based on copper, zinc, lead or cadmium.

Remedies

To prevent corrosion, use in humid conditions should be avoided, protective coating should be periodically renewed, and contact between aluminium and cement products (mortar or concrete) should be avoided.

Cost reduction can be achieved by limited use of metals and design modifications which permit the use of cheaper alternative materials. For instance, the combination of a steel main structure with timber rafters and battens may be a possible alternative.

Steel structure combined with timber rafters

4.4.4 Concrete structures

General

Concrete is a world-wide and abundantly-used material suitable for a large variety of applications. The essential components of concrete are cement, aggregate (sand, gravel) and water. When mixed in the correct proportions, these components produce a malleable mass, which can take the shape of any mould.

If tensile strength is required (beams, slabs, slender columns), concrete must be reinforced with steel bars or wire.

The main aspects that govern the quality of concrete are:

Careful selection of the type and proportion of the cement.
Clean, hard and well-graded aggregate must be used.
Correct water to cement ratio.
Proper mixing and immediate use of the mix.
Sufficient compacting after casting.

Curing after demoulding for at least 14 days.

Concrete is either cast in situ or precast to be used in construction systems using assembly procedure. To increase the load-bearing capacity, the reinforcement can be prestressed before casting.

Applications

Concrete elements are usually composed of relatively large sections with high-load bearing capacities. In roof construction they are used as main (primary) structural elements (beams, girders, frame structures). Other materials are used for the finer structural parts (battens, etc.).

Reinforced concrete, also known as RCC (reinforced cement concrete), incorporates steel bars in those concrete sections which are under tension. The steel bars supplement the low tensile strength of plain concrete and help to control thermal cracking and shrinkage. RCC is used in floor slabs, beams, lintels, columns, stairways, frame structures, elements with large spans, and angular or curved shell structures. These are all cast in situ or precast. The high strength to weight ratio of steel, coupled with the fact that its

coefficient of thermal expansion is about the same as that of concrete, makes it the ideal material for reinforcement. Where bars with ribs are available, they should be given preference, as they are far more effective than smooth bars. In this way up to 30% steel can be saved.

Prestressed concrete is reinforced concrete with the steel reinforcement held under tension during production. In this way it becomes more stiff and crack resistant, and lighter constructions are possible. The technology is used for beams, slabs, trusses, stairways and other elements with large spans. By pre-stressing, less steel is needed and the concrete is held under compression, enabling it to carry much higher loads. Prestressing is achieved either by pre-tensing, (when the steel is stressed before the concrete is cast) or by post-tensing (once the concrete has reached a specific strength, the reinforcing steel is passed through straight or curved ducts, which are filled with grout after the reinforcement has been tensed and anchored. This is essentially a factory operation requiring expensive, special equipment (jacks, anchorage, pre-stressing beds, etc.) and not suitable for inexpensive housing.

Advantages

Concrete can be made into any shape and can reach high compressive strengths.

Reinforced concrete combines high compressive strength with high tensile strength, making it appropriate for any building design and all structural requirements. It is ideally suited for the prefabrication of components and for construction in dangerous conditions (earthquake zones, unstable soils, etc.).

Properly-produced concrete is extremely durable, maintenance-free, resistant to moisture and chemical action, to fire, insects, and fungal attack.

In many areas concrete has a high prestige value.

Problems

Cement, steel and moulds are usually expensive.

Quality control on building sites is difficult. If the concrete is incorrectly mixed or cast and compacted, or insufficiently cured

with water, there is a risk of cracking and gradual deterioration. Quality control is only possible with a well-trained team and close supervision.

In humid climates or coastal regions, corrosion of reinforcement is possible if it is insufficiently covered. This can lead to expansion cracks.

Concrete is only fire resistance up to about 500·C. At this temperature steel reinforcement is no longer effective. After fire, RCC structures usually have to be demolished.

Demolishing concrete is difficult and the debris cannot be recycled, other than in the form of aggregate for new concrete.

Remedies

The cement component in concrete can be reduced by a careful mix design, grading of aggregates, testing, quality control and by substitution with cheaper pozzolanas.

Savings in steel reinforcement can be made by good structural

design and use of bars with ribs or prestressing with colddrawn low-carbon steel wire.

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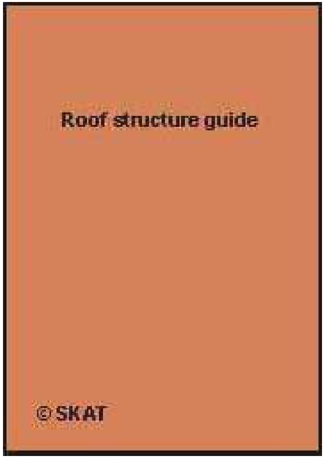


Roof Structure Guide - Basics for the Design and Construction of Leightweight Sloped Roof Structures (SKAT, 1993, 144 p.)

5. Roof construction process

This chapter contains the basic rules for erecting the roof structure. A report on a course in Ghana [15] gives a detailed step-by-step description of the construction of a L-shaped hipped roof.

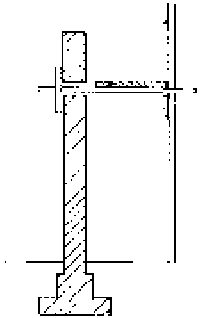
5.1 Safety

Working on roofs, especially erecting roofs, is obviously a dangerous job. There are many different dangers which can cause serious accidents.

For the safety of the workers all possible precautions must be taken to minimise the risks. The most important aspects are:

a) Construction of a reliable scaffold

For laying the roof structure, a properly-built scaffold is necessary. Often it is already needed for the construction of the walls. Where this is not the case, the scaffolding must be built subsequently.



