Softwood – hardwood hybrid members and connections

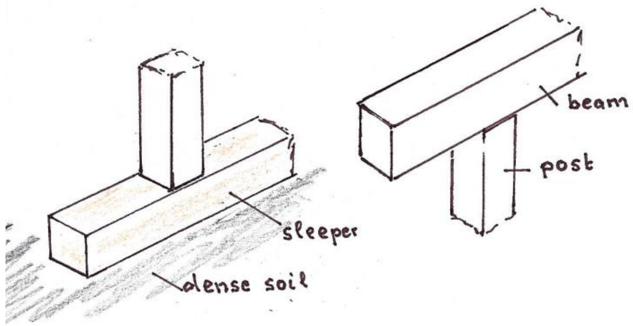
Ernst Gehri

Stockholm – 19.01.2018

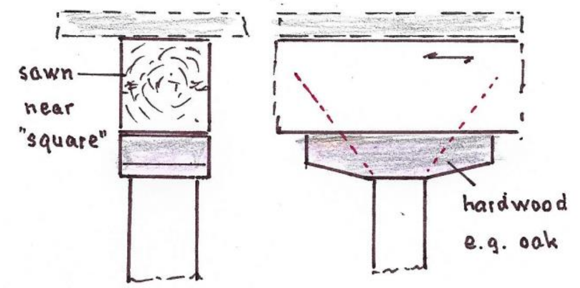
softwood ⟷ hardwood

Let’s start with a very common situation

→ Introduction of a load perp. to grain in softwood



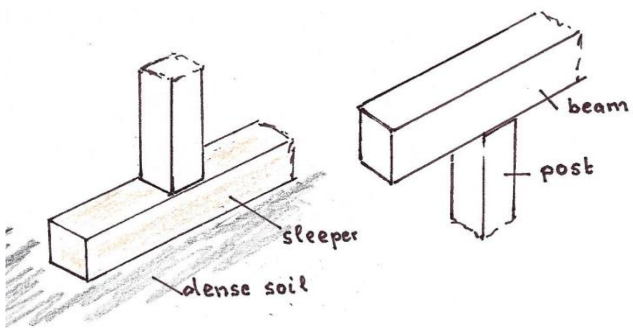
based on experience: use of hardwood sleeper or saddle



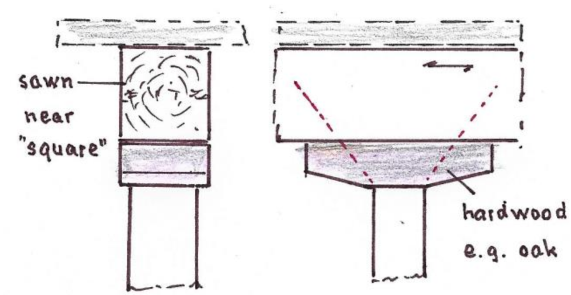
softwood ⟷ hardwood

Let's start with a very common situation

→ Introduction of a load perp. to grain in softwood

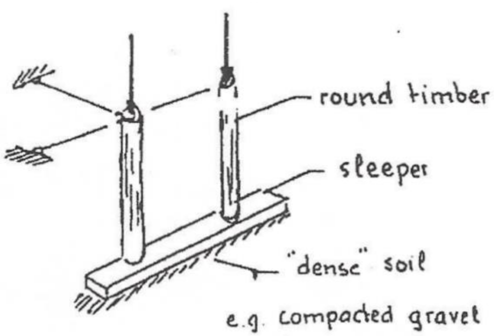


based on experience: use of hardwood sleeper or saddle



→ strength: compression perp. to grain (A. Föppl – 1904)

What is the bearing capacity? Which load should be assumed as safe or allowable?

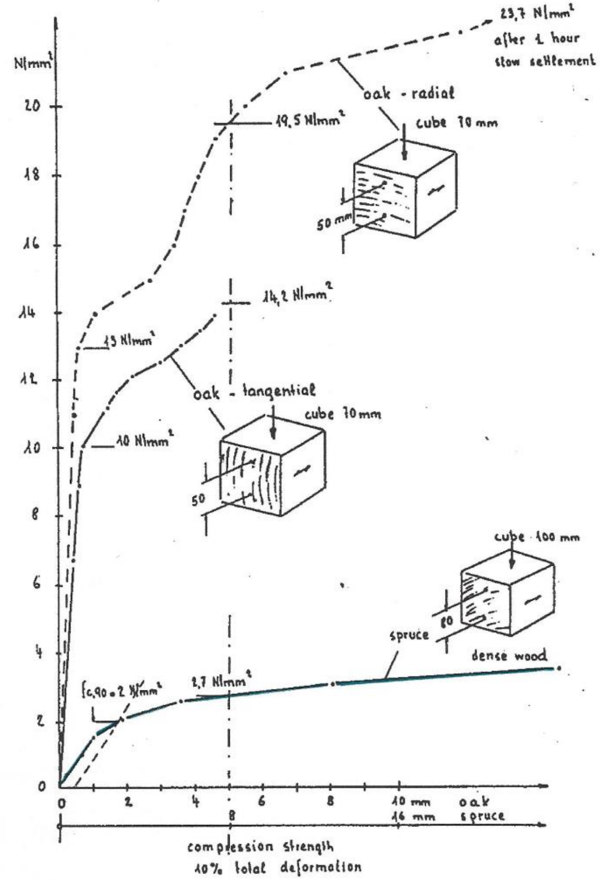


- material quality (e.g. function of species)
- material behaviour (deformation, failure)
- geometric conditions (e.g. partial loading)
- moisture content
- effect of time (creep)
- safety factors

Figure 1: Typical questions and factors which may influence the answer

Here part of the answer’s

from A. Föppl (1904)

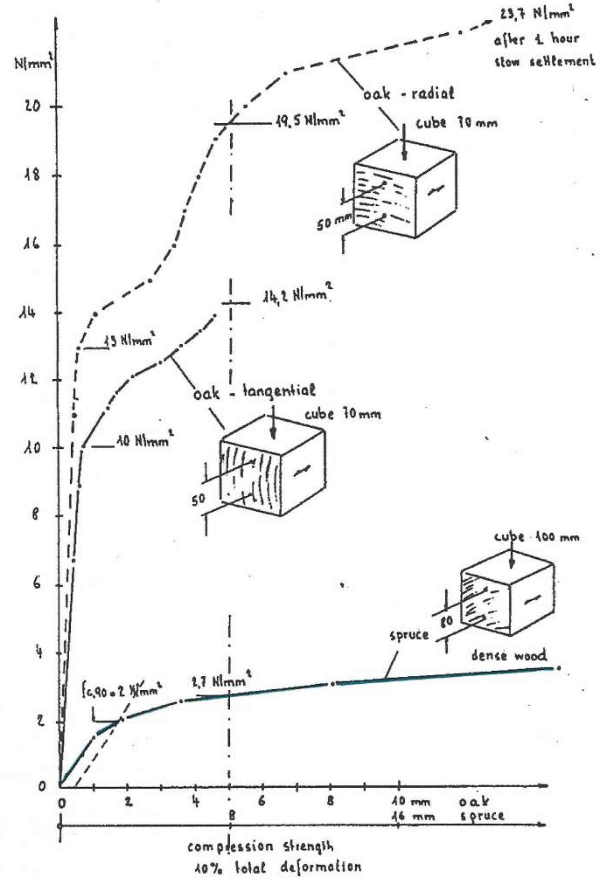


A.Föppl headed more than 100 years ago the «Mechanisch-Technisches Laboratorium» at the TU München.

He was scientist and engineer: the specimens used corresponded to structural size

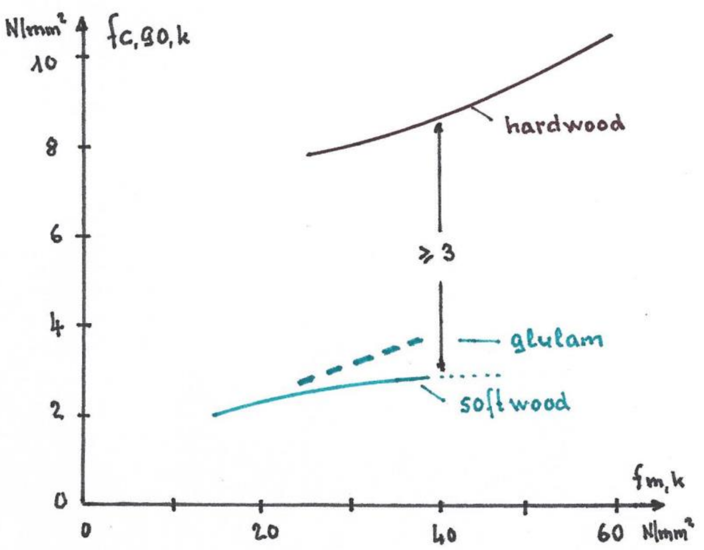
Here part of the answer's

from A. Föppl (1904)



and where we are 100 years later

char. values for sawn wood and for glulam (only softwood!)



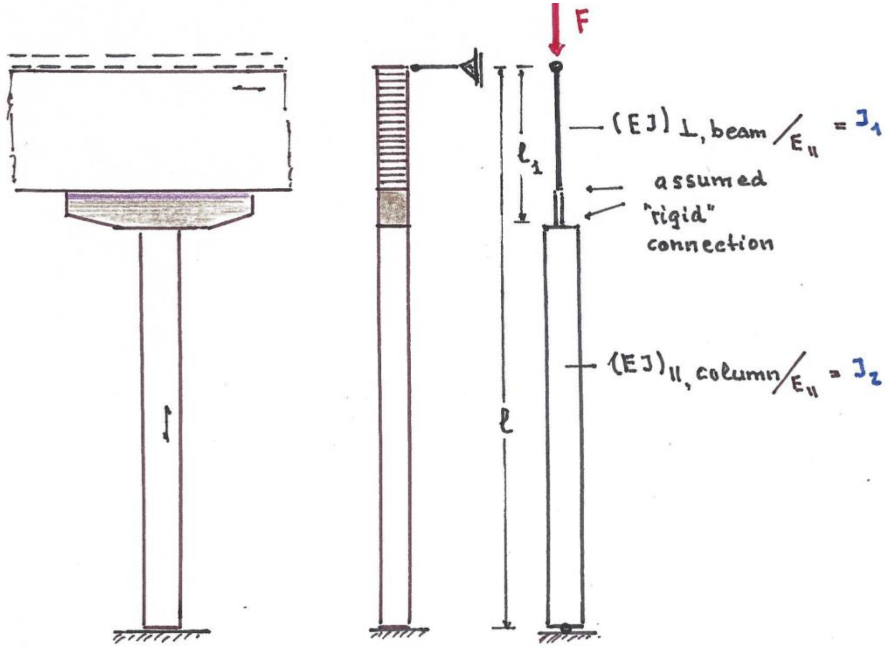
A.Föppl headed more than 100 years ago the «Mechanisch-Technisches Laboratorium» at the TU München.
He was scientist and engineer: the specimens used corresponded to structural size

