Roundwood structures

STEP lecture E19
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Objective

To give an overview of the types of structure that can be constructed from roundwood.

Summary

Different uses of roundwood are shown by means of a few examples and a calculation example for a timber pole construction is given designed in accordance with EC5. Connection methods are also considered within the lecture.

Introduction

The construction of buildings with roundwood is one of the oldest construction types known. Roundwood as construction material could be obtained without great effort allowing the material to be used by so-called primitive cultures. The applications cover simple log cabins up to highly developed pole and tower buildings. The famous Norwegian stave churches are excellent examples. The use of roundwood construction is increasing due to the low cost of the basic material and the low construction costs.

Applications

Today roundwood construction is mostly used in agricultural buildings. There are several reasons for this:

- Stables and sheds, storage for machines or barns for corn have no special need of airtightness and particularly in barns a ventilated construction is preferred to make the additional drying of harvest possible.
- The farms require high volume low cost construction.
- A lot of farms are close to woodland or own forest areas. They could use their own raw products when they only have to cut the trees, remove the bark by hand or small machines and form the connection areas with a chain-saw.
- Agricultural organisations sell kit buildings or just instructional information together with calculations and the necessary special connectors for different types of buildings from sheds to barns.
- The simplicity of construction allows the possibility of self-build.

Roundwood construction is also used for simple halls in other applications, e.g. for boat yards because the costs of the structure can be minimised. In house construction timber poles are not used very often. However, in regions with flooding problems, difficult soils, steep slopes or in cases of special architectural requirements, timber poles are sometimes used to provide an elevated building platform and the poles may be continued to form the structural frame. A new application is the construction of sound barriers using cheap readily available small diameter poles. The walls are anchored between cantilever steel columns or timber poles. This form of construction is also appropriate to small retaining walls.

For simple wall construction in agricultural buildings, as well as in retaining walls and noise barriers, pole diameters up to 140 *mm* are used, see Figure 1.

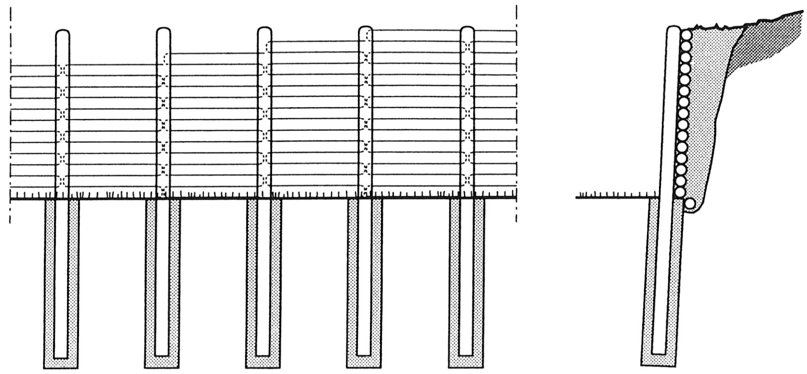

Figure 1 *Pole retaining wall.*

Sports halls in particular those for equestrian activities are built in roundwood. The roundwood is used for the columns and walls and in few cases additionally for roof trusses. The joints in the trusses are designed as steel-to-timber joints by incorporating steel nodes.

Further applications of roundwood construction are in harbour construction, e.g. bank stabilisation or catwalks for boat landing, and in simple short span bridges for agriculture and forestry use. Roundwood is also used for look-out and observation towers particularly in woodland areas.

Material Properties

Roundwood gives a very good ecological balance, because sawing is not needed. and the use of primary energy is minimised. It is necessary to remove the bark from the roundwood to minimise the risk of insect attack and for some uses the poles must be peeled to obtain constant diameters and surfaces. No sawing also means the full strength of the wood is preserved.