Scaffold built during wall construction; Scaffold added subsequently to the wall construction

If gutters or facia boards have to be mounted, it is advisable to add a railing to the scaffold.

b) Substructure

The substructure must be strong enough to support the weight of the workers as well as stacking of the required material. Battens and rafters for instance have to be strong enough to carry a man as well as the weight of the roof cover (see Chapter 4.3.4 "Sizing of

timber structures" and Appendix 3)

c) Safe access

Ladders, stairways etc. must be strong enough and should not rest on slippery surfaces. Ladders should be fixed with ropes.

d) Clothing

Workers should wear solid and non-slipping shoes. The use of helmets is advisable, especially for those working below the roof because of the danger of material and equipment falling.

e) Physical fitness

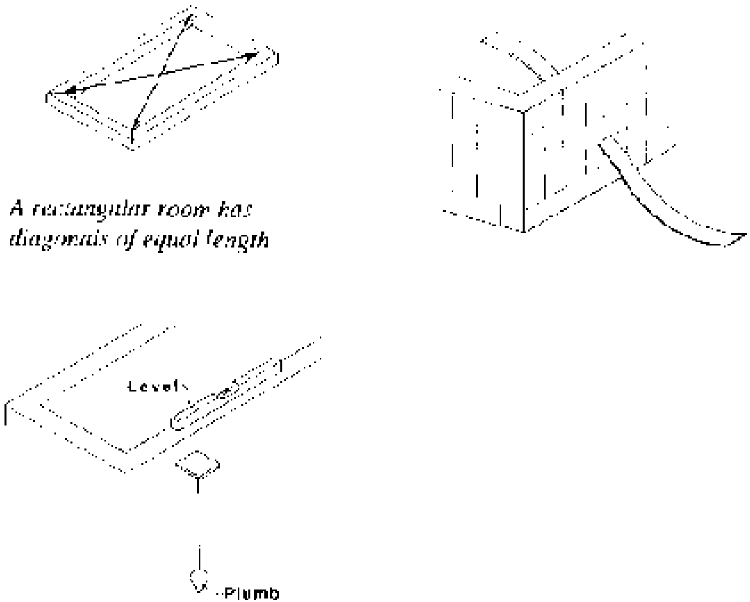
Only mentally and physically fit and healthy workers should work on the roof. The work is too dangerous for people who are ill, unfit, weak or drunk. Children and old people should also not be employed for such work.

5.2 Preparing the walls

For a proper installation of the roof, an accurately and evenly laid

roof structure is important. This is only possible if the supporting walls are built accurately as well.

Walls must be laid out accurately, with rectangular corners. This can be done by checking the diagonal dimensions of the rooms. They must be equal.



A rectangular room has diagonals of equal length

The top of the walls must be level. This should be checked with a theodolite, a spirit level or a transparent water tube. Walls must be perfectly vertical. This is checked with a spirit level or a plumb.

To secure the roof against uplift by wind, the structure has to be anchored to the walls. Straps should be placed in the wall several layers below the top of the wall, or gaps should be provided for placing fixing devices later.

5.3 Erection of roof structure

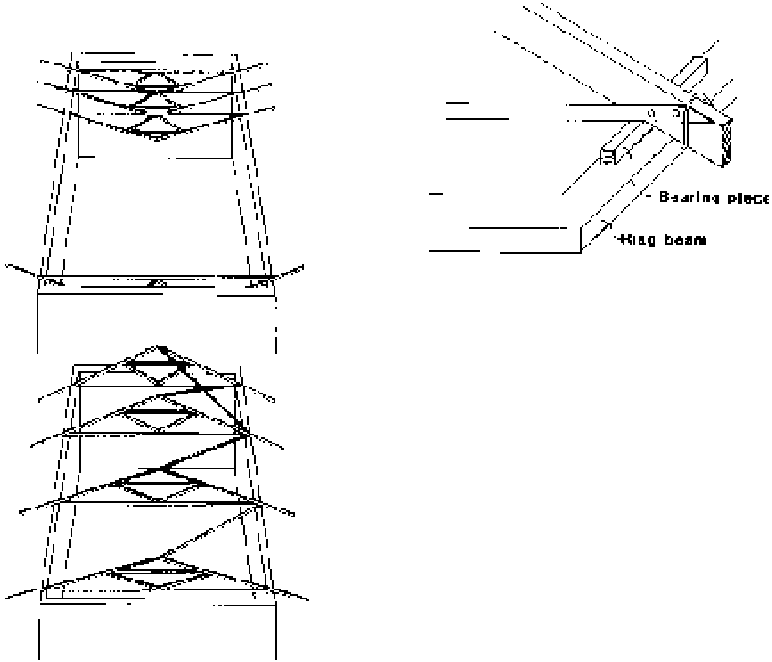
5.3.1 Step 1: Laying of trusses and bracing

If trusses are used, they should be assembled in a workshop or at the site on the ground. The ground must be perfectly even. To ensure accuracy and uniformity a template should be used.

If the roof is not erected immediately, trusses must be stored in a dry and shady place.

The trusses are erected by first hanging them upside down across the span of the building. Then they are turned over and fixed with

temporary bracing.



Step 1

Next the trusses are mounted on bearing pieces and brought into line and levelled with the help of strings and a spirit level or a theodolite. Where necessary they are wedged at the supporting

points. They are then secured at the bottom with anchor rods and the permanent bracing.

If the trusses rest on a concrete belt, roofing felt should be put between the concrete and the tie beam to prevent dampness from rising.

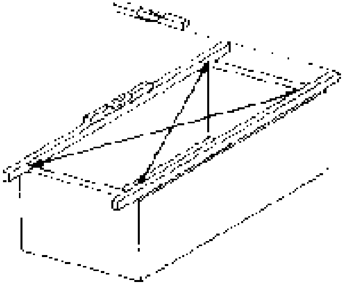
5.3.2 Step 2: Laying of wall plates
(also see Chapter 4.3.5)

To achieve an even roof structure, wall plates must be laid in level and parallel to each other. This should be checked with a theodolite, spirit level or water tube, and by measuring the diagonals.

Although the walls should in fact already be level and at right angles, the person laying the roof must re-check this. He should never rely on the mason.

If the supporting wall is not level, the wall plates must be adjusted with wedges. Any gap between the wall and wall plate may be filled with mortar.

After proper positioning, the wall plates are fixed to the wall by straps or other anchorage devices.



Wall plate with anchorage and wedges

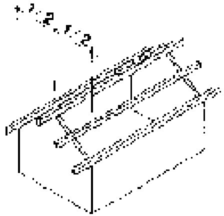
Wall plate level and at right ang

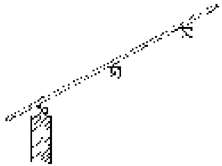
Step 2: Wall plate level and at right angles; Wall plate with anchorage and wedges

5.3.3 Step 3: Laying of ridge piece and purlins (also see Chapter 4.3.5)

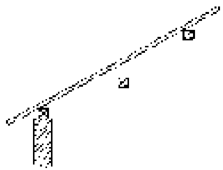
The ridge beam is fixed exactly level and over the centre of the gable walls and parallel to the wall plates. The desired pitch determines the height of the ridge piece and this can be calculated with the help of the table in Appendix 1.

