Architecture of Workplaces 1.
Lecture 4
Bearing structures of halls
Bearing structures of multi-storey buildings
lighting

water diversion = inclination

technology load, crane 90t

span = space for work

(useful) clearance = space for work
Requirements for load-bearing structure:

Economic efficiency
Flexibility of use - often changing production methods > expansion possibility,
- advantage of modular systems > more ways of extension
- large span structures
Fast construction - advantage of construction methods with standardized and prefabricated elements
Integration of building service systems
Structural possibilities of space roofing

Hierarchical bar or post and beam structure
Typical structure of halls

Surface-like roofings flexion in two directions e.g.: reinforced concrete slabs

Shell structures strain: pressure e.g.: concrete

Membrane structures strain: tension
A bit of terminology...
Main girder skeletons:

a., Post and beam structure of bar elements

- the vertical load is borne by girders, the horizontal by pillars
- the big area of the moment diagram can be equalized with the shape of the girder/truss
- the development of the roofing influences the shape of the truss

Solid webbed (<40,0m), lattice girder/truss (>30,0-40,0m)
Solutions with tension bar, pre/(under)stressed structure

Aspects of costs, construction:
Mixed solution of rc.-steel, rc.-wood
Solid webbed structure with different cross section

Alternatives for truss1. (aspect of roofing)

Alternatives for truss 2. (aspect of roofing)

Alternatives for pre/(under)stressed girder structure 1.

Alternatives for polygonal prestressed lattice girder structure 2.
Alternatives for single span main girder:

- Girder with a tension bar
- Truss
- Girder with no parallel booms
  Water diversion, moment
- Girder with parallel booms
a., Post and beam structure of bar elements – technology aspects:

a1  **Reinforced concrete columns and girders**
- typically prefabricated components
- standardized component dimension
- prefabricated columns put in bucket foundations, then grouted > restrained columns
- column-girder connection: forked support to avoid tipping over
- **typical structure** of prefabricated elements: *restrained columns with pin-connected girders*
- fireproof

a2  **Reinforced concrete columns with steel trusses**
- lightweight construction > simple foundations
- greater spans
- easier installation routes between trusses
- prefabricated columns put in bucket foundations, then grouted > restrained columns
- column-truss connection: pin-connection
- **typical structure** of prefabricated elements: *restrained columns with pin-connected steel trusses*
Post and beam structure of reinforced concrete
Post and beam structure of reinforced concrete and wood (laminated timber)
Post and beam structure of reinforced concrete and wood (laminated timber)
Main girder skeletons:

b., Three-pin frames and arches

The columns contribute to the flexural strength and stiffness of the beam, bearing function
- statically determined structures
- not sensible for heat-movements, for sag of support
The shape of the moment diagram depends on the shape of the frame
- the horizontal forces can be taken by a tension bar

Solid webbed or lattice frames
- the shape of the frame can be determined by the roofing
Alternatives for frame 1.
plate and lattice girder

Alternatives for frame 2.
plate and lattice girder
cambered and polygonal structures

Twice broken and straight-line alternatives

The shape of the structure is defined by the mass of the material to be stored.
Mixed structure with tension bar

Alternatives for structures with tension bar connecting the free supports
b., Three-pin frames and arches – technology aspects:

**Wooden frames - rare**
- lightweight construction > simple foundations
- spans up to 35m-s
- glue laminated timber can be easily shaped > to reduce moment at the edges
- wooden columns hinged to foundations
- column-truss connection: stiff connection
- **typical structure of wood: the three-pin frame**
- fire protection simply with oversizing
Cambered three-pin frame of wood (laminated timber)
Main girder skeletons:

- Two-pin and restrained frames and arches

Undefined structures,
- horizontal forces and moment are transmitted to the foundation
- sensible for heat-movements, for sag of support

Structures with complicated joints, but use of less material (economical)
Straight-line and broken-line frames
Plate girder alternatives

Straight-line and broken-line frames
Lattice girder alternatives (wide span)

Straight-line and broken-line frames
Plate girder alternatives with tension bar

Cambered and polygonal structures
Lattice girder alternatives with heavy foundation (wide span)
c., Two-pin and restrained frames and arches – technology aspects:

c1 Steel frames
- lightweight construction > simple foundations
- steel columns hinged to foundations
- column-girder connection: stiff connection
- **typical structure of steel: the two-pin frame**

c2 Trussed steel frames
- lightweight construction > simple foundations
- very big spans
- easier installation routes between trusses
- steel columns hinged to foundations
- column-truss connection: stiff connection
- **typical structure of steel: the trussed two-pin frame**
- but corrosion protection > great influence on costs
Two-pin steel frame with purlins and windbrace
Trussed two-pin steel frame with purlins
Two-pin steel frame with purlins and windbrace
Moment transmitting joint on an old plan: labour-intensive, expensive solution
Multiplying of main girder skeletons

Multi-bay halls

Multiplying of single span girders

Gerber-girder structure
(ranged at the moment zero-point)

Multiplying of different frames

Frames and half-frames of different heights
- technological needs, lighting, roofing

Frames and half-frames of different heights
- technological needs, lighting, roofing
Development of roof structure

Bearing of space separation (thermal insulation and water-proofing)
- solution of water-diversion
- inflections, air-spaces
- place and solution of skylights
greater span = greater moment = greater inertia (heavier) girder
Solution=lightened, optimized cross-section, lattice-girder structures/ trusses
Wide span (round 40 m)