In roundwood construction all European species of softwood are used, e.g. spruce, fir, pine, larch and Douglas Fir. If timber of high durability such as larch or Douglas Fir is used in a carefully detailed construction preservatives may not be necessary. Normally a chemical preservation treatment is used, particularly for structural usage. To improve the quantity and the penetration depth of the impregnation particularly where there is ground contact or at joints predrilled holes are used, see Figure 2. The kind of preservation for load bearing construction is carried out in accordance with "EN 335-1: Durability of wood and wood-based products - definition of hazard classes of biological attack. Part 1: General", "EN 335-2: Durability of wood and wood-based products - definition of hazard classes of biological attack. Part 2: Application to solid wood" and "EN 350-2: Durability of wood and wood-based products - natural durability of wood - Part 2: Guide to natural durability and treatability of selected wood species of importance in Europe".

For roundwood which is only debarked higher strength values can be used because the material is left in natural form and longitudinal fibres are not cut as in sawn timber. However, currently EC5 gives no special rules for roundwood. Also in the standards "EN 518: Structural timber - Grading. Requirements for visual strength grading standards" and "EN 519: Structural Timber - Grading.

Requirements for machine strength graded timber and grading machines" reference is only made to sawn timber, not to roundwood. Guidance could be taken from EN TC 124.210: Timber Poles for overhead lines - Requirements for strength grading standards" however this standard does not cover load-bearing construction.EN 518 is a standard for national standards. Therefore material properties could be used in accordance with the national grading standards for roundwood. In the following example roundwood class II as given in the German national standard DIN 4074-2 is used.

Timber Pole Structures

Roundwood could be used in all fields of application of sawn timber if all joints were specially designed. One of the most economic construction forms with roundwood is the use of cantilever timber poles, and this is practised in a lot of countries all over the world. Timber poles are placed in predrilled holes and the void is filled with concrete, or occasionally only with gravel. In this way cantilever poles are created which can resist vertical and horizontal forces. The diameters of such poles are normally between 200 *mm* and 350 *mm*. The costs for foundations and bracing of the buildings are mainly reduced. Dröge (1986) noted a decrease in costs of 45%. To allow this type of construction a soil is required which allows predrilling and will provide adequate characteristic values of ground pressure. Timber pole structures could be used with non-cohesive soils with a minimum medium density or cohesive soils with a stiff consistency.

An example of the construction of a base to a timber pole structure is given in Figure 2.

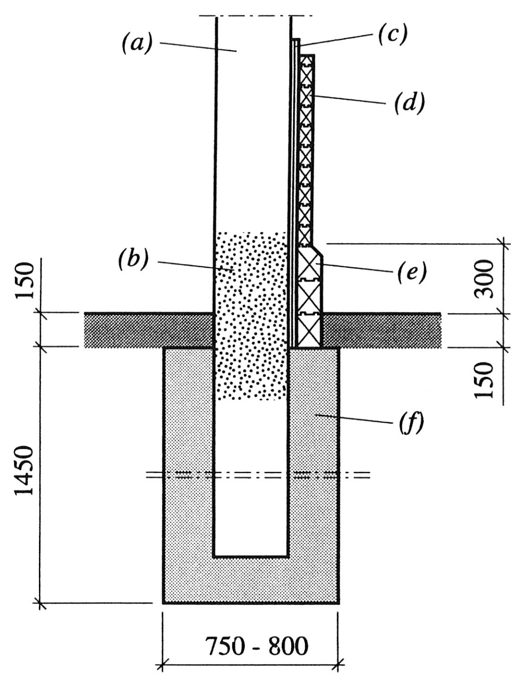

Figure 2 *Example of a base of a cantilevered timber pole (Merk, 1990). (a) Pressure treated timber pole, (b) additional perforation to facilitate penetration of preservative, (c) pressure treated board, (d) pressure treated wall planks, d = 60 mm, (e) pressure treated timbers, d = 100 mm, (f) concrete C12/15.*

The concrete used to fill the holes should be in accordance with class C12/15 given in ENV 206 and consistency class C0 given in ISO 4111. In buildings with spans up to 12 *m*, utilising lightweight roofing and with standard wind and snow loads, the distance between the poles will normally be 3,00 - 5,00 *m*.