Purlins must be placed exactly in line with the wall plate and the ridge beam. This can easily be checked with the help of a string. After the ridge beam and the purlins have been correctly positioned, they are tied down to the walls.





Correct positioning of purlin, in line with the wall plate and the ridge beam

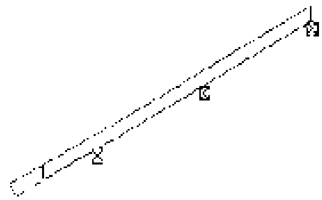


Wrong positioning of purlin

Step 3: Correct positioning of purlin, in line with the wall plate and the ridge beam; Wrong positioning of purlin

5.3.4 Step 4: Laying of rafters (also see Chapter 4.3.5)

Rafters are joined to the wall plate, purlin and ridge beam by means of a bird's mouth cut and nails or with cleats. The rafters should be slightly longer than required at the eaves and cut to the correct length after fixing the battens and before fixing the eaves board.



After the lowest batten has been fixed, the final rafter is cut to the required length..

Step 4: After the lowest batten has been fixed, the final rafter is cut to the required length..

5.3.5 Step 5; Laying of battens (also see Chapter 4.3.5)

The laying pattern of battens depends on the characteristics of the

cover material.

Details on laying battens for FCR/MCR roofs can be found in Toolkit Element 25: Roof Cover Guide [9].

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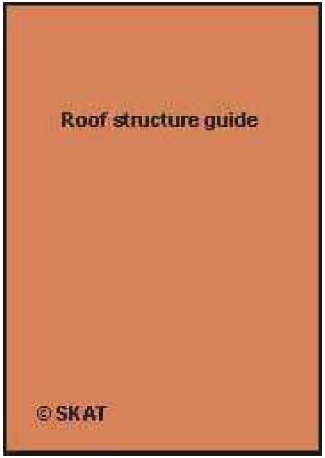

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6. Maintenance

6.1 Maintenance concept

As with all building parts, the roof structure and its cover also have a certain life span. This can be extended considerably if the roof is maintained regularly and damage is repaired in time. Severe damage can often be prevented if it is repaired immediately at the initial stage. In this sense, regular maintenance does not only retain the value of the building, but it also saves costs.

For these reasons it is advisable to plan maintenance work and to establish a maintenance concept.

Aspects of a maintenance concept

Responsibility

The persons who are responsible for checking, organising and implementing repair work have to be clearly identified.

Time schedule

Checking the structure and the roof cover should be done routinely, according to a clear time schedule. A yearly inspection should be

the minimum. The roof cover should also be checked after every storm and of course in the case of any leakage.

Material stocks
Some basic materials such as spare tiles, wire, nails and tools should be readily available to facilitate immediate minor repairs.

Money allocation
Although the maintenance costs for well-constructed roofs are minimal, difficulties can arise if there is no budget allocated for this. Therefore a small amount of money should be reserved in the yearly budget for maintenance. This can save higher costs arising from damages to the roof structure and the interior if timely repair is neglected.

6.2 Maintaining the structure

Maintaining tiles see [9], Toolkit Element 25, Roof Cover Guide

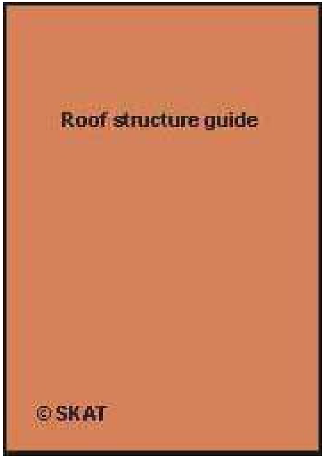
Normally the roof structure does not require maintenance. A yearly inspection is, however, advisable. Metal parts may rust and require painting. Timber parts may be infested by insects, e.g. termites,

weed beetles. In this case they should be treated chemically. The chemical should be carefully selected and the least poisonous used, especially in buildings where people live or food is stored (see chapter 4.3.2).

Insect attack is enhanced by humid conditions. Therefore rising dampness or splashing water should be avoided and leakage in the roof repaired immediately.

Fungi Fungal attack is a clear sign of moisture. In this case the source of moisture must be eliminated and chemical treatment only applied as a second choice, if at all.

Structural damages Structural parts may break due to unexpected loads, natural calamities or faulty construction. Such parts should be mended properly, either by replacing or repairing by nailing fishplates.



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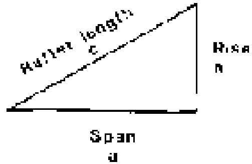
Appendices

1 Conversion factors for roof slope



Pitch (Degree)	Pitch (%)	ratio rise : span b : a	ratio rafter length : span a : c
22°	40.4%	1 : 2.47	1 : 1.079
24°	44.5%	1 : 2.25	1 : 1.095
26°	48.8%	1 : 2.05	1 : 1.113
28°	53.2%	1 : 1.88	1 : 1.133
30°	57.7%	1 : 1.73	1 : 1.154
32°	62.5%	1 : 1.60	1 : 1.179
34°	67.5%	1 : 1.48	1 : 1.206
36°	72.6%	1 : 1.38	1 : 1.236

Reading example:

With a given pitch of 30°

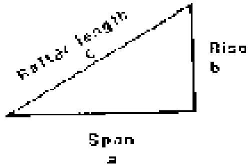
- the pitch is 57.7%
- the span is 1.73 x the rise
- the rafter length is 1.154 x the span incl. roof overhang

or

with a given pitch of 30° and a span of 5m

- the rise is 5m: 1.73 = 2.899 m
- the rafter length is 5m · 1.154 = 5.77 m

Conversion factors for roof slope 1



Pitch (Degree)	Pitch (%)	ratio rise : span b:a	ratio rafter length : span a : c
21.8°	40%	1 : 2.50	1 : 1.08
24.2°	45%	1 : 2.22	1 : 1.10
26.6°	50%	1 : 2.00	1 : 1.12
28.8°	55%	1 : 1.82	1 : 1.14
31.0°	60%	1 : 1.67	1 : 1.17
33.0°	65%	1 : 1.54	1 : 1.19
35.0°	70%	1 : 1.43	1 : 1.22
36.9°	75%	1 : 1.33	1 : 1.25