Use of glued-laminated beams: slender sections

problem of instability

higher concentrated forces

system

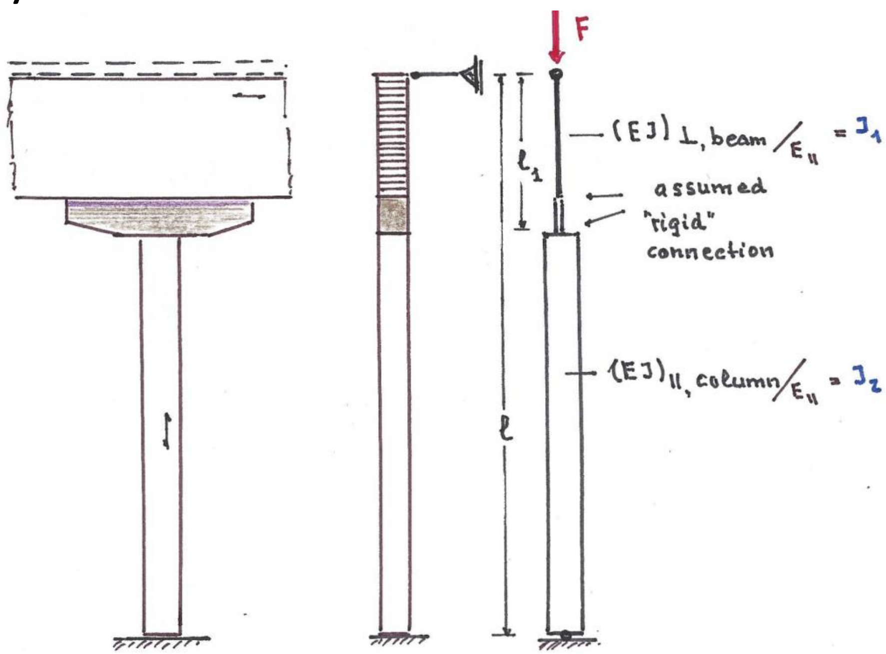


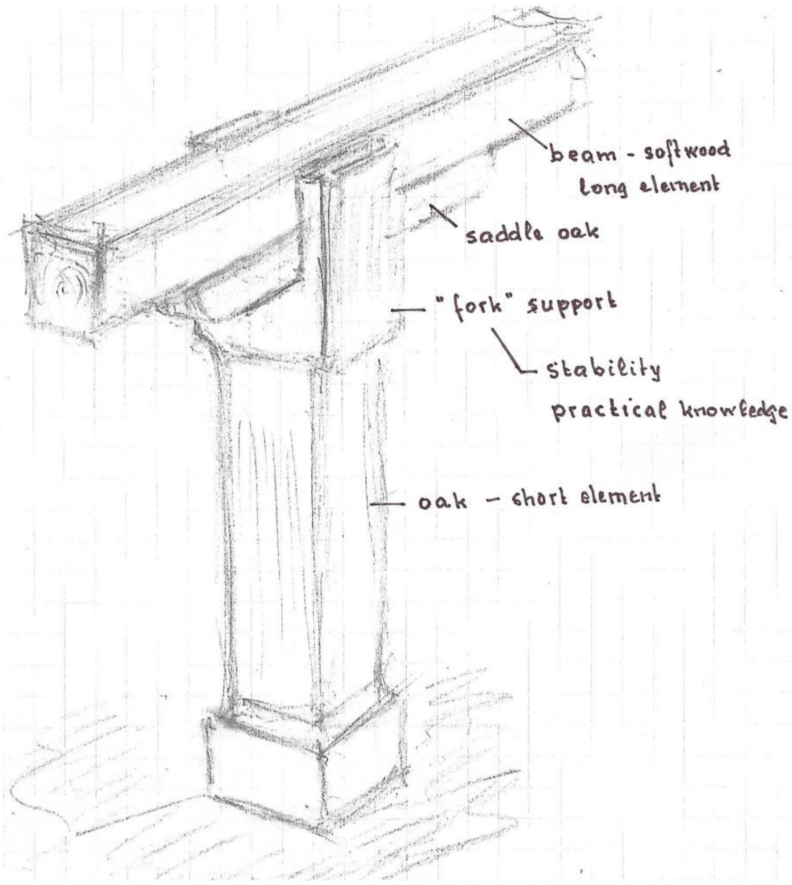
Use of glued-laminated beams: slender sections

problem of instability

higher concentrated forces

system





Possible solutions:

- by applying lateral holds (fork-like)

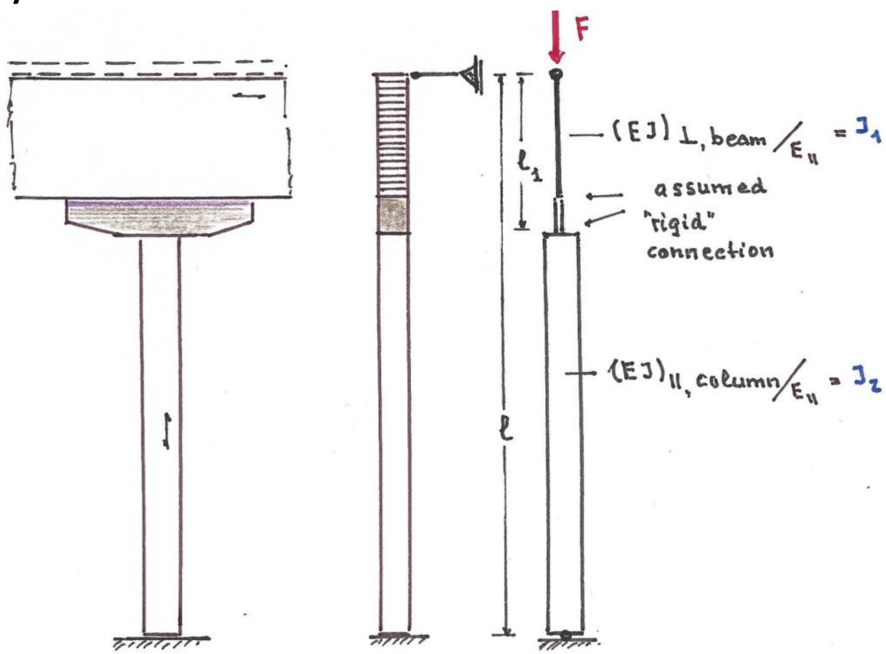
  often not accepted by architects

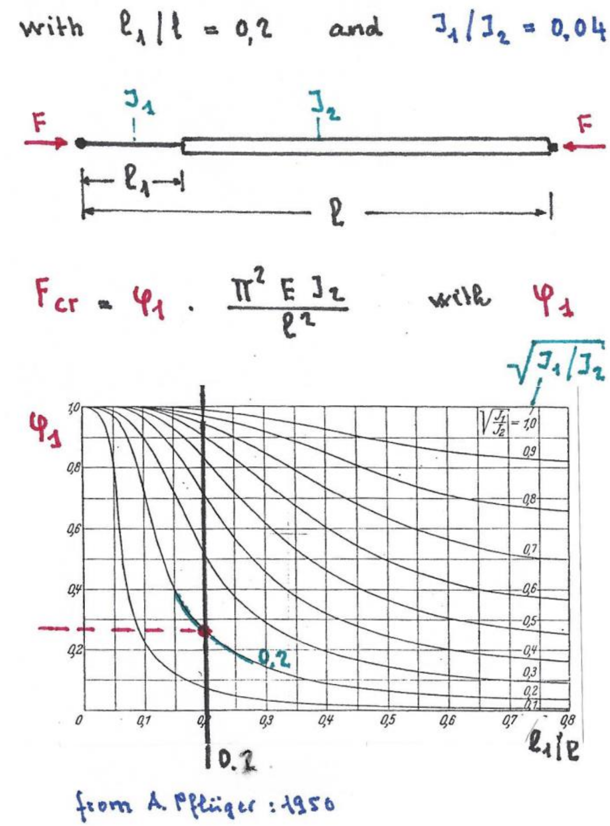
Use of glued-laminated beams: slender sections

problem of instability

higher concentrated forces

system





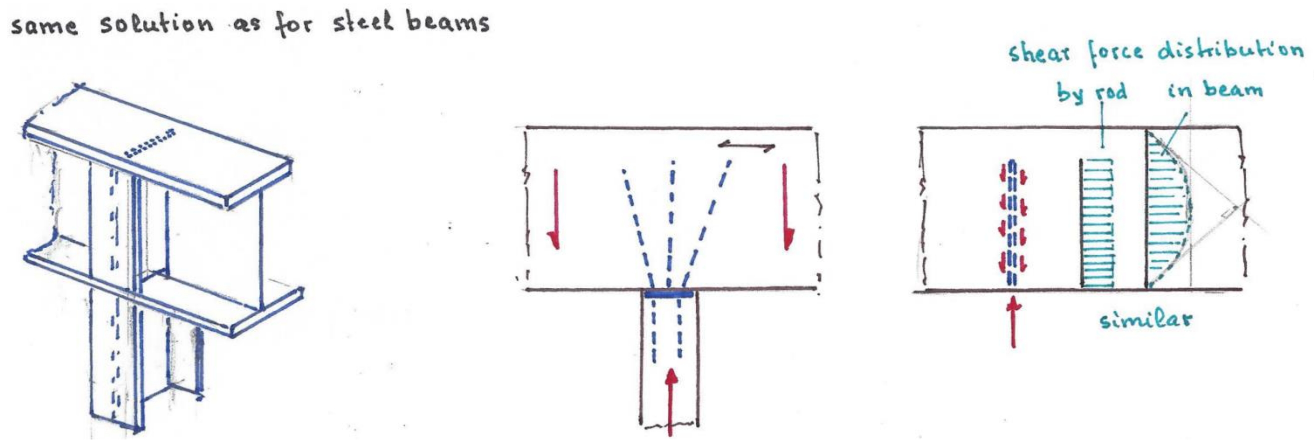
Possible solutions:

- by applying lateral holds (fork-like)
  often not accepted by architects
- by integrating hardwood saddle into beam (use of hardwood lamellae locally)

Higher load introductions

point loads up to Fd = 1’000 kN

too large contact areas (even with hardwood)



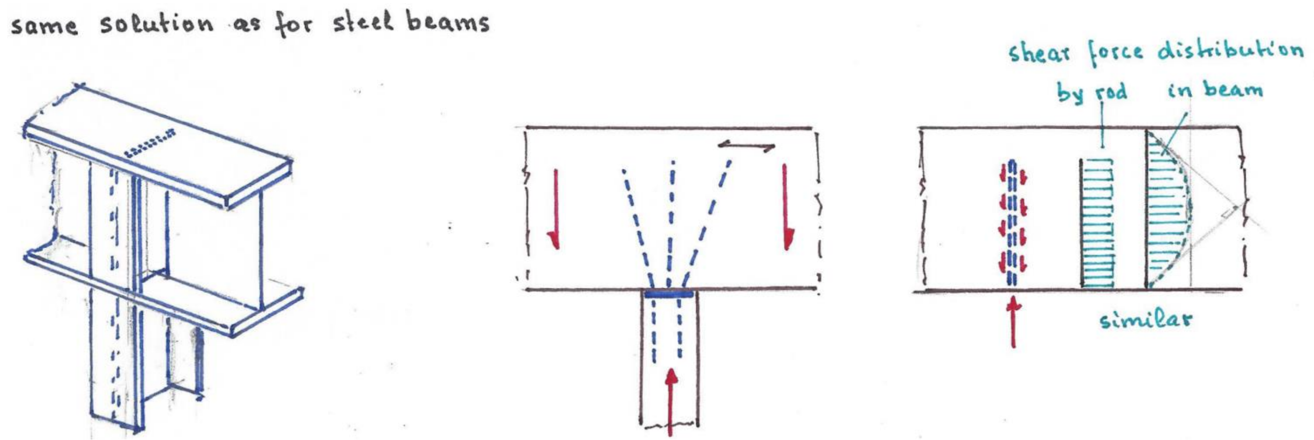
Advantages of load introduction by glued-in rods

