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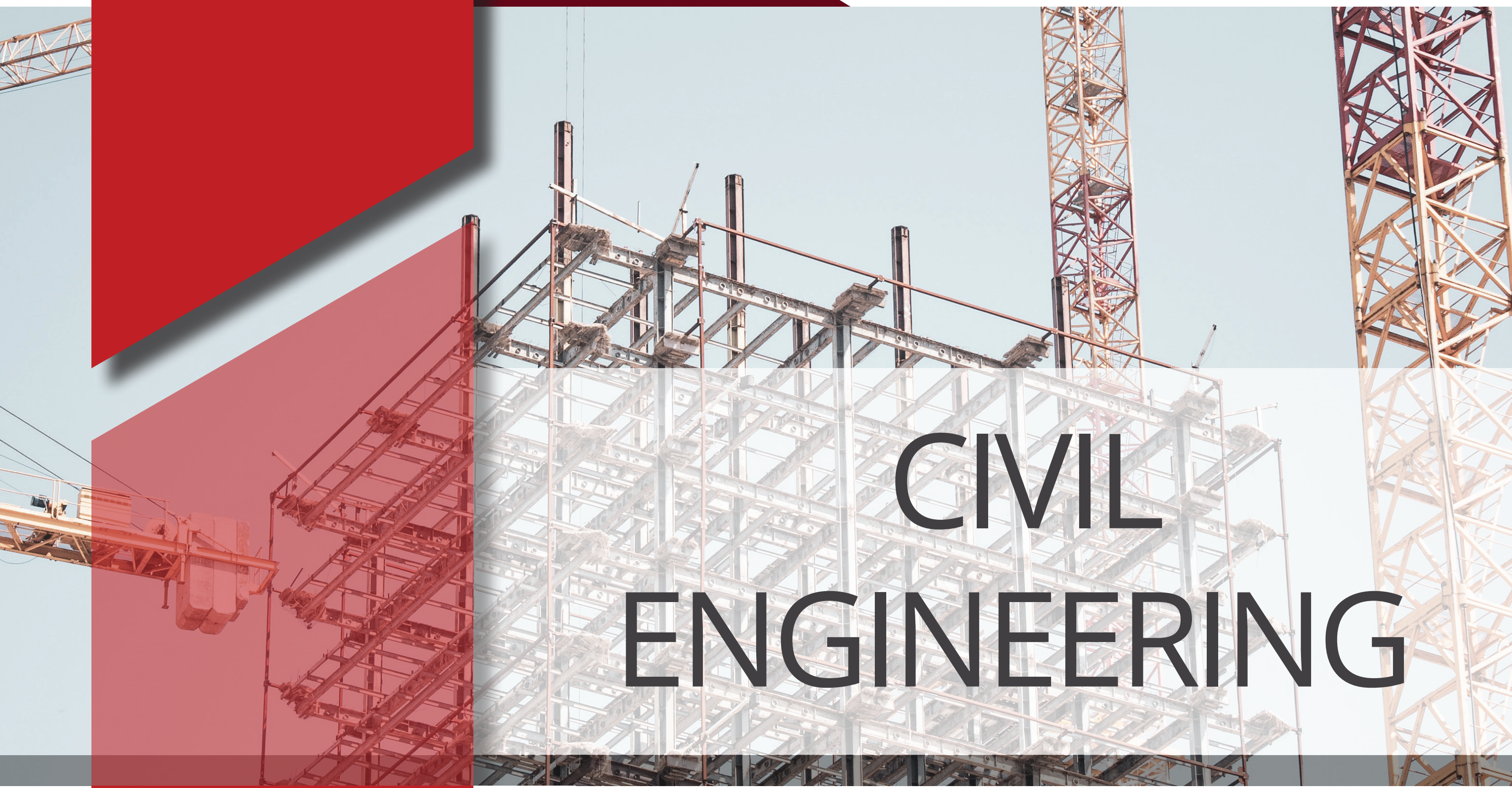

CIVIL ENGINEERING

Wooden structures

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1. INTRODUCTION TO WOODEN CONSTRUCTIONS

Wood and stone - the oldest building material.
First constructions – dwelling, then other constructions and structures (various structures for agricultural purposes, traps, footbridges ...)