The example shows how a timber pole structure is designed. The ground pressure caused by vertical loads can be calculated based on a diameter $d_b = d_b +$ 0,10 m for the ground area (symbols are given in Figure 3). To design a timber pole according to EC5 the buckling length must be known. For an elastic restraint a buckling length $s_k = \beta\, l$ ($\beta > 2$) has to be calculated. As an alternative a non-linear analysis could be carried out. In reality the rotational stiffness of the foundation depends on the rotation of the pole requiring an iterative calculation based on an estimation of the deflection of the pole head.

Rotation of the foundation and with it the buckling length could be calculated using loads with a partial safety factor $\gamma = 1$ and by using the national codes for engineering soil properties. After calculation of the buckling length the regulations of EC5 may be used. The following example is calculated according to "DIN 18900: Timber Pole Structures - design and construction". Some characteristic values for common soils are given in Table 1. If the soil underlying the building does not correspond with these classifications, the characteristic values of mechanical properties and density have to be determined by testing in accordance with National or European standards.

Example timber pole structure (taken from Nürnberger, 1988)

Assumptions

Service class 2. In many cases service class may be more appropriate.
deflection of pole head $w_k \leq h\,/\,75$
characteristic soil properties according to Table 1.

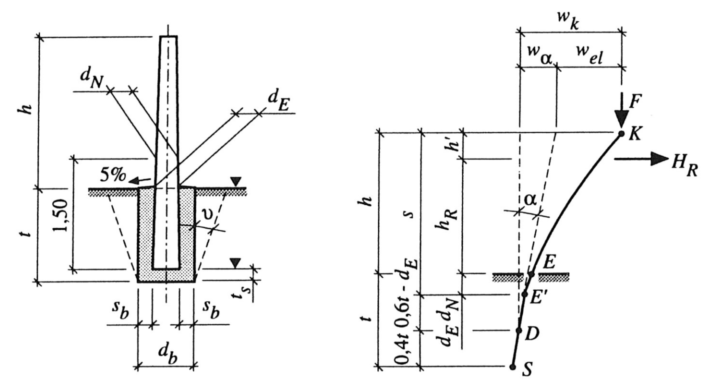

Figure 3 Symbols for timber pole structures.

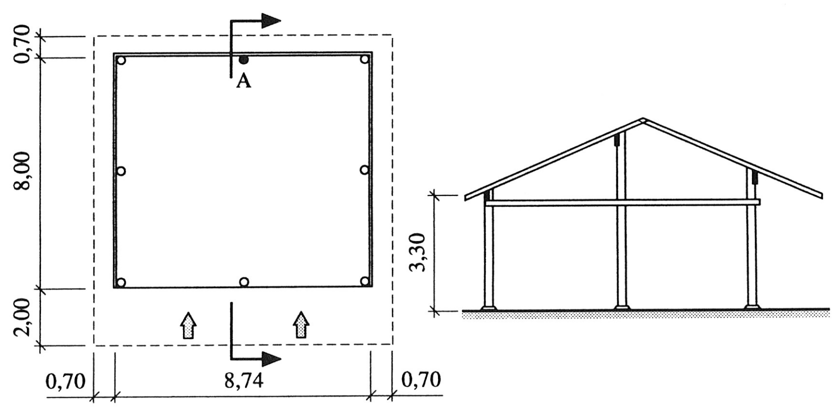

Figure 4 Geometry of the building, calculation of pole A.

Characteristic soil properties								
kind of soil		compactness or consistency	γ [kN/m^3]	φ [°]	c' [kN/m^2]	b	$\lambda \overline{p_h}$	$\lambda \overline{p_c} \cos\delta$
non-cohesive soil	sand with U ≤ 6	medium density	18,0	32,5	--	0,9	11,0	--
		high density	19,0	35,0	--	0,8	14,5	--
	gravel	medium density	18,0	35,0	--	0,8	14,5	--
		high density	19,0	37,5	--	0,7	19,5	--
	gravel-sand with U > 15	medium density	20,0	32,5	--	0,9	11,0	--
		high density	22,0	35,0	--	0,8	14,5	--
cohesive	clay	stiff	19,0	17,5	10,0	2,05	2,0	3,6
cohesive	silty clay	stiff	19,5	22,5	5,0	1,50	4,0	5,2

Table 1 Characteristic soil properties.