Possible to avoid saddle of hardwood

Higher load introductions

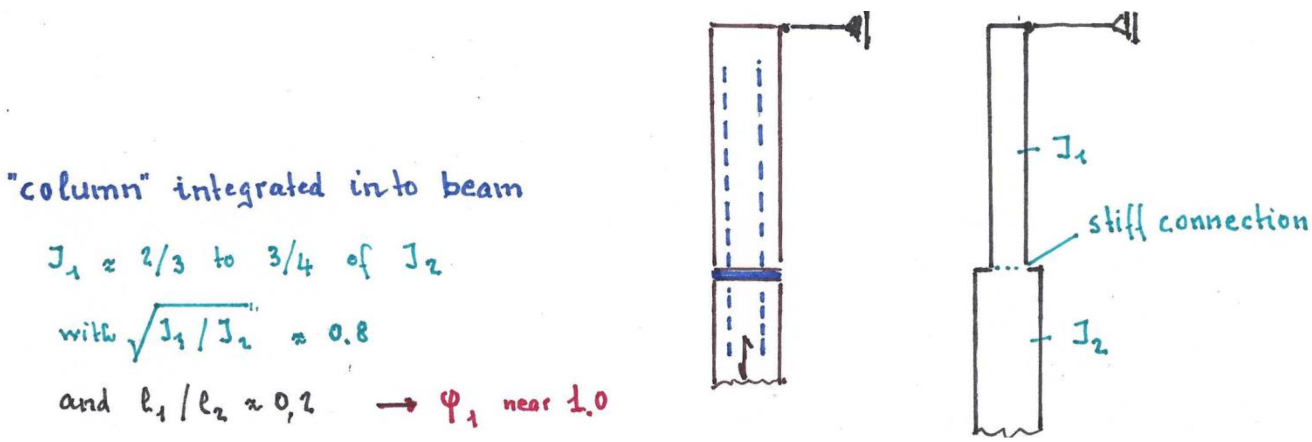
point loads up to Fd = 1’000 kN

too large contact areas (even with hardwood)



Advantages of load introduction by glued-in rods

Possible to avoid saddle of hardwood

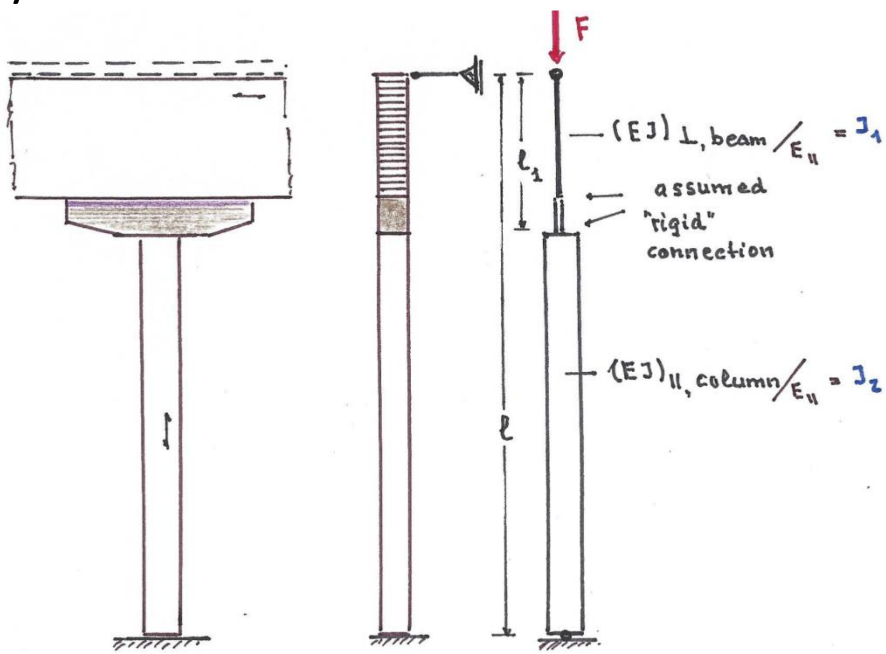


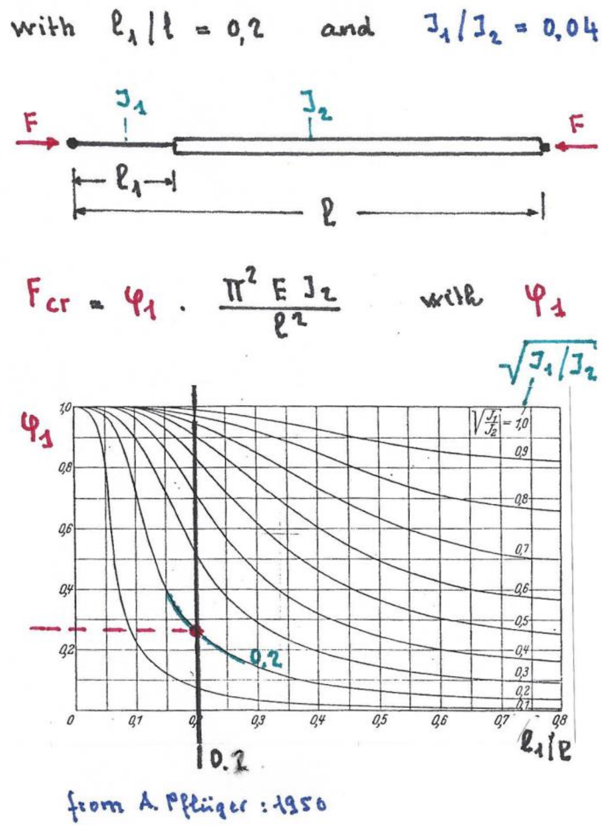
Use of glued-laminated beams: slender sections

problem of instability

higher concentrated forces

system





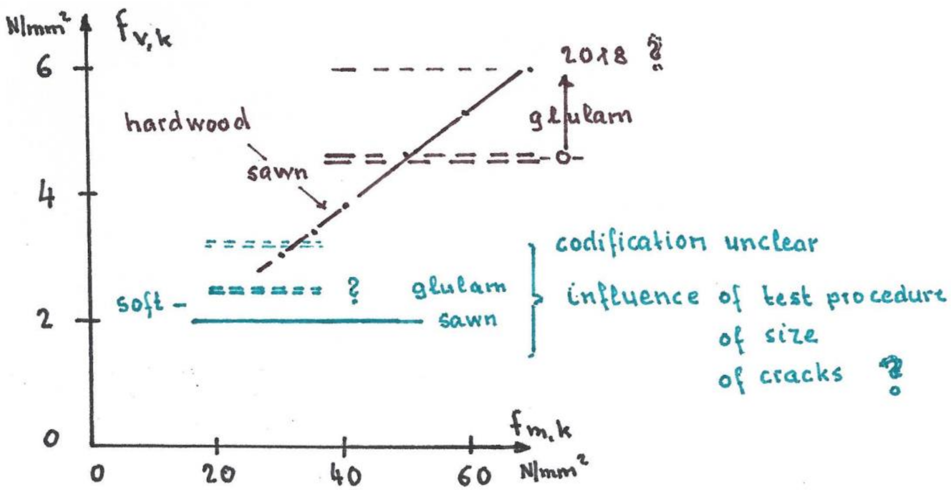
Possible solutions:

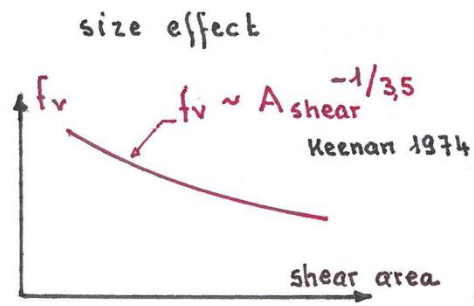
- by applying lateral holds (fork-like)
  often not accepted by architects
- by integrating hardwood saddle into beam (use of hardwood lamellae locally)

Strength – on shear (parallel to grain)

comparison softwood - hardwood

from EN's (glulam only softwood)

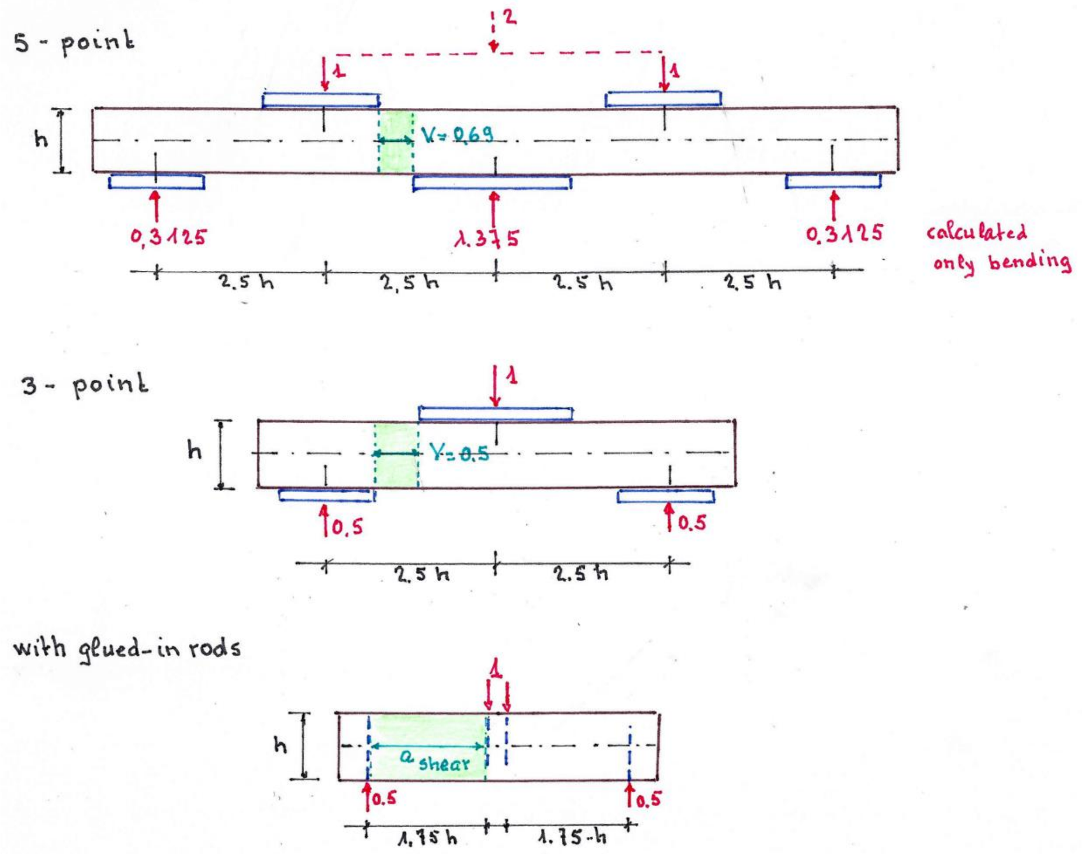




Problem: test procedure   3-point / 5-point / type of load introduction / size of shear area

Shear strength: test - procedures

Note: 5-point was introduced to avoid
influence of drying craks at beams end (often in lumber), but
no difference found (same relationship for wet and dry wood!)