1.1. Wood

- renewable building material
- timber (construction wood) – produced by states with a high degree of afforestation (CR - 35%)
- typical wood for constructions - coniferous trees (especially spruce)
- in design – necessary to consider different properties of different kinds of trees (use will depend on how the structure is exposed, dimensions of the structure, the prevailing type of stress, etc.)
- used for manufacturing structural components from:
- grown wood (almost raw - only machined to the required size and dried to the proper humidity according to purpose)
- glued wood: quite demanding production – wood processed into relatively thin lamellas (planks or boards) and glued to the required size of the structural element; complexity of the processing – reflected in 5times higher price per volume measurement unit
- wood-based materials (production of plywood, chipboard, boards – e.g. OSB, fibreboards (pressed or non-pressed)
- other elements

1.2. Methods of designing wooden constructions

- vary significantly depending on the continent; sometimes even within a single continent
- recently, possible to see the increasing tendency of architects to use this material (sometimes in comparison with steel, concrete and glass
- the design of wooden structures is very similar to designing steel structures; more significant differences appear when taking into account the different strengths of wood for different directions with regard to tree rings (growth rings)
- humidity and duration of load factor have also significant influence a time of load
- other important factors are available technology or production options).

- designing wooden structures is often affected by dimensions of the joints of wooden elements
- due to the location of the joints (necessary minimum distances between the joints), the dimension of the elements is larger than in the original design taking into account the forces acting on them,
- as in the case of steel structures, in building industry either individual structural elements are used or elements combined in more complex structural systems (trusses, beams, framing joints, roof structures, etc.)
- other similarity with steel structures: necessity to protect structures, to design the right details, to reinforce the existing structures

1.3. History of wooden constructions

- the oldest recorded wooden dwellings are from China at the time of Yang Shao Dynasty (6th to 5th millennium BC)
- the oldest preserved building is the Kondó temple in Nara Prefecture (Japan 7th century AD)

Other structures made of wood:

- bridges (430m long bridge, built in 54 BC by the Romans over the Rhine)
- arched bridge across the Danube built in 103 AD built for the Emperor Trajan (bridge light field was 35m, the pillar width 18m, the length of the bridge was 1070m)
- 1838 - Michal Ránek (1770 - 1842, carpenter) designed a very courageous project of a covered bridge over the Vltava River in Prague, with a range of 197 m x tests on a 1: 48 model triggered disputes, and the footbridge project was not implemented. Ránek´s design of trusses was granted a privilege in 1831 and architects were ordered to use them on all state and foundation.

Further development of wooden structures:

- development has always been linked to production possibilities:

  a) in terms of wood processing
  b) in terms of element joining

a) Development of wood processing:

- at the beginning, round timber was used
- later, it was dimensional lumber (hand cut), board timber, glued lamellar wood and wood-based materials

b) Development of element joining:

- first, individual elements were bound by the strands
- later, woodworking joints with wood pins, forged nails; in the 20th century - development of steel joints and gluing
- in the case of tie beam trusses, steel stirrups, hoops and rods have been used since the Ancient times

Why and how to build of wood - use of wooden constructions:

- in the Czech Republic, every year 12-13 million m3 of wood is logged
- average annual increase in forest trees in the Czech Republic - 17 million cubic meters.
- strengthening all other forest functions (reduction of logging) might appear to help improve the situation of the forests

Situation of forest where there no restoration activities take place in time:

- statistical data: in the forests of older age classes (100 years and older), there has been almost a 50% increase in wood stock over the last 20 years
- extension of average forest age increases the threat to forests
- increases the threat to forests

1.4. Tree species

Coniferous trees:

- spruce wood

- pine wood

- fir wood

- larch wood

Deciduous trees:

- oak wood

- beech wood

1.5. Structure of wood

Coniferous trees:

- the characteristic structural elements are tracheid
- make up up to 95 % of the bulk density.
- tracheids: cells of a 2 - 5mm length, 30 - 40 μm width
- cell walls thickness: 2 - 3 μm or 5 - 7 μm (spring and summer cells)

Deciduous trees:

- the characteristic structural element is a trachea = cells of a relatively wide, cylindrical shape
- make up to 75 % of the bulk density (sclerenchymatous cells)
- other element - vascular bundles = cells leading moisture
- diameter: 1/10 - 1/100 of mm (in the case of oak also 2-3 mm)
- length - up to 100 mm

2. MATERIALS FOR WOODEN CONSTRUCTIONS

2.1. Materials for wooden constructions

Timber for construction:

- solid wood
- glued laminated timber

Wood-based materials for building structures:

- plywood
- particleboard
- fibreboard
- pressed (hard)
- non-pressed (soft)

2.2. Glued laminated timber

Glued laminated wood from lamellas wider than 200 mm must be provided with grooves, or instead of one lamella, two lamellas placed side by side are used, otherwise the wood will shrink due to the stress arising if the shape deformation is prevented.