Calculations for pole A

Characteristic values of actions

vertical load, self-weight: F_g = 20,7 kN
vertical load, snow: F_s = 25,6 kN
vertical load, wind (suction): F_w = -19,9 kN
moment at point E caused by wind: M_w = 14,9 kNm
horizontal load caused by wind: q_w = 2,73 kN/m

Materials

Concrete C12/15 according to ENV 206, consistency C0 according to ISO 4111, earth moisture.

Softwood C24 according to EN 338
$E_{0,05}$ = 7400 N/mm^2
Pole diameter at bottom: d_N = 260 mm > 150 mm
(Minimum diameter)
Pole diameter at point E: d_E = 260 mm
Hole diameter: d_b = 500 mm
Depth of hole: t = 1500 mm
Thickness of concrete: s_b = 120 mm
Thickness of bottom concrete: t_s = 150 mm

Check of minimum criteria:

$120\ mm \leq 1,2\ s_b \leq t_s \leq 0,14\ t \leq 250$
$1,2\ s_b = 1,2 \cdot 120 = 144\ mm \leq 150\ mm$
$0,14\ t = 0,14 \cdot 1500 = 210\ mm \geq 150\ mm$
$400\ mm < d_b \leq 800\ mm$

Soil: sand, small particle-size distribution ($U \leq 6$), medium density
Density: $\gamma = 18,0\ kN/m^3$
Angle of internal friction: $\varphi = 32,5°$
Cohesion: $c' = 0$
According to Table 1, see Nürnberger (1988)
Rate of plane of rupture: $b = 0,9$
Volume-coefficient of passive lateral soil pressure:

$$\lambda \overline{p_h} = 11,0$$

Reduction factor: $\nu_Y = \nu_c = 0{,}35$

(Using soil values determined by tests ν_c should be $\nu_c = 0{,}25$)

Geometric properties of the pole

$d_E = 260\ mm$

$A_E = d_E^2 \cdot \pi/4 = 260^2 \cdot \pi/4 = 53100\ mm^2$

$W_E = d_E^3 \cdot \pi/32 = 260^3 \cdot \pi/32 = 1{,}73 \cdot 10^6\ mm^3$

$I_E = d_E^4 \cdot \pi/64 = 260^4 \cdot \pi/64 = 224 \cdot 10^6\ mm^4$

$i_E = d_E / 4 = 260/4 = 65\ mm$

Limiting value of fixed end moment

$u_K = 40\ mm$ (estimated)

$M_E = M_W + u_K F = 14{,}9 + 0{,}04 \cdot (20{,}7\text{-}19{,}9 + 25{,}6) = 16{,}0\ kNm$

$H_R = q_w h = 2{,}73 \cdot 3{,}30 = 9{,}01\ kN$

$h_R = M_E / H_R = 16{,}0/9{,}01 = 1{,}77\ m = 1770\ mm$

$n = h_R / t = 1770/1500 = 1{,}18 > 1{,}0$

$k_1 = 0{,}217/(n + 0{,}6) = 0{,}217 / (1{,}18 + 0{,}6) = 0{,}122$

Limiting value of H_R

$$H_{R,lim} = \nu_y\, k_1\, (\gamma / 3)\, 9 \boldsymbol{\lambda}\, \overline{\boldsymbol{p_h}}\, (t + (b\, d_b / 4))^3 + \nu_c\, k_1\, c'\, \boldsymbol{\lambda}\, \overline{\boldsymbol{p_c}} \cos\delta\, (t + (b\, d_b / 4))^2$$

$$H_{R,lim} = 0{,}35 \cdot 0{,}122 \cdot \frac{18}{3} \cdot 11 \left(1{,}5 + \frac{0{,}9 \cdot 0{,}5}{4}\right)^3 + 0 = 11{,}8\ kN > 9{,}01\ kN$$

$M_{E,lim} = H_{R,lim}\, h_R = 11{,}8 \cdot 1{,}77 = 20{,}9\ kNm \geq M_E$

Deflection of pole head

$u_K = u_\alpha + u_{el}$

$a = M_E / M_{E,lim}$

$tan\ \alpha = (a_3 + a_2 + a)\ 10^{-3}$

$tan\ \alpha = [(16{,}0/20{,}9)^3 + (16{,}0/20{,}9)^2 + 16{,}0/20{,}9]\ 10^{-3} = 0{,}00180$