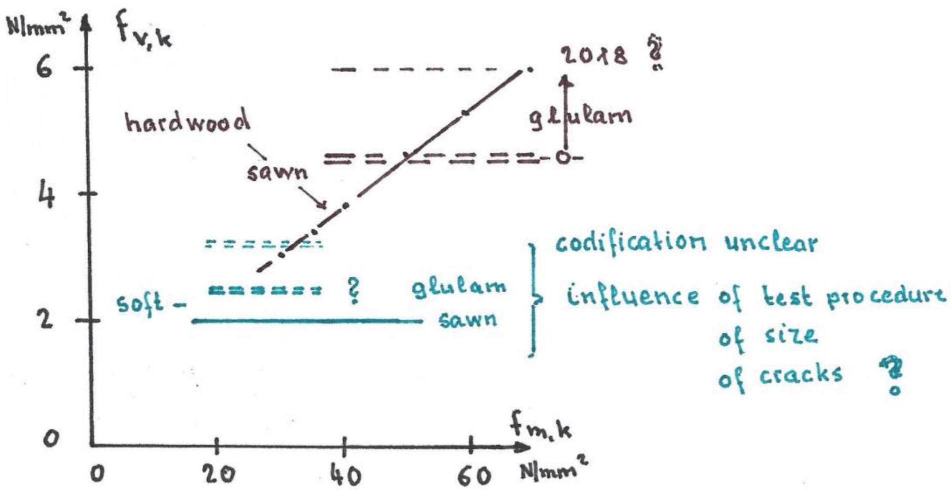


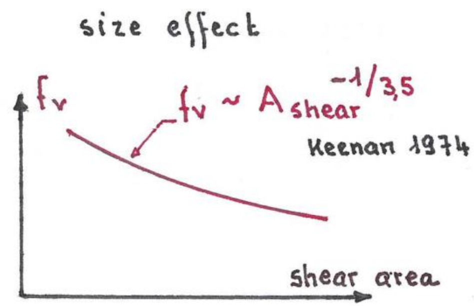
Note: higher strength values obtained 5-point than 3-point, due to smaller effective shear area

Strength – on shear (parallel to grain)

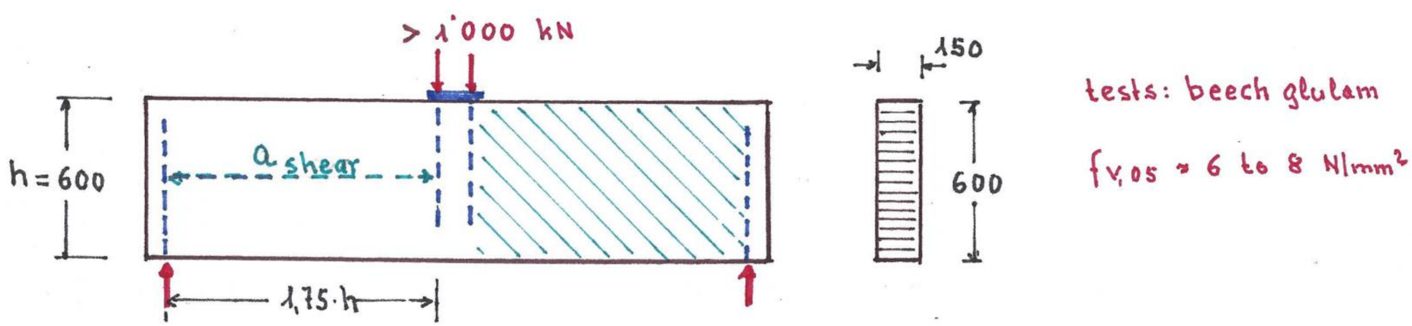
comparison softwood - hardwood

from EN's (glulam only softwood)





Problem: test procedure 3-point / 5-point / type of load introduction / size of shear area



shear test on larger sections (glulam spruce and hardwoods)

shear test on glulam beech 120/600

Limited by capacity of testing rig:

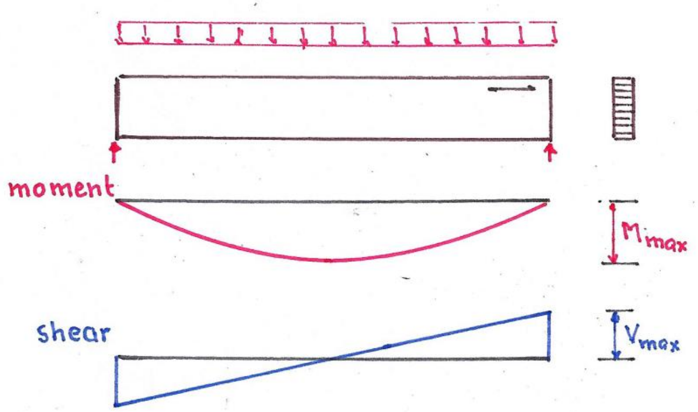
$$2 \cdot V = 900 \text{ kN}$$

with measurement of shear modulus

shear test on glulam spruce 140 / 1'000

How to optimize the classical glulam beam?

→ use better specific properties of timber species

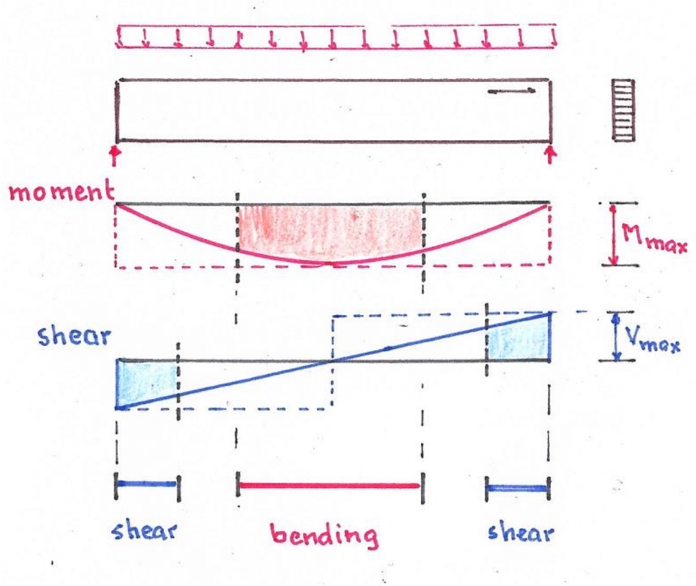


classical glulam beam

constant, prismatic, rectangular sections

How to optimize the classical glulam beam?

→ use better specific properties of timber species



classical glulam beam

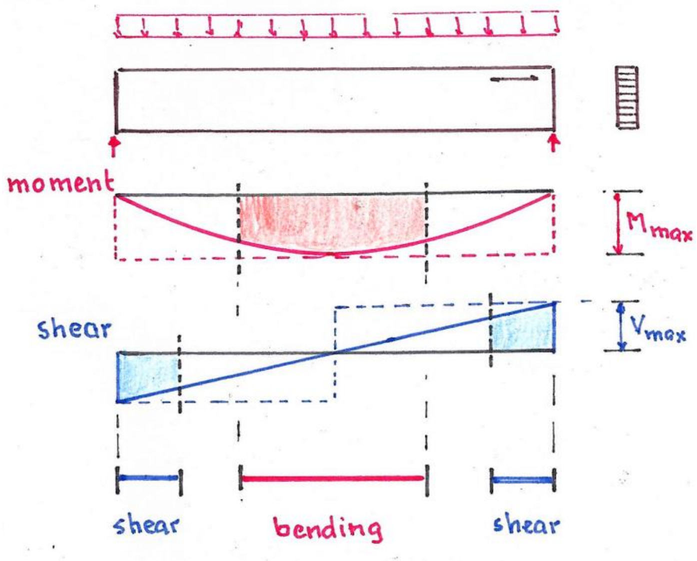
constant, prismatic, rectangular sections

same resistance - **bending / shear** – over length

not needed !

How to optimize the classical glulam beam?

→ use better specific properties of timber species



classical glulam beam

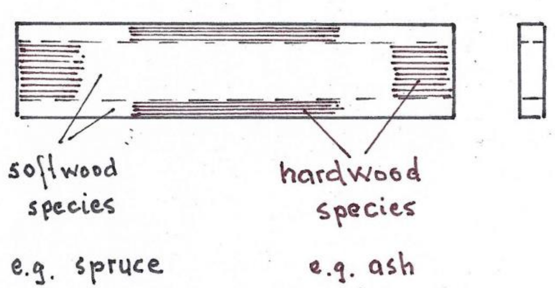
constant, prismatic, rectangular sections

same resistance - **bending / shear** – over length

not needed !

from **actual** fabrication requirements:

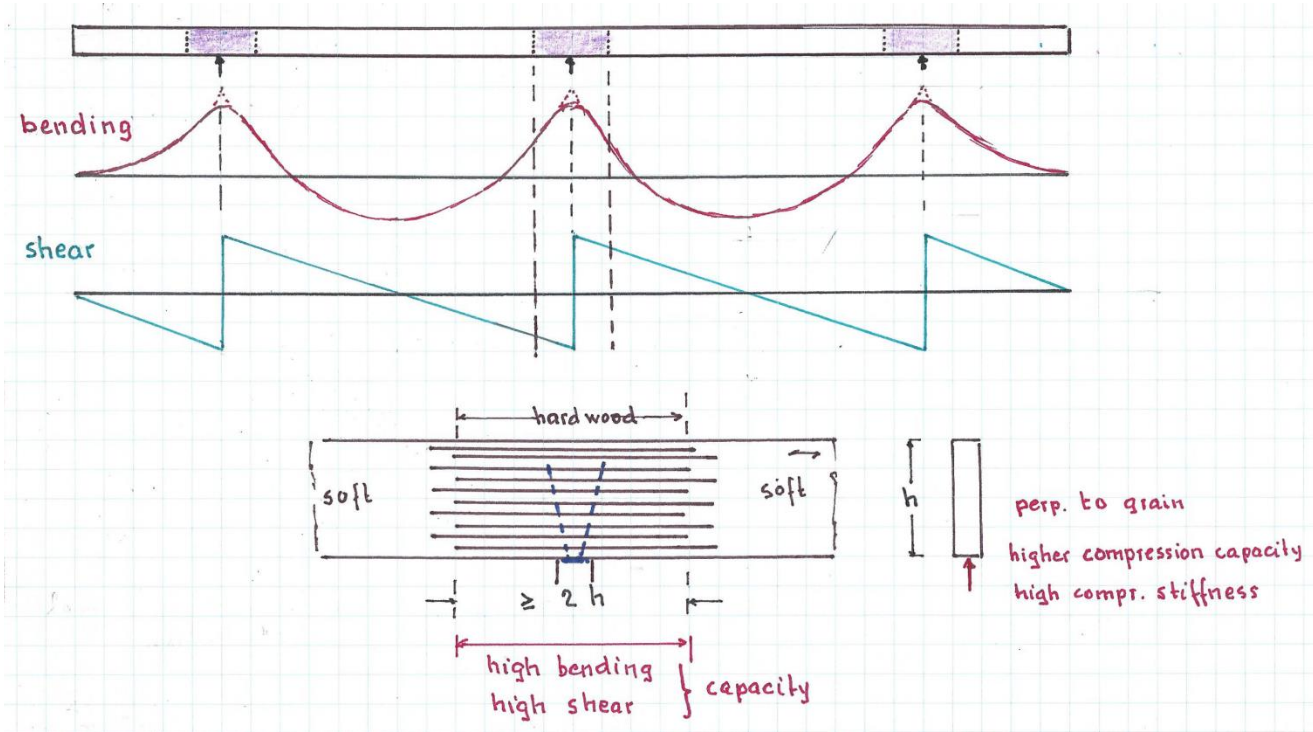
use same glue-laminating procedure



actual properties of hardwood glulam

bending strength	$f_{m,k}$	=	48 N/mm2
shear strength	$f_{v,k}$	=	6 N/mm2
compression strength	$f_{c,90,k}$	=	8 N/mm2

Continuous beams: Use only in high stressed zones (e.g. over supports)