Plywood:

- glued from an odd number (at least three) of layers of peeled or sliced veneer sheets
- veneer layers usually have a 90° angle
- for wooden structures, waterproof plywood glued by waterproof adhesive is used

Particleboards:

- produced from wood chips
- board is hot-pressed after glue is added
- two types are produced - flat-pressed boards and extruded boards (it is possible to produce a continuous strip)
- particleboards with large oriented chips are labelled OSB

Fibreboard:

- pressed (hard)
- non-pressed (soft)
- made of garnetted waste from sawmill
- produced by means of pressure, heat and additives
- used for non-load bearing structures

2.3. Basics of designing wooden structures

Wooden structures must be designed and constructed so that it meets the following criteria:

- it must be possible (with acceptable probability) to use it for the desired purpose considering the expected lifetime and costs of acquiring
- to withstand (with corresponding degree of reliability) all types of loads and influences that can be expected in their construction and use
- to have adequate lifetime in relation to maintenance costs
- wooden structure is reliable if its sufficiently load-bearing, solid, and stable
- the structure is sufficiently load-bearing if stressing of its elements and joints does not exceed acceptable values (design strength):
    - solid, if the deformation of the structure and the elements does not exceed the permissible limit values
    - stable, if its protection against rollover, shifting and lifting is proved

In CR: design service time of buildings is usually 80 years. The corresponding reliability index is $\beta = 3.8$ for ULS (ultimate limit state) and $\beta = 1.5$ for SLS (Serviceability limit states).

Limit states:

- ultimate limit state: $Sd \leq Rd$; Sd is the design value of the internal force, Rd is the limit state design
- serviceability limit state $Ed \leq Cd$;

Limit state - basic cases of stress:

- bending
- shearing
- twisting
- bending with loss of stability
- buckling pressure
- bending and pressure
    - with buckling
    - without buckling
- bending and tension
- twisting and shearing

3. ASSESSMENT OF ULTIMATE LIMIT STATE

- assessment of deflections
- vibration assessment
- glued beams with variable cross-section

3.1. Deflection assessment of designed rod

Basic relationship:

- instantaneous deflection - uinst
- final deflection - ufin = uinst. (1 + Kdef)
- for some beams, it is possible to carry out so-called EXCESS HEIGHT - most often, this is used to eliminate deflection from permanent load

3.2. Deflection limit

- instantaneous deflections
- final deflections

Influence of shifting forces on beam deflections:

- generally, it cannot be neglected - the value of the shear modulus of elasticity of wood is very small
- nevertheless, it can be said that the shifting forces significantly influence only the deflections of “high and slender” beams of rectangular cross-section

Beams of glued wood of varying height:

- in the case of simply supported beams with a distributed load, the deflection from the moments um can be determined approximately from the beam deflection corresponding to the deflection of beam with a constant height [(hmin + hmax) / 2] according to the relation: um = ku. U0 (where ku is a coefficient)

4. TYPOLOGY AND CONSTRUCTION OF TRUSSES

4.1. Types of roofs

Types of roofs by slope:

- angular (roof height v = ½ span)
- French (the profile forms an equilateral triangle)
- gothic (roof height v = span)
- Italian (VLAŠSKÝ in Czech) (roof height v = 1/5 span)
- tower (height of roof v is several times larger than span)

Types of roofs by shape:

1) with flat roof areas:

- saddle (oldest, most used, space restricted)
- countertop (half saddle roof)
- hipped (cut saddle roof, trapezoidal shape)
- half-hipped
- gable (combination of two saddle roofs)
- half-gable
- mansard (curb)
- tented (pyramidal shape)
- shed (saddle roofs of different slope)
- tower

2) with curved areas:

- onion / bulbous dome (bulbous towers with lanterns)
- all of the aforementioned roofs except shed (e.g. saddle roof turns into a hipped, tented into bulbous)

4.2. Slopes of roofs

- Romanesque churches (slope of 30 ° to 40 °)
- Gothic churches (slope of about 60 °)
- Renaissance period (slope of about 55 ° to 40 °)
- Baroque period (slope around 55 ° to 40 °)
- Classicism (slope of about 30 °)
- 19th century (slope of about 45 °)
- 20th century (slope of about 45 °)

Construction of roof trusses:

- construction of roof trusses changed with the change of roof slopes
- gradually, an ideal type of structure has been developed, which is economical, statically and structurally solved
- certain types of structures are typical of individual periods (e. g. gothic roof, baroque stools), but this is not always true

4.3. Key factors for changes in roof slope

I. Architectural style

II. Geographical (where the architectural style came from):

- dry areas - the area of the subtropics - flat roofs, short rains
- areas with high precipitation - tropical zones or Asia - roof slope 40 ° -60 °, long rains
- South Europe - Roof trusses slope 30 ° - 40 °, construction stressed predominantly by pressure and tension, the supporting element - Italian trusses
- Northern Europe - steep "gothic" roof slope 60 ° or 63 °, 43 ° (gothic triangle height is the same as the base - increases with the wind load)
- mountain areas - roofs with a slope of less than 30 °, minimum wind load, maximum snow load (snow performs the function of thermal insulation)
- temperate climate

4.4. Temperate climate

- first mostly the influence of Italian architecture (small slopes)
- in the Romanesque period - increased slope (about 60 °)
- 16th century - again smaller slopes (tendency to reduce the volume of the attic) x slender rafters used in Baroque period were not suitable any more - rafters thus started to be reinforced. Later it showed that reinforcement of only several rafters is enough, while the other rafters are reinforced by purlins, which are supported by these reinforced bonds
- this created a new design element - queen post, which partially works as a solid frame and can be bent
- this construction system developed for more than 100 years, with its peak in the 17th and 18th centuries
- in classicism - due to influence of architectural styles, the slopes of roofs are more into the Mediterranean type
- in the case of slopes below 40 °, queen post is no longer suitable, trusses (preferred for roof slopes of up to 30 °) appear only rarely in the Czech Republic (in the second half of the 19th century)
- roof trusses with sloping and vertical columns (king post) are used until now
- slope is 45 ° - the most suitable in terms of self-weight load, snow load, wind load (suitable also for attic)

4.5. Structure systems of roof trusses

Saddle and pitched roofs trusses are divided into the following systems:

- truss - composed of the same transverse constructions - trusses that carry roofing directly or
  through horizontal beams (rafters)
- rafter - composed of the same bonds bearing roofing directly
- collar - group of rafter systems for which “collar” is characteristic - it strengthens the roof and shortens the span
- purlin - we distinguish full and empty connections; characteristic element - purlin
- sometimes there are also trusses with supported collars mentioned - similar to purlin, purlin supports collar, not rafter

Truss systems (rafters with Italian rafters):

- suitable for roofs with small slope (about 30 °)
- with larger roof slopes (necessary for conventional roofing in the conditions of the CR - at least 45°), efficiency of trusses is low - therefore they were not used in the historical buildings until the 19th century

Truss:

- transverse support structure, characteristic of truss roof frames
- significantly higher effective height compared to massive beams

Rafter systems:

- rafter - a characteristic bearing element
- slope of the roof and the span determined by the support method is decisive for the design of rafters
- in the case of bigger slopes (over 45 °) above the bend - pressure stress prevails
- the simplest roof frames consist of rafters only
- in the case of saddle roofs, the rafters at the top support each other, and the rafter is stressed b its own weight and the reaction of the opposite rafter

5. TYPES OF WOODEN CONSTRUCTIONS

- planar structures
- spatial structures
- planar structures
    - solids
    - solid
    - glued (with cross-section, saddle, convex, arched)
    - composed of several parts (only wooden or combined - e. g. wood - plywood or OSB board ...; wood - concrete)
- truss beams
- wood only
- combined (e. g. drawn diagonals are made of steel connecting rods)
- trusses
- arcs
- frames
- other (for example, rafters, staplers)

5.1. Joints of wooden structures

Classification by type of joint:

- steel joints
- carpentry joints
- gluing

Classification by arrangement:

- adjusting
- pooling
- joining into a joint

Classification by the nature of the action:

- flexible joints (carpentry, connections with steel joints)
- rigid joints (glued)

Flexibility of joints results from their working diagrams:

- mechanical means => large deformation
- bolt joints - excessive openings cause initial slip occurs (also in the case of one-sided joints, especially inserted or pressed dowels)
- board rigors show little capacity for plastic deformation

- joints behaviour is influenced by the forces transmitted in relation to the wood fibers
- for a single fastener, this depends on the diameter of the joint in relation to the width of the wood ring
- tests have also shown that in the case of joints up to the diameter of 8 mm the resistance does not depend on the direction of force in relation to the wood fibers

Some unconventional ways of joining in wooden structures to create semi-solid connections:

- joints using a combination of steel joint board with pre-drilled holes and steel nails of oval cross-section - Glulam Rivets

Joining through joint boards with pressed mandrels:

- load bearing capacity of joints can be based on relevant standards ČSN (ČSN EN 1075)

- this type of joining allows for the construction of very diverse types of rigors and frame connections

Joining using stick bars:

- to determine the bearing capacity of the rods, it is possible to start from valid standards of ČSN P ENV 1995-2, Design of wooden structures - Part 2: Bridges (this chapter will be in the future a part of the prepared standard EN 1995-1-1).