$u_\alpha = (0{,}6\ t + h) \tan \alpha = (0{,}6 \cdot 1500 + 3300)\ 0{,}00180 = 7{,}6\ mm$

$s = h + d_E = 3{,}30 + 0{,}26 = 3{,}56\ m$

$y = h / s$

$$u_{el} = \frac{q\, s^4}{8\, EI_E} = \frac{2{,}73 \cdot 3560^4}{8 \cdot 7400 \cdot 224 \cdot 10^6} = 33{,}1\ mm$$

Condition:

$u_K = u_\alpha + u_{el} \leq h / 75$

$u_K = 7{,}6 + 33{,}1 = 40{,}7\ mm \leq 3300/75 = 44\ mm$

$u_K = 40{,}3\ mm > 40\ mm$ (estimated value)

therefore

$M_E = 14{,}9 + 0{,}0407 \cdot 26{,}4 = 16{,}0\ kNm = 16{,}0\ kNm$

new calculation of deflection of pole head is not necessary

Pole buckling length

$M_E = 16{,}0\ kNm$

$tan\ \alpha = [(16{,}0 / 20{,}9)^3 + (16{,}0 / 20{,}9)^2 + 16{,}0 / 20{,}9] \cdot 10^{-3} = 0{,}00180$

$K_r = M_E / tan\ \alpha = 16{,}0 / 0{,}00180 = 8890\ kNm$

$s = h + d_E = 3300 + 260 = 3560\ mm$

$$\beta = 1{,}03 \sqrt{4 + \frac{\pi^2\, EI_E}{s\, K_r}} = 1{,}03 \sqrt{4 + \frac{\pi^2 \cdot 7400 \cdot 224 \cdot 10^6}{3560 \cdot 8890 \cdot 10^6}} = 2{,}19$$

$l_{ef} = s\,\beta = 3560 \cdot 2{,}19 = 7800\ mm$

Design values of actions according to EC5

Load case 1: permanent load

$max\ F_{c,d} = 1{,}35 \cdot 20{,}7 = 27{,}9\ kN$

Load case 2: permanent load + snow

$max\ F_{c,d} = 1{,}35 \cdot 20{,}7 + 1{,}50 \cdot 25{,}6 = 66{,}4\ kN$

$M_d = 0$

Load case 3: permanent load + snow + ψ wind

$max\ F_{c,d} = 1{,}35 \cdot 20{,}7 + 1{,}50 \cdot 25{,}6 - 1{,}50 \cdot 0{,}60 \cdot 19{,}9 = 48{,}4\ kN$

$M_d = 13{,}4\ kNm$

Load case 4: permanent load + ψ snow + wind

$max\ F_{c,d} = 1{,}35 \cdot 20{,}7 + 1{,}50 \cdot 0{,}7 \cdot 25{,}6 - 1{,}50 \cdot 19{,}9 = 25{,}0\ kN$