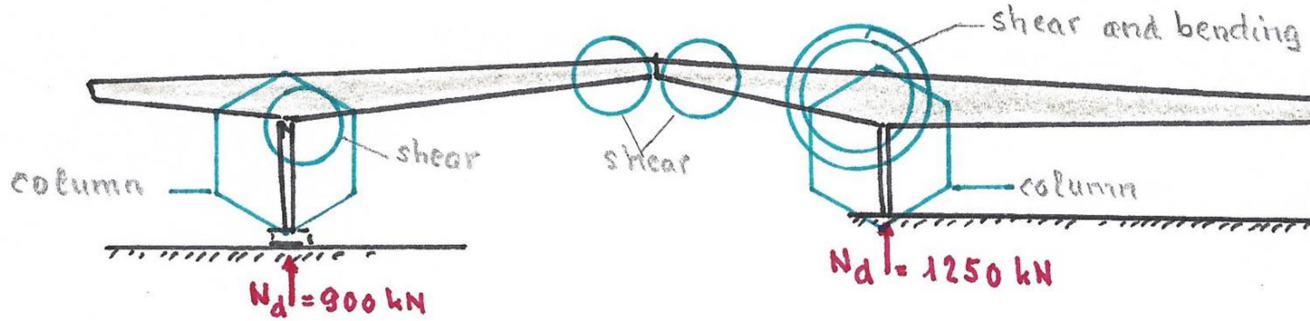


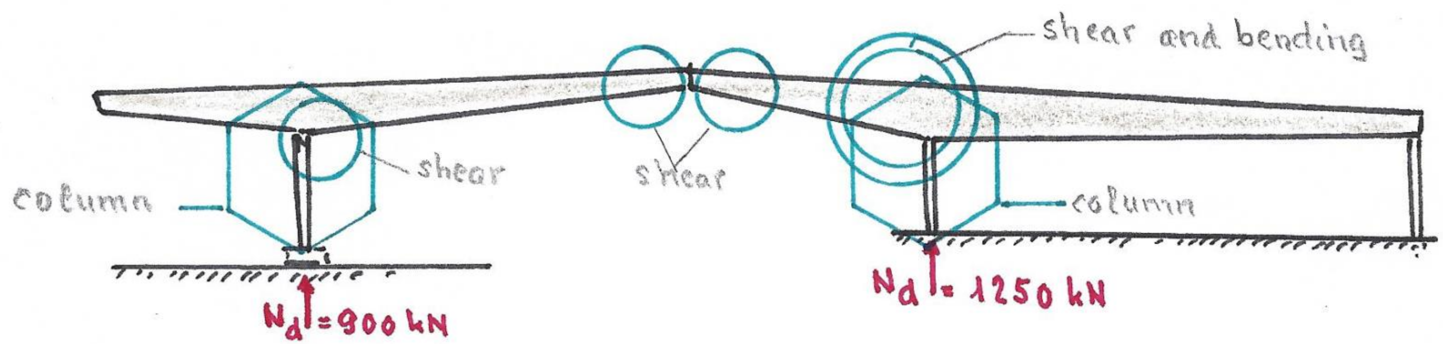
Preferably ash → (same lamella thickness as spruce = 40 mm)

Finger-joint: no problem to achieve softwood data ($f_{t,j,k}$ up to 33 N/mm^2)

Hybrid beams (lengthwise) spruce/ash

Case Arosa: hybrid beams ash / spruce

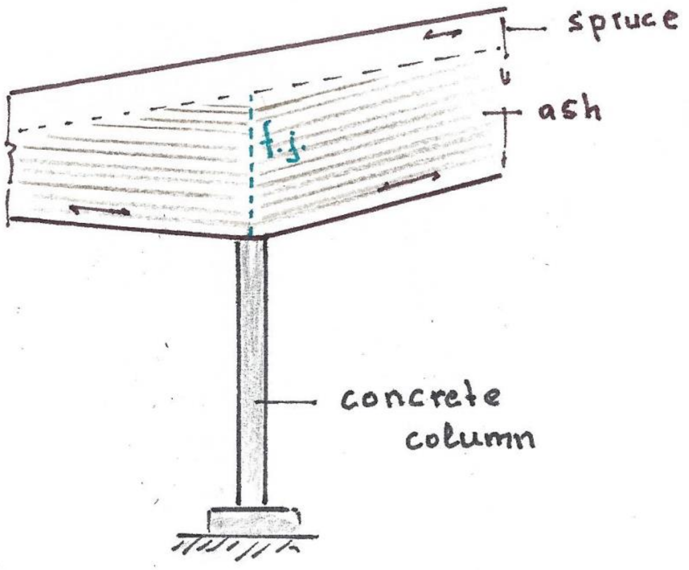


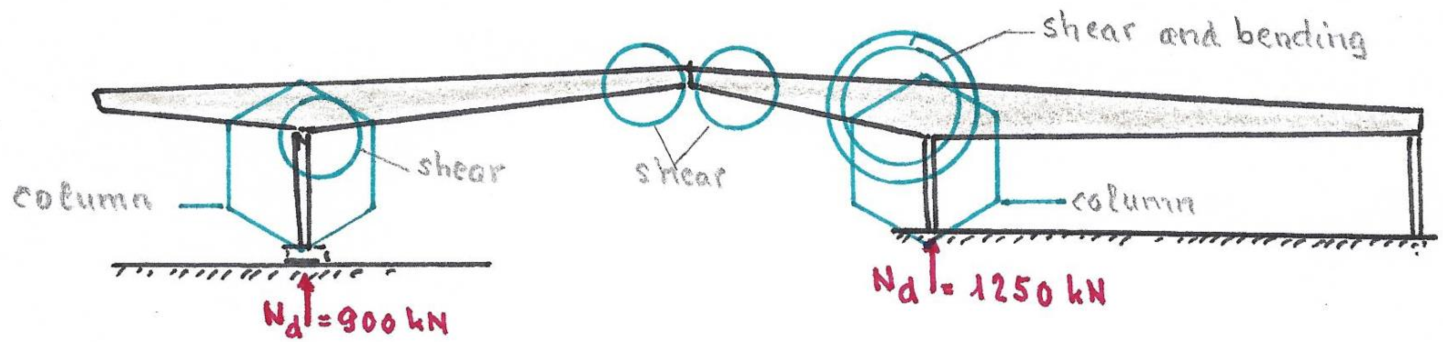


load introduction column/beam → ash + glued-in rod

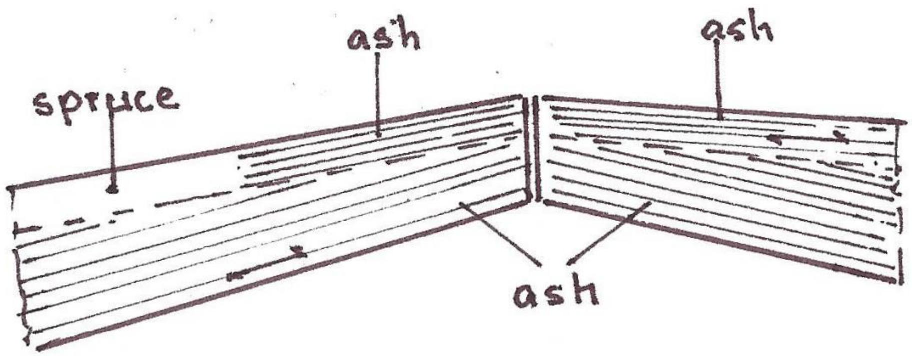
shear force → ash

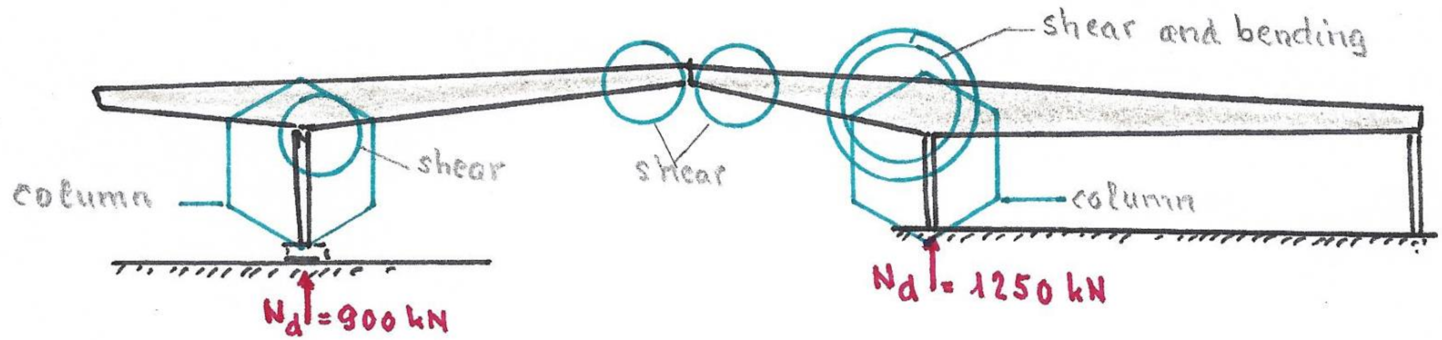
free standing column → glued-in rod

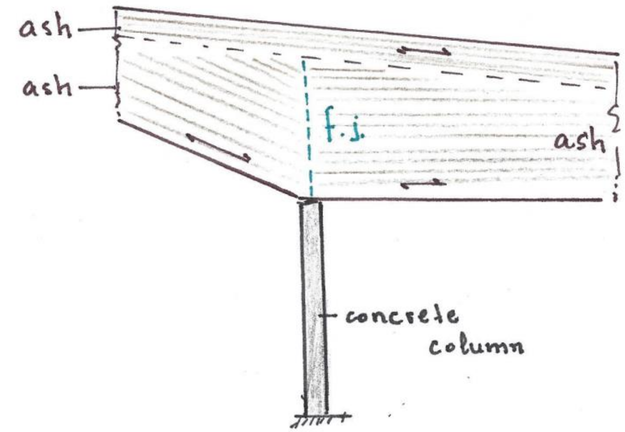




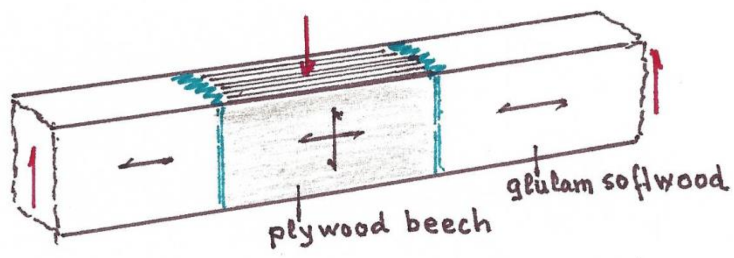
shear force → ash




shear and bending
shear
shear
column
column
Nd = 900 kN
Nd = 1250 kN

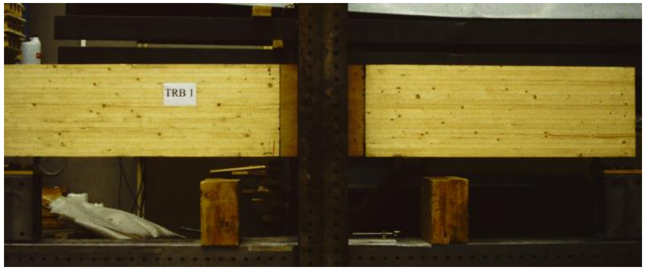

ash
ash
f.j.
ash
concrete column

glulam softwood / plywood beech



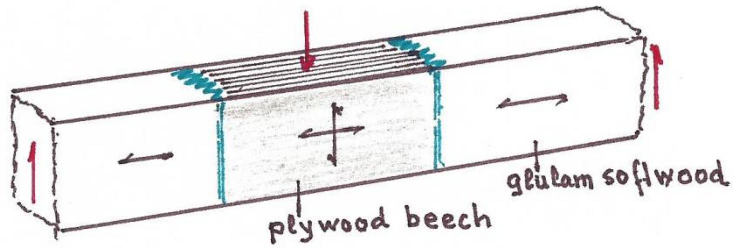
finger-joint resistance governed by softwood

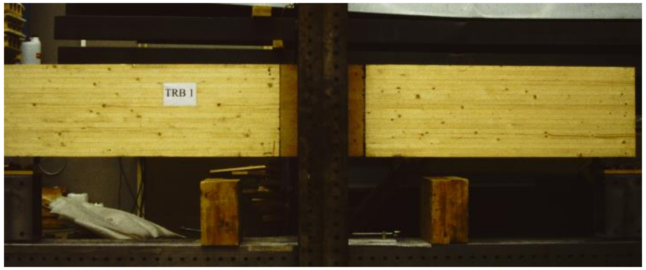
bending capacity taken as **0,8 · $f_{m,k,spruce}$**



!