Anything else (6.0 ~ 30.0 m)

truss<>plate girder
80 pieces of structural elements greater labour-intensity, specific smaller structural weight > there is no real other solution in case of spans greater than 40 m

5 pieces of structural elements greater labour-intensity, specific bigger structural weight > high tensile steel

truss<>plate girder
Roofs of reinforced concrete structures

- hierarchical bar elements

direction of development:
reduction of the number of elements,
standardization of the lifting weights
Roofs of steel structures

the high tensile, wide span trapezoidal sheet metals allow the reduction of the number of elements
Mixed systems:

- column + main girder = reinforced concrete
- purlins + trapezoidal sheet metal = steel
- bearing the roofing = steel

Advantage: economical, fire protection aspects

Typical span of trapezoidal sheet metal:
- 7.50 m, max. 9.00 m

Typical span of purlins:
- max. 7.50 m

Span of trapezoidal sheet metal:
- 3.00 m
Precast rc. main beam with T section

Precast rc. column with I section
Long main girder system under construction
Hall roofing with long main girder and purlins
Hall roofing with long main girder and purlins of wood (laminated timber)
Hall roofing with long main girder and great roof elements – mixed system
Hall roofing with gerber-girder structure (ranged at the moment zero-point)

Multiplying single span long main girders
the question of the last stand, last wall = smaller load, distribution of the span = the wall column can bear the roof as well!

unnecessary overcalculated

more congenial!
Bracing of frames of steel structures = „windbrace”

In frame direction bigger cross sections because of the span > moment resistance, but the perpendicular direction is crucial > bracing (with shear-resistant panels in the level of wall or roof) where the geometry, joints of the structural elements and the stress is symmetric.
Two-pin steel frame with purlins, windbrace and wall comuns
Great horizontal frame > distribution: perpendicular windbrace in every frame
Great roof element
Usually reinforced concrete

Flat, hollow-core roof panel

Shell-like roof panel

Ribbed roof panel (TT panel)
Wide span roof element
Usually reinforced concrete

TT („pi”) panel, sometimes stressed panel

T panel, stressed panel

Rare unique form panel, usually stressed
Flat, hollow-core roof panel
Wide span roof element TT ("pi") panel
Surface-like roofings
Slab-like structures
Inflection in two directions

Grid of bars, space truss
Material: steel, wood

Slabs with multiple support eg: rc. slabs
Problem of load transmission, punching > beams, mushroom slab
McCormick Place, Chicago, C. F. Murphy and Ass. 1968 – space truss, 45.7 m span)
Exhibition hall, Grenoble, Jean Prouve, 1967
Surface-like roofings

shell structures (vault analogy) for wide, sometimes extremely wide span

Material: mostly concrete
Special (self-stiffening) spatial forms, complicated formwork, less material, attractive outlook

Sometimes prefabrication on the site
Hangars for zeppelin, airport Orly, Paris, Eugène Freyssinet, 1916–24
CADYL Grain Silo, Young, Uruguay, Eladio Dieste, 1978

double bent shell

218 m wide, 54 m high, roofed area of 22 500 m² (the greatest reinforced concrete hall of the world without internal support)
Light Metal Works, Székesfehérvár, Hungary
Farkas Ipoly, Menyhárd István, IPARTERV 1958-1959
Ellipsoidal shell roofing with tension bar
Xochimilco Restaurant (Los Manantiales) Mexico City, 1968, Felix Candela
Multiplied shed, hyperbolic paraboloid surface roofing
Surface-like roofings

Membranes and suspended roofs for wide, sometimes extremely wide span

New technology
Strain in the structure: tension
Very thin, very light structure.

The suspension roofs are usually doubly cambered structures (pattern design)
Awnings as bearing structures quite awkward joints
National Exhibition, N. Novgorod, Vladimir Shukov, 1896 suspension steelweb structure
Olimpic Stadion, München, Otto Frei, 1968
height: 50m, height of the posts: 100m, diameter: 365m
Surface-like roofings

Overpressure structures for wide, sometimes extremely wide span

The stability, form resistance is assured by different types of inflated tyres, pillow blocks.
Different types of specific plastic specific joints.
National Space Center, Leicester, England, Nicholas Grimshaw, 2001
Solutions of very wide hall spans
Main girder of great structural height (h/20-h/15) in some cases even more storey high

The bearing structure is outside:
- there is no „useless“ inner space
- unified inner appearance
- high quality details (stabbing the water proofing)
- accepting structural movements

Only in case of really large span!

main girders (plain, lattice)
Mixed: understressed, suspension solutions
Sainsbury Centre for Visual Arts, Norman Foster, 1978
INMOS Processor factory, Newport, Wales, Richard Rogers, 1982-87
Bearing structures of multi-storey buildings

The development of the skeleton structure

Going downwards, more load on the pillars
  greater number of elements
  difficult to unify
  complicated calculation
  many times undefined frame

Expediently monolith reinforced concrete structure

There were more kinds of precast reinforced concrete structures in the past
Multi-storey skeleton structure (dividing in bar elements), cantilevers because of great weights
Multi-storey skeleton structure (dividing in bar elements), cantilevers because of great weights
**Bearing structures of multi-storey buildings**

Bracing of the buildings
> wind load
> earthquake (shape of the plan, symmetry)

Main girder skeleton + bracing structure

Usually with bracing corns:
- wallsystems connected to each other
- staircases, shafts for building services, lifts

Important question of floor plan organization

With bracing walls: at least three
With bracing frames: easy to pass
Thank you for your attention.