Reading example: With a given pitch of 60%,

- the pitch is 31.0°

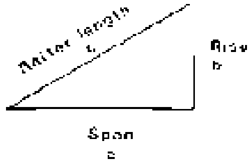
- the span is 1.67 x the rise
- the rafter length is 1.17 x the span incl. roof overhang

or

with a given pitch of 60° and a span of 5m

- the rise is 5m:1.67 = 2.99 m
- the rafter length is 5m · 1.17 = 5.85 m

Conversion factors for roof slope 2



Pitch (Degree)	Pitch (%)	ratio rise : span b:a	ratio rafter length : span a : c
21.8°	40%	1 : 2.5	1 : 1.08
26.6°	50.0%	1 : 2	1 : 1.12
33.7°	66.7%	1 : 1.5	1 : 1.20

Reading example: With a given ratio of slope (rise : span) of 1 : 2

- the pitch is 26.6° or 50%
- the span is 2.0 x the rise
- the rafter length is 1.12 x the span incl. roof overhang

or

with a given ratio of slope (rise:span) is 1:2 and a span of 5 m
- the rise is 5m:2 = 2.5 m
- the rafter length is 5m · 1.12 = 5.6 m

Conversion factors for roof slope 3

2 Common timber for roof construction

Name (English - local - German)	Botanical name	Area of origin	Suitability	Bending breaking point N/mm2	Classification according to text in chapter 6.1.4	Resistance to fungi	Resistance to insects	Possibility of chemical impregnation
Douglas fir / Oregon pine / Douglasie	Pseudotsuga menziesii	Westcoast N America, Europe	Medium-stressed structures, ship construction, indoor and (with protection) outdoor use	68	C	Medium	Medium	Sapwood medium, heartwood poor
Pine (Austrian) / Schwarzkiefer	Pinus nigra	S. and Central Europe	Medium-stressed structures, furniture, decorative use, indoor and (with protection) outdoor use	80 - 105	C	Low	Low	Sapwood good, heartwood poor
Pine (radiata) / Lärche	Larix decidua	Central Europe, Japan	Highly stressed structures, furniture, indoor and outdoor use	88 - 99	C	Medium to low	Medium to high	Sapwood good, heartwood poor

Conifers

Name (English : local : German)	*Botanical name*	*Area of origin*	*Suitability*	*Bending breaking point N/mm2*	*Classification according to test in chapter 4.3.4*	*Resistance to fungi*	*Resistance to insects*	*Possibility of chemical impregnation*
Pine (radiata) / Lärche	Larix decidua	Central Europe, Japan	Highly stressed structures, furniture, indoor and outdoor use	88 - 99	C	Medium to low	Medium to high	Sapwood-good, heartwood-poor
Pine (Scots), redwood / Kiefer, Föhre	Pinus sylvestris	Europe, N.-W.- Asia	Medium-stressed structures, furniture, industrial use, indoor and (with protection) outdoor use	79 - 100	C	Low to medium	Low	medium
Pine (Southern)	Pinus palustris	Southern and southeastern N. America, Central America	Heartwood for highly-stressed structures, indoor and (with protection) outdoor use, Sapwood for medium-stressed structures, indoor use	75 - 105	C	Sapwood-low, heartwood-medium	Low	Sapwood-good, heartwood-poor

Conifers 2

Name (English / local / German)	*Botanical name*	*Area of origin*	*Suitability*	*Bending breaking point N/ mm2*	*Classification according to test in chapter 4.3.4*	*Resistance to fungi*	*Resistance to insects*	*Possibility of chemical impregnation*
Silver fir, whitewood / Tanne, Weisstanne	Abies Alba	Central and S. Europe	Medium stressed structures, industrial use, indoor and (with protection) outdoor use	62 - 74	C	Low	Low	Varying, generally medium
Spruce (European) white wood / Fichte	Picea abies	Europe	Medium-stressed structures, industrial use, indoor and (with protection) outdoor use	65 - 77	C	Low	Low	Poor when dry

Conifers 3

Name (English / local / German)	*Botanical name*	*Area of origin*	*Suitability*	*Bending breaking point N/ mm2*	*Classification according to text in chapter 4.3.4*	*Resistance to fungi*	*Resistance to insects*	*Possibility of chemical impregnation*
Afara / Limba	Terminalia superba	W. Africa	Medium-stressed structures, indoor use	75 - 100	C	Low	Low	Varying
Afrormosia / kokrodua, assamela	Pericopsis	Tropical W. Africa, Ivory Coast to Zaire	Medium to highly stressed structures, ship construction indoor and outdoor use	118 - 140	B	Very high	High, generally, also to termites	

Deciduous trees

Name (English / local / German)	*Botanical name*	*Area of origin*	*Suitability*	*Bending breaking point N/ mm2*	*Classification according to test in chapter 4.3.4*	*Resistance to fungi*	*Resistance to insects*	*Possibility of chemical impregnation*
Afzelia, doussie / apa chanfuta, lingue	Afzelia pachyloba, A. bipindensis, A. africana	Tropical Africa	Highly-stressed structures, ship construction, indoor and outdoor use	110 - 150	B	Very high	Very high, generally also to termites	
Agba / tola branca	Balsamiferum	Central and W. Africa	Medium stressed structures	63 - 85	C	Very high	Medium to high, limited resistance to termites	Sapwood-good, heartwood-poor
Andiroba / crabwood, cedro macho, krappa	Carapa guianensis, C. surinamensis	Tropical America	Highly stressed structures, ship construction, indoor and outdoor use	98 - 108	C	Low to medium	Medium	
Ash (European) / Esche	Fraxinus excelsior	Europe, W. Asia	Highly-stressed structures, furniture, indoor use	100 127	B	Low	Low	Medium