$$M_d = \frac{1{,}5 \cdot 2{,}73 \cdot 3{,}30}{2} = 22{,}3\ kNm$$

Load case 5: permanent load + wind

$max\ F_{t,d} = 1{,}0 \cdot 20{,}7 - 1{,}50 \cdot 19{,}9 = -9{,}15\ kN$

$$M_d = \frac{1{,}5 \cdot 2{,}73 \cdot 3{,}30}{2} = 22{,}3\ kNm$$

Characteristic values of material properties

Softwood C24

$d_E = 260\ mm$

$f_{m,k} = 24\ N/mm^2 \qquad f_{c,0,k} = 21\ N/mm^2$

$E_{0,mean} = 11000\ N/mm^2 \qquad E_{0,05} = 7400\ N/mm^2$

Design values of material properties

Service class 2

$\gamma_M = 1{,}3$

$k_{mod} = 0{,}6$ for load case 1

$f_{m,d} = 11{,}1\ N/mm^2 \qquad f_{c,0,d} = 9{,}7\ N/mm^2$

$k_{mod} = 0{,}9$ for load cases 2 to 4

$f_{m,d} = 24 \cdot 0{,}9/1{,}3 = 16{,}6\ N/mm^2$

$f_{c,0,d} = 21 \cdot 0{,}9/1{,}3 = 14{,}5\ N/mm^2$

Column calculation according to EC5: Part 1-1: 5.2.1

$$\lambda_{rel} = \frac{l_{ef}}{i}\sqrt{\frac{f_{c,0,k}}{\pi^2\,E_{0,05}}} = \frac{7800}{260/4}\sqrt{\frac{21{,}0}{\pi^2 \cdot 7400}} = 2{,}03 > 0{,}5$$

$\beta_c = 0{,}2$ for solid wood

$$k = 0{,}5\,(1 + \beta_c\,(\lambda_{rel} - 0{,}5) + \lambda_{rel}^2) = 2{,}72$$

$$k_c = \frac{1}{k + \sqrt{k^2 - \lambda_{rel}^2}} = \frac{1}{2{,}72 + \sqrt{2{,}72^2 - 2{,}03^2}} = 0{,}221$$

Verification

$\sigma_{c,0,d} = F_{c,d} / A$

$\sigma_m = M_d / W$

$(\sigma_{c,0,d} / k_c\,f_{c,0,d}) + (\sigma_m / f_{m,d}) \leq 1{,}0$

governing load combination: load case 4

$$\sigma_{c,0,d} = \frac{N_d}{A} = \frac{25000}{53100} = 0{,}47\ N/mm^2$$

$$\sigma_{m,d} = \frac{M_d}{W} = \frac{22{,}30 \cdot 10^6}{1730000} = 12{,}9\ N/mm^2$$

$$\frac{\sigma_{c,0,d}}{k_c\, f_{c,0,d}} + \frac{\sigma_{m,d}}{f_{m,d}} \leq 1$$

$$\frac{0{,}47}{0{,}221 \cdot 14{,}5} + \frac{12{,}9}{16{,}6} = 0{,}92 < 1$$

Soil pressure

d_b $= d_b + 100\ mm$ $= 500 + 100$ $= 600\ mm$

A_b $= d_b^2\ \pi/4$ $= 600^2\ \pi/4$ $= 0{,}283 \cdot 10^6\ mm^2$

$\sigma_{c,d}$ $= \max F_{c,d} / A_b$ $\leq f_{c,d}$

calculation according to EC7 or NAD

Pull-out calculation of load case 5

lower radius of frustum of cone

r_u $= d_b /2$ $= 0{,}50 / 2$ $= 0{,}25\ m$

upper radius of frustum of cone

r_o $= r_u + t \tan \delta$ $= 0{,}25 + 1{,}50 \tan 17{,}5° = 0{,}72\ m$

Weight calculation with volume of radius of frustum of cone and cylinder

G_{soil} $= 18{,}0 \cdot 1{,}50 \cdot \pi\ [(0{,}72^2 + 0{,}72 \cdot 0{,}25 + 0{,}25^2)/3 - 0{,}50^2/4]$
$= 16{,}21\ kN$

$G_{concrete}$ $= 23{,}0 \cdot \pi\ [0{,}50^2 \cdot 1{,}50 - 0{,}26^2\ (1{,}50 - 0{,}15)/4]$
$= 5{,}13\ kN$

G_{timber} $= 6{,}0 \cdot 0{,}26^2 \cdot 1{,}35 \cdot \pi/4$ $= 0{,}43\ kN$

G_{tot} $= G_{soil} + G_{concrete} + G_{timber}$ $= 16{,}21 + 5{,}13 + 0{,}43$
$= 21{,}77\ kN$

$\max F_{t,d}$ $= 9{,}15\ kN < 21{,}77\ kN$

Joints

Connections in roundwood construction are more difficult to manufacture than connections with sawn timber. Often roundwood can only be cut by chain-saws. The roundwood will need to be cut to facilitate splice joints and to ensure good bearing between members in compression joints. If the loads are low or the joint is used purely for location, joist hangers or thin metal plates may be used. Special joist hangers for roundwood construction with different diameters are distributed by special firms. If these metal parts have no load-bearing function or if they only act in tension they could be designed according to EC5. Joist hangers for roundwood construction which are similar to joist hangers for sawn timber are not covered by any European Standard. They have to be designed according to an European Technical Approval or to a National Technical Approval. Figure 5 shows examples of typical joints, Figure 6 shows a joint at a pole head to connect a double beam. If pole heads are connected by girders it should be noted that compression loads will be set up. Curved or pitched cambered beams should not be used in this form of construction in order to avoid lateral movements of the column heads.