glulam softwood / plywood beech



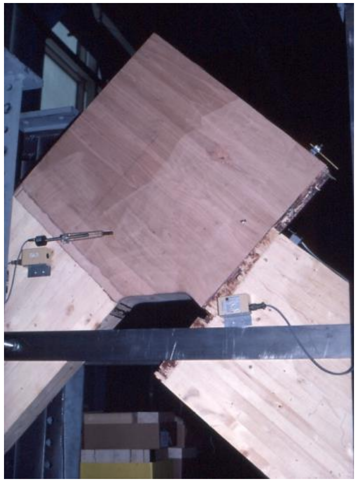


finger-joint resistance governed by softwood

bending capacity taken as **0,8 · fm,k,spruce**

→ important: **higher shear capacity**

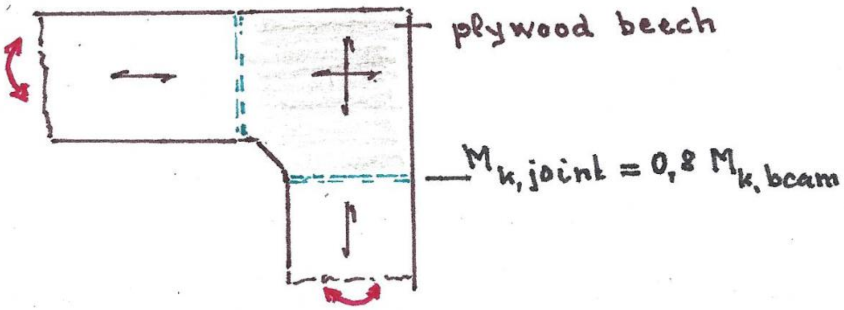
→ e.g. use as **frame corner**



simple design

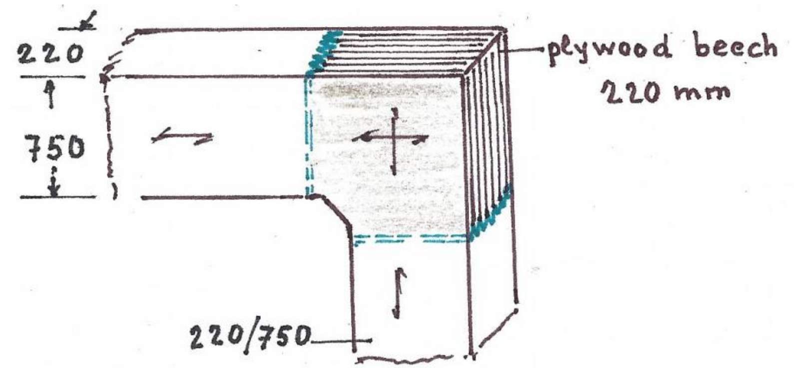
only control of

finger-joint capacity!



Case: bridge Eggiwil (1982) 2-lanes bridge

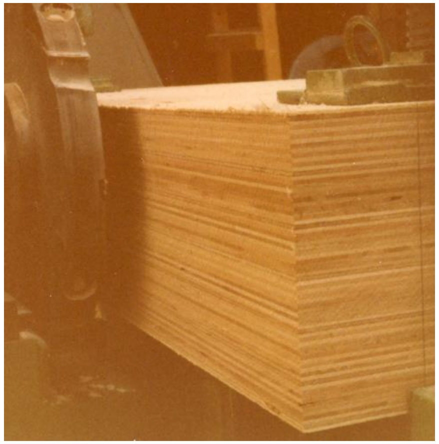
Portal frame



plywood beech: thickness 220 mm
outside veneer: spruce (esthetic)

Case: bridge Eggiwil (1982) 2-lanes bridge

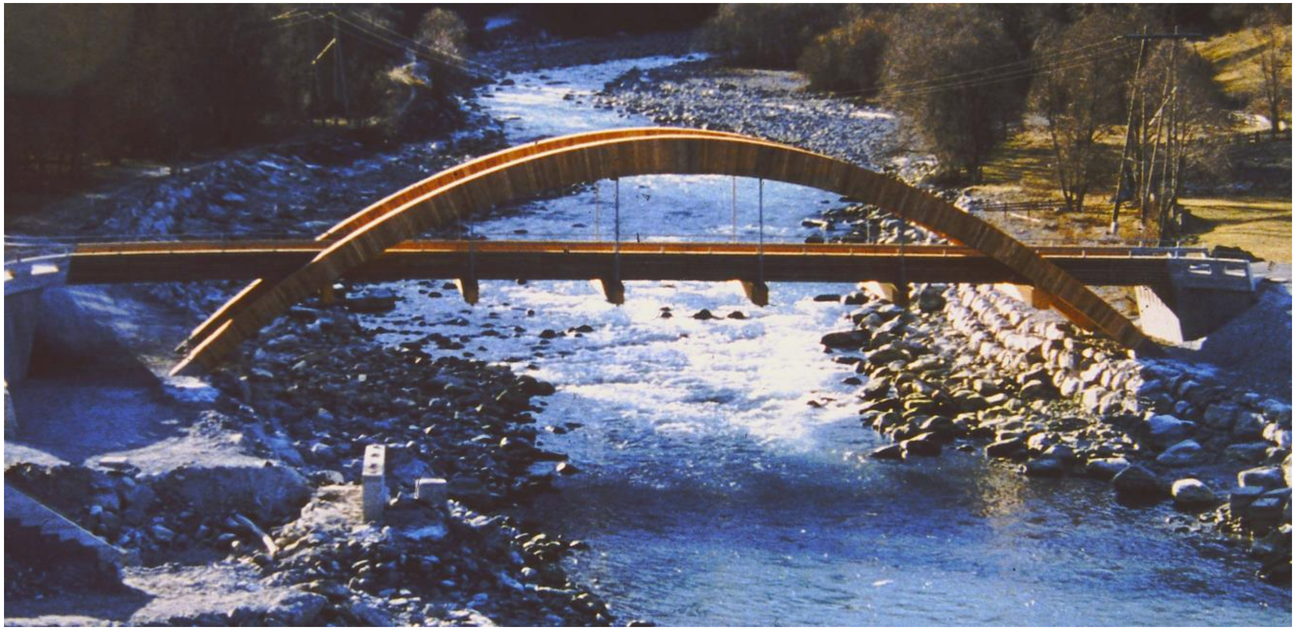
Portal frame



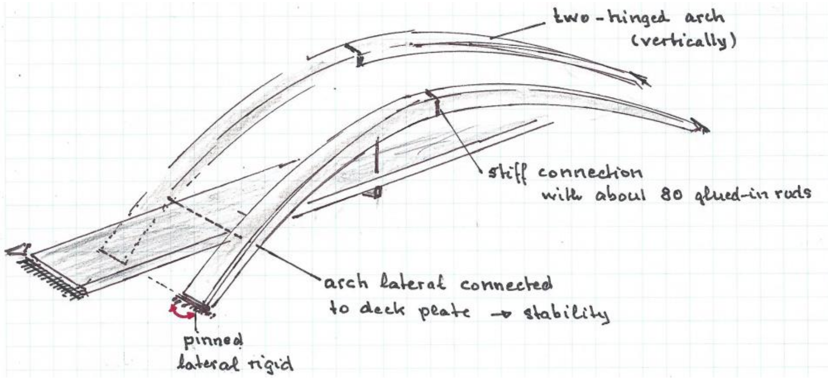
plywood beech: thickness 220 mm
outside veneer: spruce (esthetic)

plywood configuration adapted to geometry of finger-joint-cutter

Case: bridge San Niclà (1993)

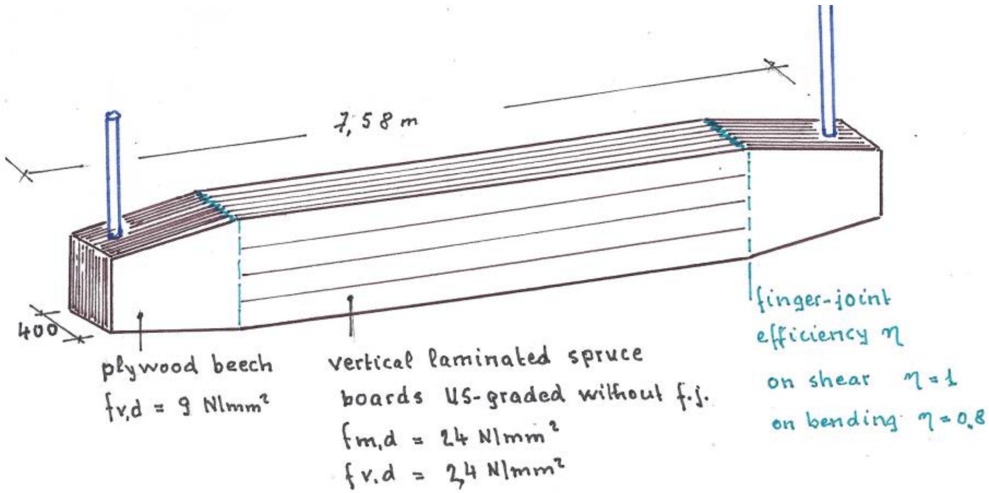


static system:

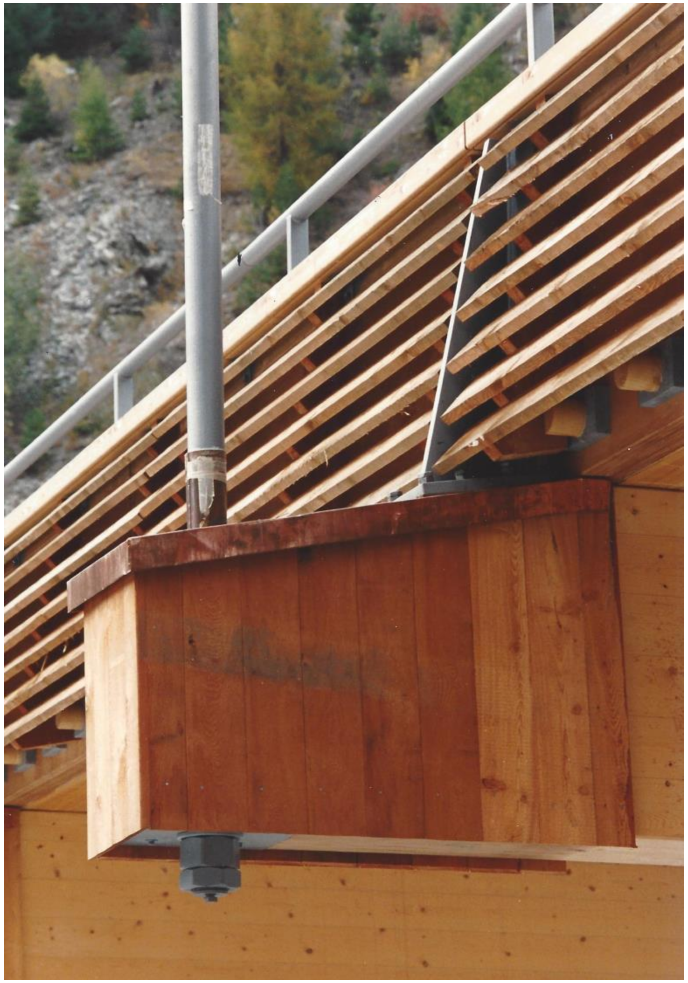


Cross-beam: vertically glued-laminated spruce (without finger-joints)
ends in plywood beech finger-jointed

Dimensions:



Cross-beam: vertically glued-laminated spruce + ends in plywood beech finger-jointed