Deciduous trees 2

Name (English / local / German)	Botanical name	Area of origin	Suitability	Bending breaking point N/mm2	Classification according to text in chapter 4.3.4	Resistance to fungi	Resistance to insects	Possibility of chemical impregnation
Ayan, "Nigerian satinwood" / Movingui	Distemonanthus benthamianus	W. Africa	Highly stressed structures, indoor use	103 - 125	B	Medium to high	Medium to high	Poor
Azobe, bongossi / ekki, eba	Lophira alata	W. Africa	Highly stressed structures, indoor and outdoor use	165 - 240	A	High	Very high, also to termites	Not possible
Bangkirai / balau kumus, selangan batu	Shorea laevis, Shorea atrinervosa, S. glauca	S-E. Asia	Highly-stressed structures, indoor and outdoor use	192 - 145	A	High to very high	High	Poor
Beech (European) / Rotbuche	Fagus sylvatica	Europe	Medium to highly stressed structures, industrial use, indoor use	90 - 125	C	Very low	Low	Very good
Birch (European) / Birke	Betula verrucosa	Europe, N-Asia	Highly stressed structures, furniture	120 - 144	B	Very low	Low	Good

Deciduous trees 3

Name (English / local / German)	*Botanical name*	*Area of origin*	*Suitability*	*Bending breaking point N/ mm2*	*Classification according to tests chapter 4.3.4*	*Resistance to fungi*	*Resistance to insects*	*Possibility of chemical impregnation*
Chestnut (sweet) / Edelkastanie	Castanea sativa	Central- and S. Europe	Medium-stressed structures, furniture indoor and outdoor use	63 - 79	C	High to very high	High to very high	Sapwood-Medium, heartwood-poor
Chuéfata / Iotagbois, Iatola / Tchitola	Oxystigma oxyphyllum	Central and W. Africa	Medium-stressed structures, indoor and outdoor use	85 - 115	C	Low, heartwood high	Low, heartwood high	
Dabema / Dabemba	Piptadeniastrum africanum	Central and W. Africa	Medium to highly stressed structures, furniture indoor and outdoor use	104 - 110	B	High	High to very high	
Danta / Koube	Nesogordonia papaverifera	W. Africa	Medium to highly stressed structures, ship construction, indoor and outdoor use	123 - 145	A	Medium to high	High	

Deciduous trees 4

Name (English / local / German)	*Botanical name*	*Area of origin*	*Suitability*	*Bending breaking point N/ mm2*	*Classification according to test in chapter 4.3.4*	*Resistance to fungi*	*Resistance to insects*	*Possibility of chemical impregnation*
Greenheart	Ocotea rodiei	Northern South America, Guyana	Very highly stressed structures, indoor and outdoor use	180 215	A	Very high	High	
Hickory / carya, tomenteux	Carya glabra, C. ovata	Eastern North America	Highly-stressed structures, tools, indoor and outdoor use	115 - 139	B	Low	Low	Medium to poor
Idigbo / Black afara, emeri / Framiré	Terminalia ivorensis	Tropical W. Africa	Medium-stressed structures, indoor use	76 - 95	C	Medium	Medium	Sapwood-good, heartwood-medium
Iroko / kambala, mvule	Chlorophora excelsa, C. regia	Tropical Africa	Highly-stressed structures, indoor and outdoor use	90 - 120	C	Very high	High, rather resistant to termites	Sapwood-medium, heartwood-not possible

Deciduous trees 5

Name (English / local / German)	*Botanical name*	*Area of origin*	*Suitability*	*Bending breaking point: N/mm2*	*Classification according to test in chapter 4.3.4*	*Resistance to fungi*	*Resistance to insects*	*Possibility of chemical impregnation*
Keruing / apitong, dau, eng, gurjun	Dipterocarpus alatus, D. grandiflorus	Tropical Asia	Highly-stressed structures, indoor use	110 - 160	B	Medium	Medium	
Lauan (red) / tanguile, mayapis, tiaong, "meranti" in Malaysia, "seraya" in Kalimantan	Shorea spp., e.g. Shorea negrosensis	Philippines	Low to highly stressed structures, furniture, ship construction, indoor and outdoor use	80 - 100	C	Medium to high	Medium, not resistant to termites	Very poor
Lauan (white) / almon, "meranti" in Malaysia, "seraya" in Kalimantan	Shorea spp., parashorea spp., pentacme	Philippines	Low to highly stressed structures, furniture, ship construction, indoor and outdoor use	71 - 100	Highly varying (C)	Medium to high	Medium, not resistant to termites	Very poor
Longhi / abingre, akatin	Gambeya albida, G. subnudum	W. Africa	Medium to highly stressed structures, furniture, indoor use	94 - 104	C	Probably low	Probably low	

Deciduous trees 5

Name (English / local / German)	*Botanical name*	*Area of origin*	*Suitability*	*Bending breaking point N/mm2*	*Classification according to text in chapter 4.3.4*	*Resistance to fungi*	*Resistance to insects*	*Possibility of chemical impregnation*
Makoré / baku / Makore	Tieghemella, heckelii	W. Africa	Highly-stressed structures, furniture, indoor and outdoor use	95 - 115	C	Very high	Very high	Very poor
Mansonia / béré	Mansonia altissima	W. Africa	Highly-stressed structures, furniture, indoor and outdoor use	120 - 130	B	High	High	Very poor
Meranti (dark red), seraya	Shorea pauciflora	S-E. Asia	Low to highly stressed structures, furniture, ship construction, indoor and outdoor use	90 - 126	Highly varying (C)	Medium to High	Medium to high	Not possible
Meranti (light red) , seraya	Shorea leprosula, shorea negrosensis etc.	S-E. Asia	Low to highly stressed structures, furniture, ship construction, indoor and outdoor use	78 - 108	Highly varying (C)	Low to medium	Medium	Poor

Deciduous trees 6

Name (English / local / German)	*Botanical name*	*Area of origin*	*Suitability*	*Bending breaking point N/mm2*	*Classification according to test in chapter 4.3.4*	*Resistance to fungi*	*Resistance to insects*	*Possibility of chemical impregnation*
Merbau / ipil, kwila, hintzy	Intsia bijuga	S-E Asia, Madagaskar, Papua New Guinea	Highly-stressed structures, ship construction, indoor and outdoor use	105 - 142	B	Very high	High to very high	
Mussanda / mumara / Tali	Erythroph-leum guineense	Tropical Africa	Highly stressed structures, ship construction, indoor and outdoor use	120 - 140	B	High	High	
Niangon / nyankom, wishmore	Tarrietia utilis	W. Africa	Medium-stressed structures, indoor and outdoor use	90 - 110	C	Medium to high	Medium	Very poor
Oak (American, red) / northern red oak / Roteiche	Quercus robur, Qu. petraea	Central and eastern North America	Highly-stressed structures, furniture, ship construction, indoor and outdoor use (if impregnated)	98 - 110	C	Low	Low	Good