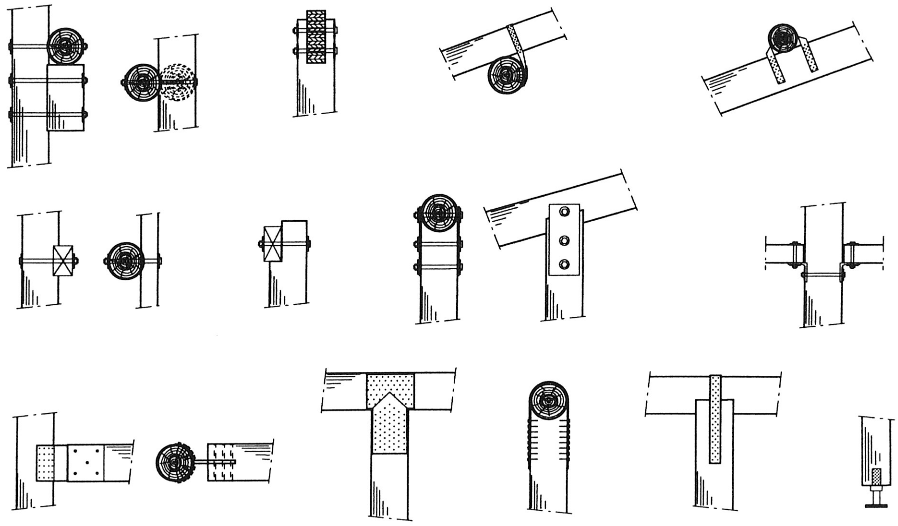

Figure 5 *Different types of roundwood joints.*

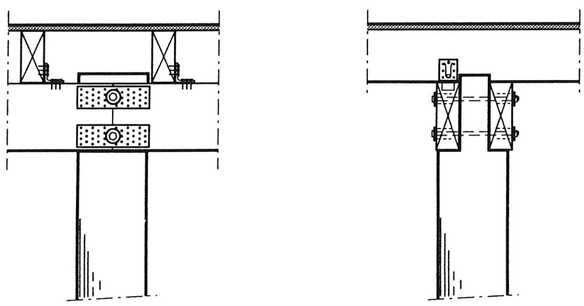

Figure 6 *Timber Pole Construction: joint at pole head.*

If the restraint of poles is not strong enough or if an additional bracing to reduce buckling length is necessary, additional diagonals could be used, see Figure 7.

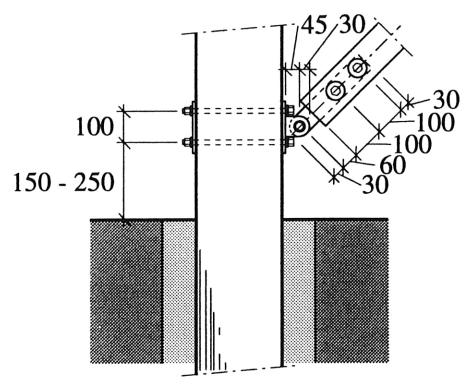

Figure 7 *Timber Pole Construction: Connection of diagonal.*

Concluding Summary

Roundwood construction enables cheap buildings particularly suited to agricultural needs but also available for many other fields of application. Using timber pole construction can reduce costs up to 45%. Roundwood structures are particularly good in their low use of primary energy and they also provide an excellent ecological balance. Most European softwood can be used bot poles should be protected by wood preservatives where they are buried in the ground or in concrete to form foundations. Special rules for roundwood construction have yet to be provided in any European Standard.

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