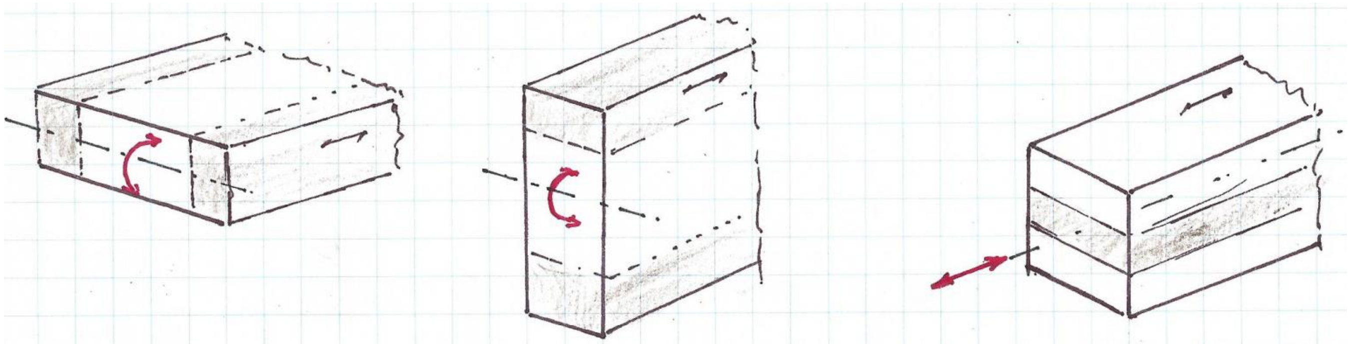


natural protection of plywood beech by encasement

finger-joint plywood / softwood glulam
section 400 x 885 mm

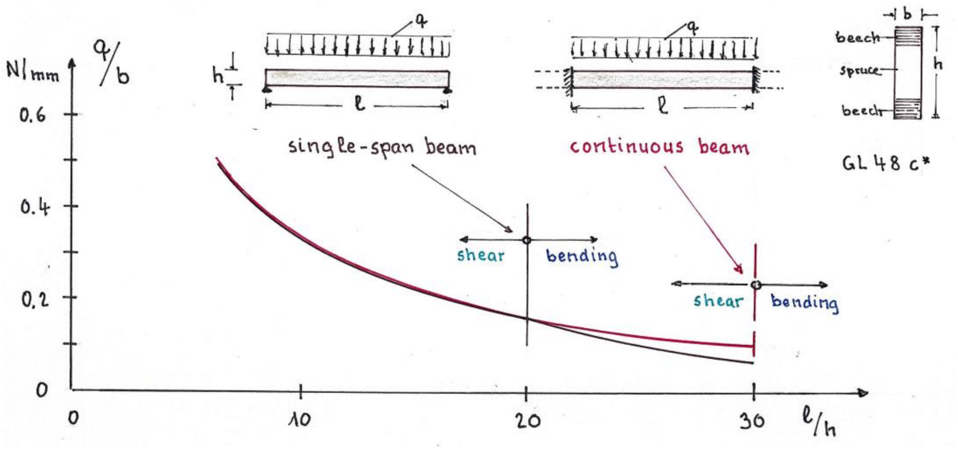
composite elements - softwood + hardwood

classical hybrid beam

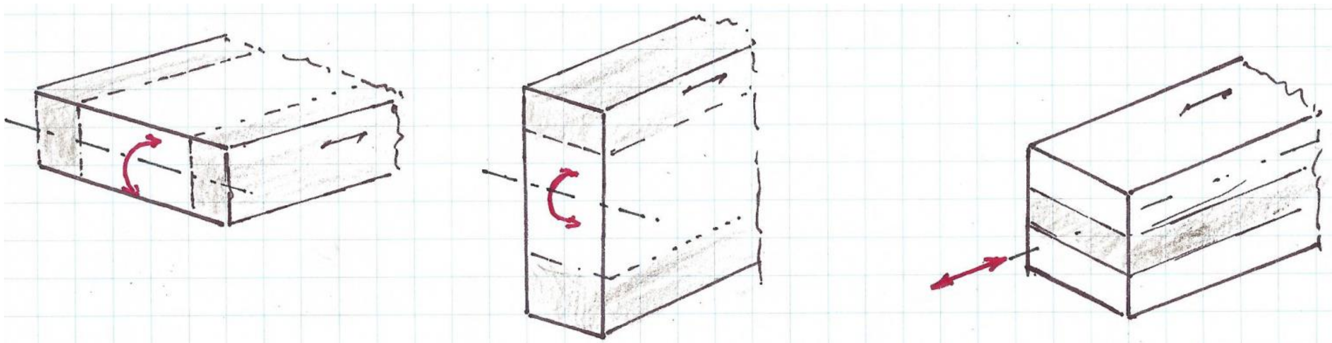


higher bending strength + stiffness

attention: low shear capacity



composite elements - softwood + hardwood



bridge decks prestressed

edge element: **perp. to grain** → hardwood

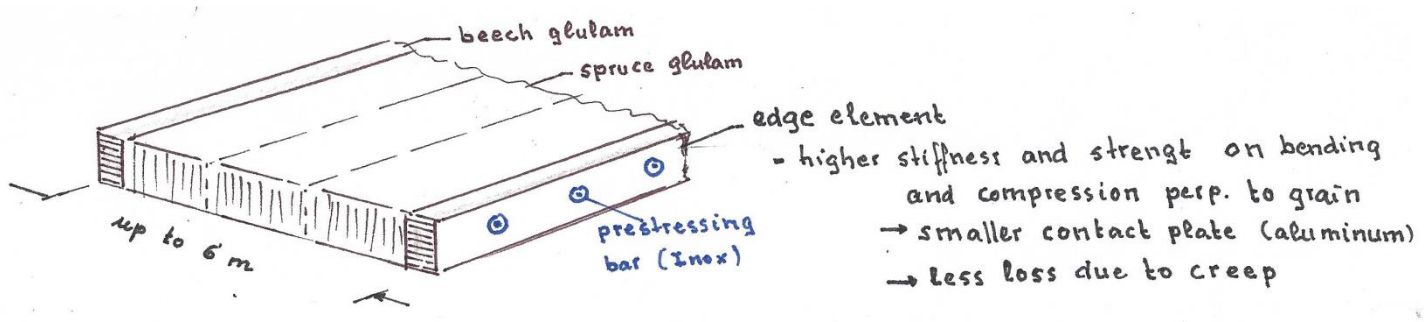
sawn / glulam / LVL / plywood

for chord of trusses

higher **rolling shear strength**

needed at node area

Sins: Deck plate glulam spruce / glulam beech (≈ 70 m long)



Connections

High performing hybrid elements → need of performant connections

dowelled connections

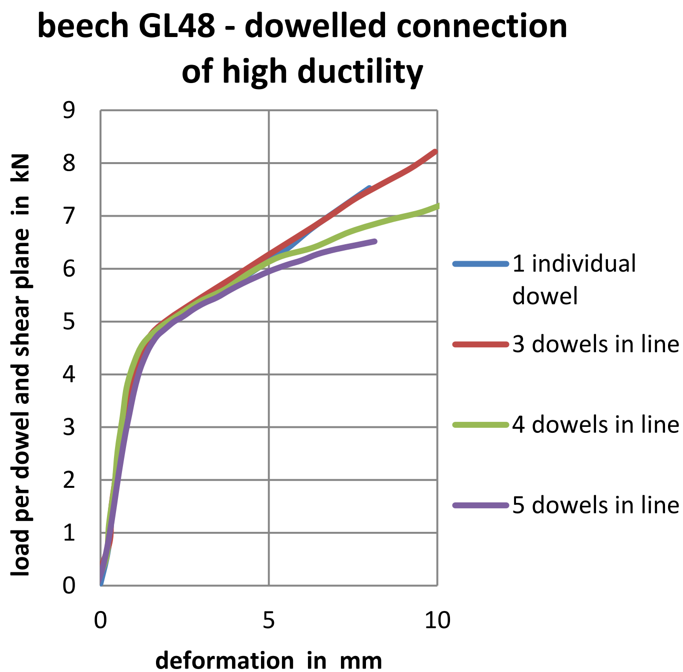
- Most used in softwood-glulam limited to $\eta \leq 0{,}65$ (due to reduction of section)
- Actual (EYM) design rules lead to brittle behaviour !
- Need for design rules specific for hardwood (and high ductility D = ${w_u}/{w_y} > 5$)

Dowelled connection

for ductile behaviour → high slenderness of dowel
→ sufficient distances a_1

no group effect! → independent of **n** → $k_{red} = n^0 = 1$

test with LVL-beech:



performance max. ≈ 30 N/mm^2 (based on full section)

Connections

High performing hybrid elements → need of performant connections

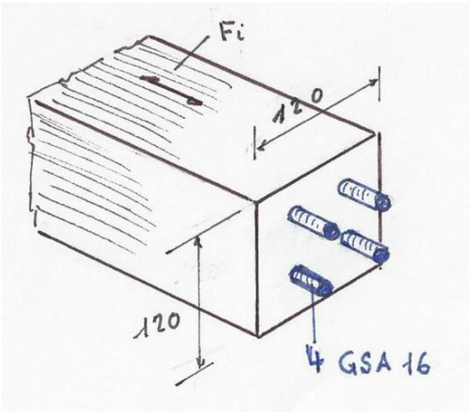
dowelled connections

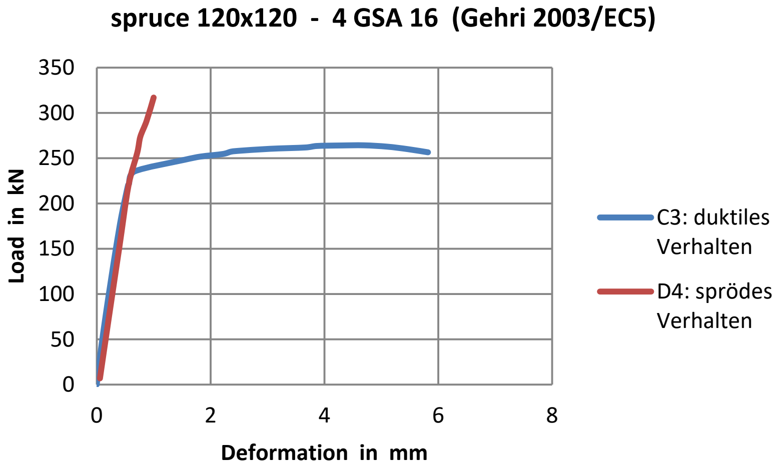
- Most used in softwood-glulam limited to η ≤ 0,65 (due to reduction of section)
- Actual (EYM) design rules lead to brittle behaviour !
- Need for design rules specific for hardwood (and high ductility D = $w_u / w_y > 5$)

glued-in rods

- Technology: same as for softwood glulam
- Criteria: behaviour is governed by the steel (strength and **ductility**)

  all other (brittle) failure modes are excluded (Gehri/1996)

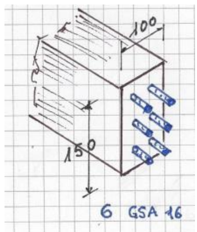




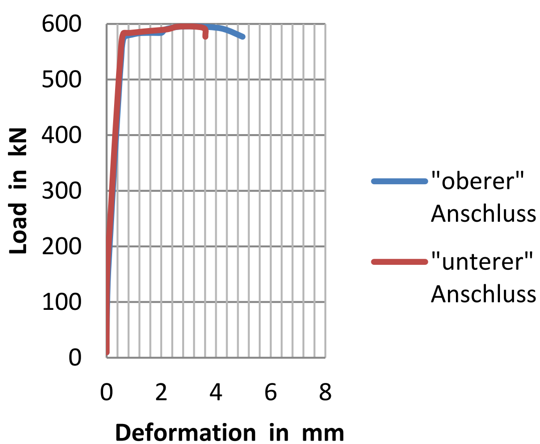
Tests of glued-in rods with LVL beech

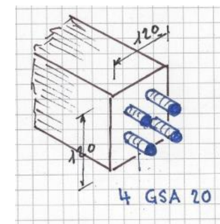
GSA-system glued-in rods

ductile behaviour   no group effect !