Deciduous trees 7

Name (English / local / German)	Botanical name	Area of origin	Suitability	Bending breaking point N/ mm2	Classification according to text in chapter 4.3.4	Resistance to fungi	Resistance to insects	Possibility of chemical impregnation
Oak (European) / Eiche, Stieleiche	Quercus robur, Qu. petraea	Europe	Highly-stressed structures, furniture, ship construction, indoor and outdoor use	86 - 108	C	High	High	Sapwood-good, heartwood-poor
Omu / Kosipo	Entandro-phragma candollei	W. Africa	Medium to highly stressed structures, furniture, ship construction, indoor and outdoor use	88 - 105	C	Medium	Medium	
Opepe / kusia, badi / Bilinga	Nauclea diderichii	Central and W. Africa	Medium to highly stressed structures, indoor and outdoor use	105 - 120	B	Very high	High, generally also to termites	Sapwood-good, heartwood-very poor
Paldao (Dao)	Dracontomelum dao	Malaysia, Philippines	Medium-stressed structures, furniture, indoor and outdoor use	ca. 100	C	Low	Low	

Deciduous trees 8

Name (English / local / German)	*Botanical name*	*Area of origin*	*Suitability*	*Bending breaking point N/ mm2*	*Classification according to text in chapter 4.1.4*	*Resistance to fungi*	*Resistance to insects*	*Possibility of chemical impregnation*
Panga panga / Wenge	Milletia laurentii	Central Africa (Cameroon, Zaire)	Highly-stressed structures, furniture, indoor and outdoor use	125 - 165	A	High to very high	High	Very poor
Ramin / melawis	Gonystylus bancanus	S-E. Asia, Malaysia	Medium to highly stressed structures, indoor use	110 - 134	B	Low	Low	Good
Robinia, black, yellow locust / Robinie, falsche Akazie	Robinia pseudoacacia	S-E. North America	Highly-stressed structures, indoor and outdoor use	118 - 145	B	Very high	High	Very poor
Sapele / aboudikro / Sapelli-Mahagoni	Entandro-phragma cylindricum	Tropical Africa	Medium-stressed structures, ship construction, indoor and outdoor use	85 - 135	C	Medium	Medium to high	Sapwood-medium, heartwood-poor

Deciduous trees 9

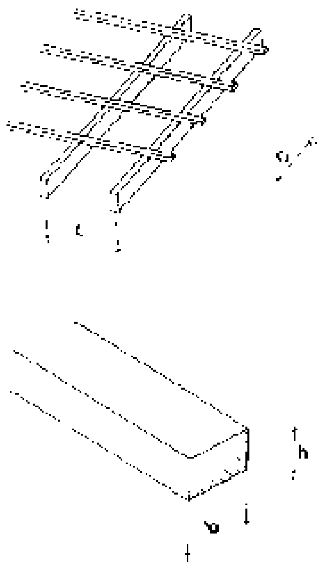
Name (English / local / German)	Botanical name	Area of origin	Suitability	Bending breaking point N/ mm2	Classification according to text in chapter 4.1.4	Resistance to fungi	Resistance to insects	Possibility of chemical impregnation
Sterculia (yellow) / okoko / Eyong	Sterculia oblonga	W. Africa	Medium to highly stressed structures, indoor use	100 - 123	B	Low	Low	Sapwood good Heartwood not possible
Teak / Teek	Tectona grandis	S. Asia tropical regions	Medium-stressed structures, ship construction, indoor and outdoor use	85 - 110	C	Very high	Very high	Not required
Utile / assié, sipo / Sipo-Mahagoni	Entandro-phragma utile	Tropical Africa	Medium stressed structures, ship construction, indoor and outdoor use	90 - 104	C	High	High	Not possible
Walnut (African) / bibolo / Dibetou	Lovoa brownii, L. trichilioides	Central and W. Africa	Medium-stressed structures, furniture, ship construction, indoor and outdoor use	69 - 100	C	Medium	Low to medium	Not possible

Deciduous trees 10

3 Sizing tables for timber structures

3.1 Sizing of battens

Reading example



Load

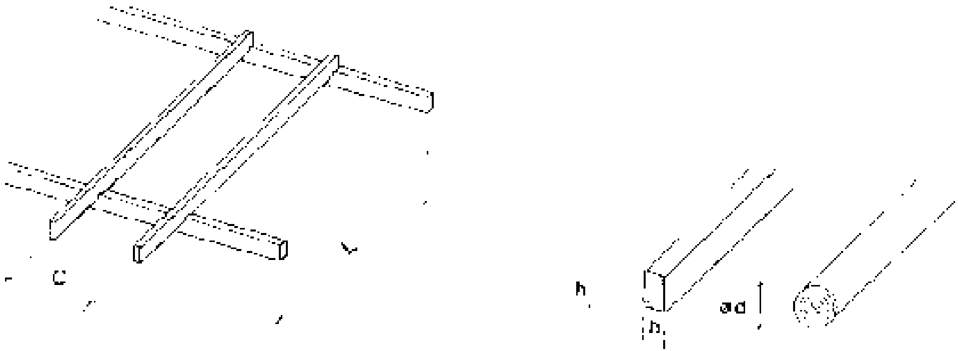
Sizing of battens

Timber Category							
		A		B		C	
L (m)	c (m)	h	b	h	b	h	b
0.6	0.4	20	31	20	38		
				25	24	25	41
						30	28
0.6	0.5	20	31	20	39		
		25	25	25	41		
						30	29
0.8	0.4	20	42	20	52		
		25	27	25	33	25	55
						30	38
0.8	0.5	20	43	20	53		
		25	27	25	34	25	56
						30	39
1	0.4	25	34	25	42		
				30	29	30	49
1	0.5	25	35	25	43		
				30	30	30	50
1.3	0.4	25	45	25	56		
				30	32	30	39
						35	48
						40	57
1.3	0.5	25	47				

		30	33	30	40		
						35	49
						40	38
1.6	0.4	25	57				
		30	40	30	49		
				35	36	35	61
						40	46
1.6	0.5	25	59				
		30	41	30	51		
				35	38	35	63
						40	48