6. WOODEN CONSTRUCTION SYSTEMS OF BUILDINGS

- usually up to 3 floors
- it is divided into the following constructions:
- log cabins
- half-timbered
- frame structures
- skeletal
- panel
- cellular

6.1. Skeletal construction systems

- simple columns and girders
- one-piece girders and double pillars
- simple pillars and double girders

In the case of skeletons, it is important to determine the buckling lengths of the columns correctly:

6.2. Column construction systems

- structures made mainly of planks and boards
- placed close side by side (usually at a distance of 400 or more often 600 mm)

- 3 types of construction systems:
    - balloon frame
    - modified balloon frame
    - platform frame

Balloon frame:

- pillars are from the base plinth to the eaves (roof construction);
- floor threshold is made up of a simple one girder that lies behind the columns and a ceiling beam lies on it
- buckling length of the columns is shortened by stiffening

Modified balloon frame:

- pillars are interrupted on the floor threshold x column is usually continuous and consists of a prism or planks
- floor threshold is a prism or made of planks
- structure is stiffened in the walls

Platform frame:

- individual floors are made of parts placed on each other
- the most widely used system today
- columns have different designs according to the position in the structure

6.3. Woodworking systems

Use of wood in housing construction very well complies with today's functionality requirements and affordability of housing and sustainability construction in terms of exhaustiveness resources.

Types of wooden constructions:

- log cabins and log cabins
- sandwich wooden buildings

6.4. Present trends

- assembled family houses
- low-rise apartment buildings
- light roof superstructures

6.5. Wooden houses systems

Use of wood in construction of housing corresponds to the current requirements on the functionality or financial accessibility of housing, and sustainability of the building in terms of using resources.

Types of wooden houses:

- log and timber constructions
- sandwich wooden houses

Wooden houses systems in Europe:

- Germany:
  - 0.13 ha of forests compared to 0.26 ha of forests in the Czech Republic
  - logging per capita is half compared to the Czech Republic
  - the annual construction of wooden houses - about 30 thousand, which accounts for about 7% of the total construction of houses; about 1500 houses - multi-storey houses

- Austria:
  - share of wooden houses for housing construction is about 10%
  - long tradition in using wood for housing construction
  - currently - great attention is paid to using wood for constructing multi-storey buildings

- Switzerland:
  - share of wooden houses - approx. 10%
  - long-term government support for the development of constructing multi-storey wooden buildings
  - some banks support efforts to reduce for example by lower interest rates
  - intention promoted - to make an environmental assessment in practice according to the methodology Life Cycle Assessment taking into account the complex construction costs for its lifetime - that is, the cost of its acquisition, operation and disposal

- Finland, Sweden, Norway, Denmark:
  - housing construction using wood accounts for more than 60 % of total housing construction (large stocks of wood mass and top processing industry)
  - 1995 - 2000 - realized all-Scandinavian "NORDIC WOOD" programme with a budget of NOK 230 million, focused primarily on the possibility of building multi-storey buildings on the basis of wood

- under this programme, 600 flats were built in 14 locations, three to five store houses

- Great Britain:
  - the area of forests is 0.04 ha per capita - 6.5 times less than in the Czech Republic x the share of wooden buildings in residential construction is currently high
  - Scotland - the share of wooden buildings - 45 % (England and Wales 15%)
  - growing interest in using wood more in housing construction

Advantages of wooden houses in residential and civil construction in Czech Republic:

- the speed and non-seasonal character of the construction
- high degree of light prefabrication and reduced requirements for construction site equipment
- high productivity of work in production and assembly
- lower loading of foundations and lower costs for their implementation
- dimensional accuracy
- thermal efficiency
- low cost of operation
- good estimate of acquisition cost
- short-term commitment of capital
- good environmental characteristics (use of renewable resources, reduction of waste and energy consumption)