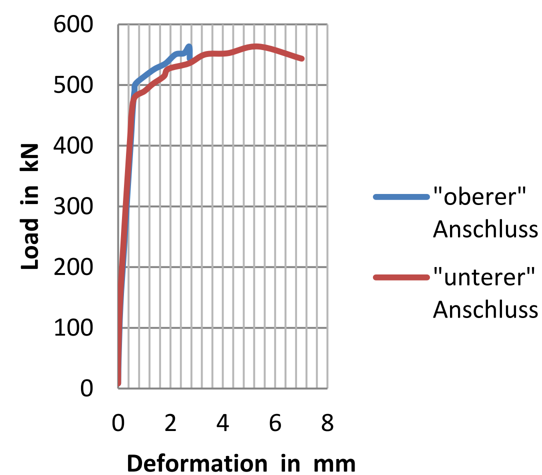


GSA 16.8 - 52.1 – group of 6



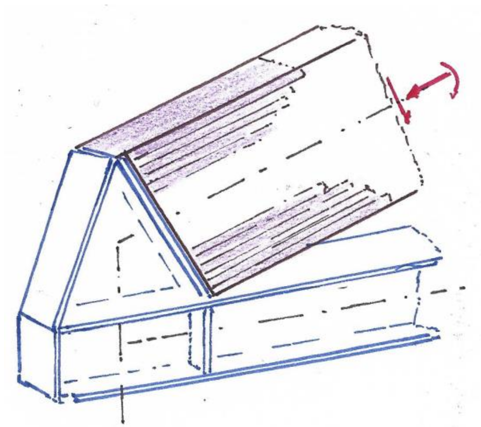


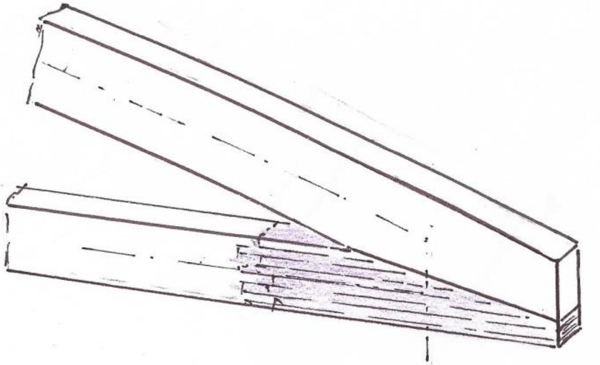
GSA 20.8 - 46.1 - group of 4



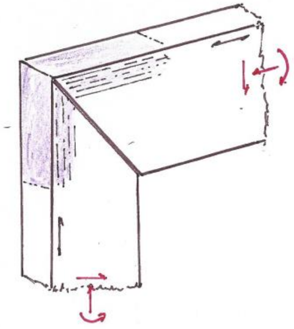
$f_{t,0,brutto} \approx 40\ N/mm^2$ with optimized configuration

Connections with hardwood inserts and glued-in rods





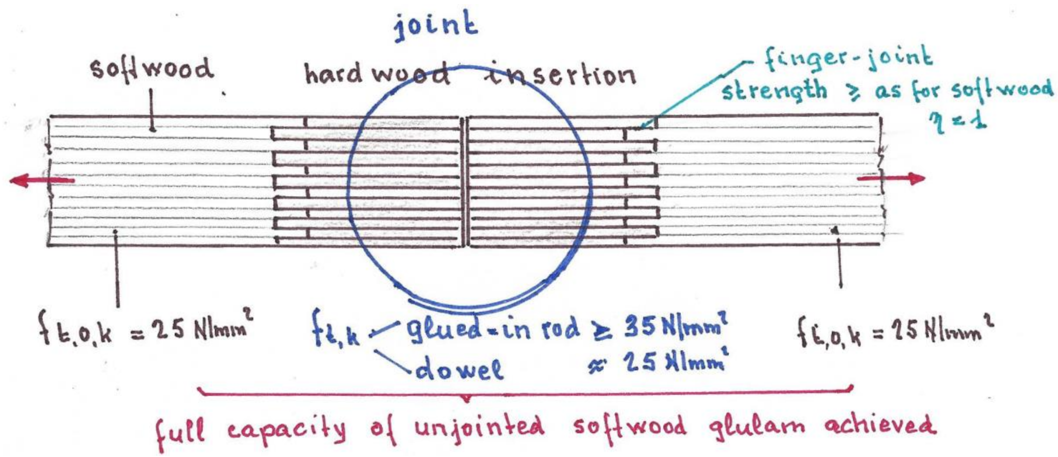
EIZ – Frutigen 2005



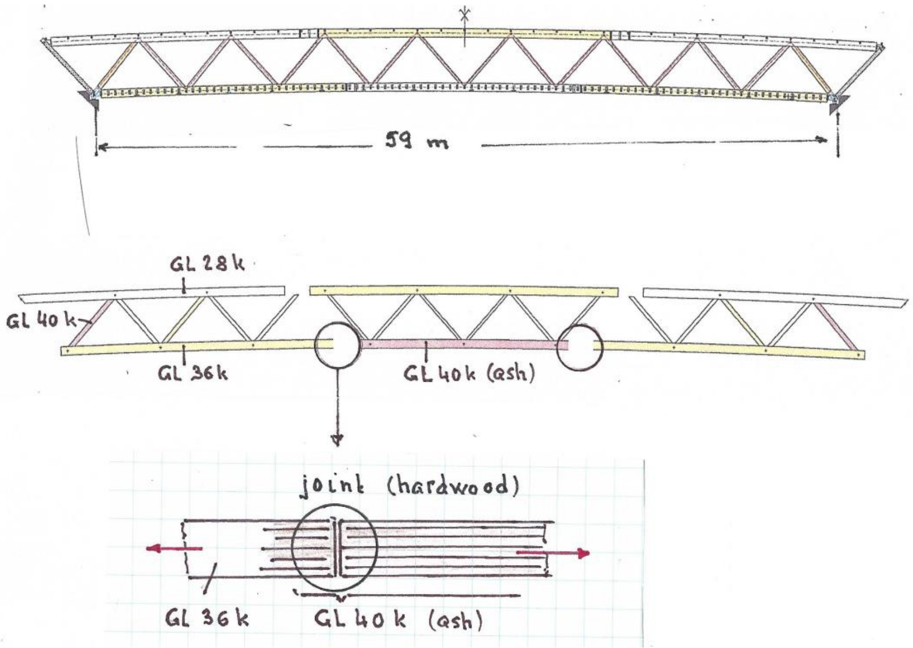
Local inserts of hardwood (glulam/plywood)

- Use higher performance of connectors (dowels / glued-in rods) in hardwood
- **Avoid reduction in softwood members**

With glulam insert: **joint performance η = 1** (for softwood members)



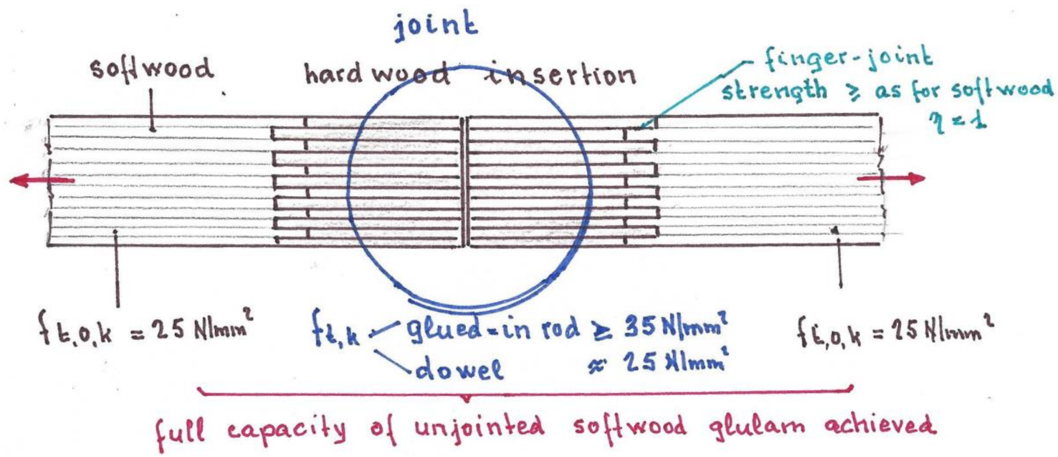
Neumatt bridge – truss system – glulam spruce / ash



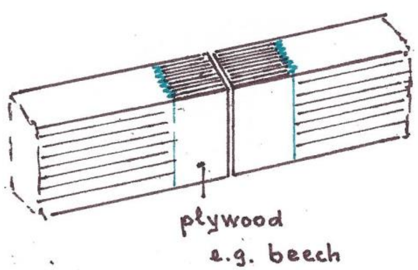
Local inserts of hardwood (glulam/plywood)

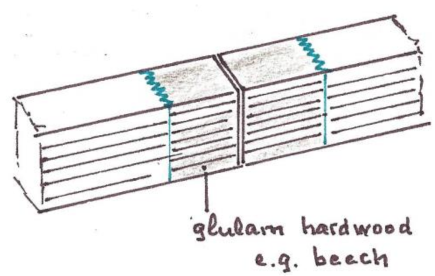
- Use higher performance of connectors (dowels / glued-in rods) in hardwood
- Avoid reduction in softwood members

With glulam insert: joint performance η = 1



With plywood insert: **joint performance η = 0,8**

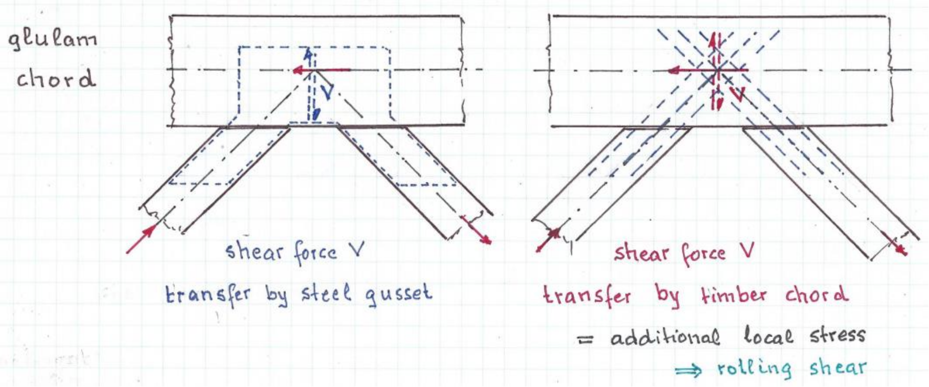


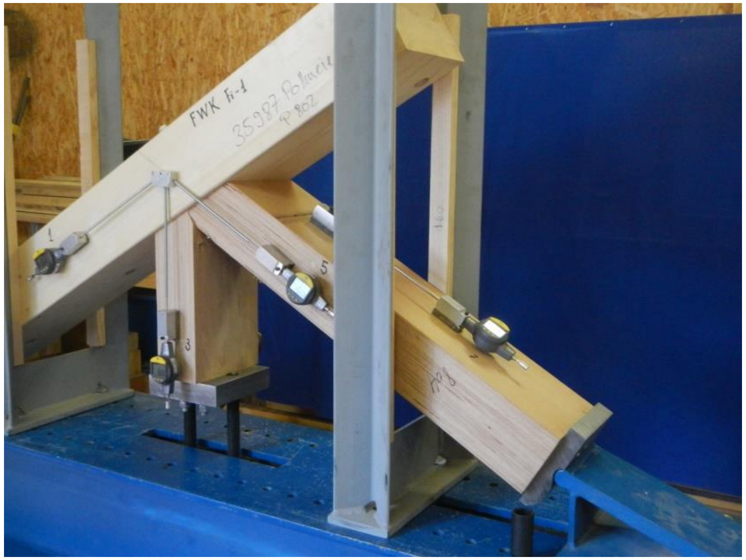


finger-joint over full section

Typical situation in parallel chord trusses
→ transfer of diagonal forces in chord

Connected : with dowels with glued-in rods





Use – as possible – more appropriate systems

→ **fishbelly girder**

(here for a footway:
exposition at n'H 2009)

Upper chord: glulam ash
Diagonals: sawn lumber ash
Lower chord: LVL ash
End nodes: plywood beech

Connections: diagonals screwed
End nodes: finger-joint/glued-in rods

and remember

August Föppl (1854-1924) : scientist and engineer

Experiments should be done under realistic conditions

material and size

Good luck !