Timber category

3.2 Sizing of rafters



Sizing of rafters

	Timber Category	

								Use for subordinate structures only					
		A		B		C		A		B		C	
L (m)	c (m)	h	b	h	b	h	b	h	b	h	b	h	b
1.5	0.6	40	46					40	34	40	44		
		50	30	50	37			50	22	50	28	50	46
		60	21	60	26	60	43					60	32
						80	24						
		Ø d	50	Ø d	54	Ø d	64	Ø d	45	Ø d	49	Ø d	58
1.5	0.8							40	37				
		50	32	50	40	50	66	50	24	50	30	50	50
		60	22	60	20	60	46			60	21	60	34
						50	26						
		Ø d	51	Ø d	55	Ø d	65	Ø d	46	Ø d	50	Ø d	59
1.5	1							40	39				
		50	34	50	42	50	71	50	25	50	32	50	53
		60	24	60	29	60	49			50	22	60	37
				70	22	70	36					70	27
						80	28						
		Ø d	53	Ø d	56	Ø d	67	Ø d	47	Ø d	51	Ø d	61
1.5	1.3							40	43				
		53	37	50	48			50	28	50	35		
		60	26	60	32	60	54			60	24	60	40
				70	24	70	39					70	30
						80	30						
		Ø d	54	Ø d	58	Ø d	69	Ø d	49	Ø d	53	Ø d	63
1.5	1.6	50	41	50	53	50	30	50	38				
		60	28	60	35	60	58	60	21	60	27	60	44
				70	26	70	45					70	32
						80	33					80	25
		Ø d	56	Ø d	60	d	71	Ø d	50	Ø d	[illegible]	Ø d	[illegible]

		Ø d	[illegible]	Ø d	[illegible]	[illegible]	[illegible]	Ø d	[illegible]	Ø d	[illegible]	Ø d	[illegible]
2	0.6	50	43	50	53			50	31	50	40		
		60	30	60	37	60	51	60	22	60	28	60	46
		70	22	70	27	70	45					70	34
						80	34					80	26
		Ø d	57	Ø d	61	Ø d	72	Ø d	51	Ø d	55	Ø d	65
2	0.8	50	46					50	34	50	44		
		60	32	60	40	60	67	60	24	60	30	60	50
		70	24	70	29	70	49			70	22	70	37
						80	38					80	28
		Ø d	58	Ø d	63	Ø d	74	Ø d	53	Ø d	57	Ø d	67

Timber category 1

		Timber Category											
		A		B		C		Use for subordinate structures only A		B		C	
L (m)	c (m)	h	b	h	b	h	b	h	b	h	b	h	b
2	1	50	50					50	37	50	47		
		60	35	60	43	60	72	60	26	60	33	60	54
		70	26	70	32	70	53			70	24	70	40
				80	24	80	41					80	30
		Ø d	60	Ø d	64	Ø d	76	Ø d	54	Ø d	59	Ø d	69
2	1.3							50	41	50	53		
		60	39	60	48	60	81	60	29	60	37	60	60
		70	29	70	36	70	59			70	27	70	44
				80	27	80	45					80	34
						100	29						
		Ø d	[illegible]	Ø d	[illegible]	Ø d	[illegible]	Ø d	[illegible]	Ø d	[illegible]	Ø d	[illegible]

2	1,6							50	46				
		60	43	60	53			60	32	60	40		
		70	32	70	39	70	65	70	23	70	30	70	49
				80	30	80	50					80	36
						90	40					90	30
						100	32						
		Ø d	64	Ø d	69	Ø d	82	Ø d	58	Ø d	63	Ø d	74
3	0.6	60	50	60	63			60	37	60	47		
		70	37	70	46			70	27	70	35	70	57
		80	28	80	35	80	59			80	27	80	44
				90	28	90	46					90	35
						100	38					100	28
		Ø d	66	Ø d	73	Ø d	86	Ø d	61	Ø d	66	Ø d	78
3	0.8	60	56					60	42	60	53		
		70	41	70	51	70	86	70	31	70	39	70	64
		80	32	80	39	80	66			80	30	80	49
				90	31	90	52					90	39
						100	42					100	32
		Ø d	70	Ø d	75	Ø d	89	Ø d	63	Ø d	69	Ø d	81

Timber category 2

		Timber Category											
								Use for suburdinate structures only					
		A		B		C		A		B		C	
L (m)	c (m)	h	b	h	b	h	b	h	b	h	b	h	b
3	1	60	63					60	45	60	59		
		70	45	70	57	70	95	70	34	70	43	70	71
		80	35	80	44	80	73	80	26	80	33	80	54

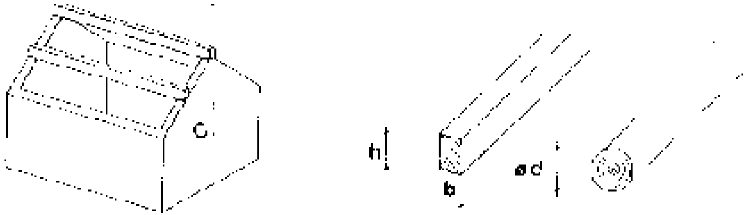
		90	29	90	34	90	57			90	26	90	43
				100	28	100	47					100	35
						120	32						
		Ø d	73	Ø d	78	Ø d	92	Ø d	65	Ø d	71	Ø d	84
3	1.3							60	53				
		70	53	70	65			70	39	70	49		
		80	40	80	50	80	83	80	30	80	38	80	62
		90	32	90	39	90	66			90	30	90	49
				100	32	100	53					100	40
						120	37						
		Ø d	76	Ø d	82	Ø d	97	Ø d	69	Ø d	74	Ø d	88
3	1.6							60	60				
		70	59	73	73			70	44	70	56		
		80	45	80	56			80	33	80	43	80	70
		90	36	90	44	90	74	90	25	90	34	90	56
		100	29	100	36	100	60					100	45
						120	42					120	31
		Ø d	79	Ø d	85	Ø d	101	Ø d	71	Ø d	77	Ø d	91
4	0.6							60	56				
		70	55	70	69			70	41	70	52		
		80	42	80	53			80	31	80	40	80	66
		90	33	90	41	90	69			90	31	90	52
				100	34	100	56					100	42
						120	39						
		Ø d	77	Ø d	83	Ø d	98	Ø d	70	Ø d	76	Ø d	89
4	0.8	70	63					70	47	70	59		
		80	49	80	60			80	35	80	45	80	75
		90	38	90	47	90	79	90	28	90	36	90	59
		100	31	100	38	100	64			100	29	100	48
						120	44					120	33
						140	33						
		Ø d	81	Ø d	87	Ø d	103	Ø d	73	Ø d	79	Ø d	93

Timber category 3

		Timber Category						Use for subordinate structures only					
		A		B		C		A		B		C	
- (m)	c (m)	h	b	h	b	h	b	h	b	h	b	h	b
4	1							70	52	70	67		
		80	54	80	68	80	113	80	40	80	51	80	84
		90	43	90	53	90	89	90	32	90	40	90	67
		100	35	100	43	100	72			100	33	100	54
				120	30	120	50					120	36
						140	37						
		Ø d	84	Ø d	90	Ø d	107	Ø d	76	Ø d	82	Ø d	97
4	1.3							70	6'				
		80	64	80	79			80	47	80	60		
		90	50	90	62			90	37	90	47	90	78
		100	41	100	50	100	84	100	30	100	38	100	63
				120	35	120	58					120	44
						140	43					140	32
		Ø d	68	Ø d	95	Ø d	113	Ø d	80	Ø d	87	Ø d	102
4	1.6							70	75				
		80	77					80	57	80	73		
		90	61	90	76			90	45	90	57	90	95
		100	50	100	61	100	102	100	37	100	47	100	77
		120	34	120	43	120	71			120	32	120	53
						140	52					140	39
						160	40						
		Ø d	94	Ø d	101	Ø d	120	Ø d	85	Ø d	92	Ø d	109

Timber category 4

3.3 Sizing of purlins



Sizing of purlins

		Timber Category						Use for subordinate structures only					
		A		B		C		A		B		C	
L (m)	c (m)	h	b	h	b	h	b	h	b	h	b	h	b
3	1.5							60	61				
								70	45	70	57		
		80	46	80	57			80	34	80	43	80	72
		100	30	100	37	100	61			100	28	100	46
						120	42					120	32
		Ø d	79	Ø d	85	Ø d	101	Ø d	72	Ø d	78	Ø d	92
3	2							70	56	70	71		
		80	53	80	72			80	43	80	54		
		100	37	100	46	100	77			100	35	100	57
				120	32	120	53					120	40
						140	39						
		Ø d	86	Ø d	92	Ø d	109	Ø d	77	Ø d	84	Ø d	99
3	3							80	64	80	81		

[illegible]	[illegible]	90 69 100 56 120 39 Ø d 98	90 85 100 69 120 48 140 35 Ø d 105	120 80 140 59 160 45 Ø d 125	[illegible] 90 51 100 41 Ø d 89	[illegible] 90 64 100 52 120 36 Ø d 96	100 86 120 60 140 44 160 34 Ø d 113
3	4	90 91 100 74 120 51 140 38 160 36 Ø d 108	100 92 120 64 140 47 160 60 Ø d 116	120 106 140 78 180 47 200 38 Ø d 137	80 85 90 67 100 55 120 38 Ø d 98	90 86 100 70 120 48 140 35 Ø d 106	120 80 140 59 160 45 Ø d 125
4	1.5	80 77 100 49 120 34 Ø d 94	100 61 120 43 Ø d 101	100 102 120 71 140 52 160 40 Ø d 120	80 57 100 36 Ø d 86	80 72 100 46 120 32 Ø d 92	100 77 120 53 140 39 Ø d 109

Timber category

		Timber Category						Use for subordinate structures only					
		A		B		C		A		B		C	
L (m)	c (m)	h	b	h	b	h	b	h	b	h	b	h	b
4	2							80	76				
		90	81					90	60	90	76		

		100 66 120 46 140 34 Ø d 104	100 82 120 57 140 42 Ø d 111	120 94 140 69 160 53 180 42 Ø d 132	100 49 120 34 Ø d 94	100 62 120 43 140 32 Ø d 102	100 102 120 71 140 52 160 40 Ø d 120
4	3	100 99 120 69 140 50 160 39 Ø d 119	120 85 140 62 160 48 180 38 Ø d 128	140 104 160 80 180 63 200 51 220 42 Ø d 151	100 73 120 51 140 37 Ø d 107	100 93 120 64 140 47 160 36 Ø d 116	120 106 140 78 160 60 180 47 200 38 Ø d 137
4	4	120 91 140 67 160 51 180 41 Ø d 131	120 113 140 83 160 64 180 50 200 41 Ø d 140	140 139 160 106 180 84 200 68 220 56 Ø d 167	100 97 120 67 140 50 160 38 Ø d 118	120 86 140 63 160 48 180 38 Ø d 128	140 104 160 80 180 63 200 51 220 42 Ø d 151
5	1.5	100 77 120 54 140 39 Ø d 109	100 96 120 66 140 49 160 37 Ø d 118	120 111 140 81 160 62 180 49 200 40 Ø d 139	100 57 120 40 Ø d 99	100 72 120 50 140 37 Ø d 107	120 83 140 61 160 47 180 37 Ø d 127
5	2	100 103 120 71 140 52	120 89 140 65	120 53 140 108	100 76 120 57 140 39	100 97 120 111 140 49	140 81

	160 40	160 50	160 83		160 38	160 62
		180 39	180 66			180 49
			200 53			200 40
			220 44			
	Ø d 120	Ø d 129	Ø d 153	Ø d 109	Ø d 118	Ø d 139

Timber category 2

		Timber Category						Use for subordinate structures only					
		A		B		C		A		B		C	
L (m)	c (m)	h	b	h	b	h	b	h	b	h	b	h	b
5	3	120	107					120	79	120	101		
		140	79	140	98			140	58	140	74	140	122
		160	60	160	75	160	125	160	44	160	57	160	93
		180	48	180	59	180	98			180	45	180	74
		200	39	200	48	200	80					200	63
				220	40	220	66					220	49
						240	55						
						260	47						
		Ø d	138	Ø d	148	Ø d	176	Ø d	125	Ø d	135	Ø d	160
5	4							120	105				
		140	105	140	130			140	77	140	99		
		160	80	160	100	160	166	160	59	160	75	160	125
		180	63	180	79	180	131	180	47	180	60	160	98
		200	51	200	64	200	106	200	36	200	48	200	80
		220	42	220	53	220	88			220	40	220	66
				240	44	240	74					240	55
						260	63					260	47
						280	54						
		Ø d	152	Ø d	163	Ø d	193	Ø d	137	Ø d	149	Ø d	176

Timber category 3