Metal Structures

Lecture VII

Rules of forming of steel structures
Contents

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Philosophy of design

Philosophy of design is the result of three factors:

Photo: Author
Standards
What is acceptable by standards?

I\textsuperscript{st} design project: $E / R \leq 1,0$ for each plates, bolts and welds;

Economy
What is the cheapest?

I\textsuperscript{st} design project: minimalization of bolts number, plates dimensions and welds dimensions;

Experience
What is the most useful / the simplest?

I\textsuperscript{st} design project: initial assumption of plates dimensions and distribution of cross-sectional forces;
The standard requirements change over time with the development of science and technology.

<table>
<thead>
<tr>
<th>Date</th>
<th>Standard</th>
<th>Notices</th>
</tr>
</thead>
<tbody>
<tr>
<td>before 1980</td>
<td>Old Polish Standards older version</td>
<td>• Permissible Stress Design (one common safety factor);</td>
</tr>
<tr>
<td>1980 – 2005/10</td>
<td>Olsd Polish Standards</td>
<td>• Limit States Method;</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Partial safety factors (for material and actions);</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Division between $I^{st}$ and $II^{nd}$ order methods;</td>
</tr>
<tr>
<td>from 2005/10</td>
<td>Eurocodes</td>
<td>• Extensive consideration of the impact of imperfection;</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Analysis of stiffness of joints;</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Detailed analysis of the resistance of joints;</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Increase, due to technological progress, design strength of welds;</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Taking into account the cooperation of housing and structure;</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Diversification of the degree of structural responsibility by CC;</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• The obligation to use numerical models for shell structures CC3;</td>
</tr>
</tbody>
</table>
Types of structures

Steel structures

- Shell
- Tension
- Bar

- "Special"
- "Normal"

- Bridges
- Masts
- Crane support structures
- Other

Photo: Author
Shell structures

EN 1993-3-2
EN 1993-4-1
EN 1993-4-2
EN 1993-4-3

Photo: carrasquilloassociates.com

Photo: wakro.com.pl

Photo: kbpomorze.pl

Photo: iniekt-system.pl
Tension structures
EN 1993-1-11

Masts and towers
EN 1993-3-1
Crane supporting structures
EN 1993-3-6

Electro-energetic towers
EN 50341-1

Piling
EN 1993-5
"Normal" steel structures
EN 1993-1-1
EN 1993-1-5
EN 1993-1-8
Hall: the most often type of steel structure

Steel hall: repetitive arrangement of flat steel frames, interrelated by purlins, roof bracings, walls bracings and wall girts
Halls: industrial, warehouse, trade, cooler, garage, hangar, office, agricultural, sport, exhibition…

Photo: steel.com.au

Photo: pebsteel.com

Photo: easyhalls.com

Photo: aviationbuildingsystem.com

Photo: internationalsteelspan.com

Photo: ekbud.lublin.pl

Photo: parkmag.pl

Photo: sztuka-architektury.pl

CHAIR OF METAL STRUCTURES
CRACOW UNIVERSITY OF TECHNOLOGY
Parts of structure

Each steel structure can be divided into three parts:

- members
- connections
- joints
Members

Bars, beams, purlins, rafters, girders, columns, bracings - calculations according to level of cross-section and level of element.

Example from I\textsuperscript{st} design project: resistance of cross-section is basic level for calculation of cross-sectional forces in joint

\[
\begin{align*}
M_{Ed} &= \alpha f_y W_{pl, y} \\
N_{Ed} &= \beta f_y A \\
V_{Ed} &= \gamma f_y A_v / \sqrt{3}
\end{align*}
\]
Connections

Welds and shank of bolts - calculation according to level of point (for welds) or cross-section (shearing resistance or tension resistance of shank of bolts).

Example from 1st design project: $\sigma_{\text{HMH}}$ for welds, shearing resistance for shank, tension resistance (during calculations of preloaded force) for shank of bolts.
Joints

Small parts of members, where are contact between two or more members. There are many specific phenomenons on these short part of beams, columns, etc. Calculation according to level of cross-section and level of element.

Example from 1st design project: bearing resistance and punching resistance (effects of contact between bolts and plates and members), slip resistance and block tearing (effect of contact between plates and members).
General requirement:

angles between axis of members and internal angles for plates can't be too small

(EN 1090-2)

\[ \beta_i \geq 30^\circ \]
Reflex angles in plates we must make in special way to avoid cracking.

\[ \beta > 180^\circ \]

Wrong

Photo: Author

Well

Well

Wrong
Generally, structures analysed on I\textsuperscript{st} step of study (including halls), can be divided into different parts, which have different roles:

- roofing and housing → #t / 20 - 27
- purlins → #t / 28 - 40
- girts → #t / 41 - 46
- bracings → #t / 47
- truss → #t / 48
- beams, girders, columns → #t / 49 - 54
- joints → #t / 55 - 75
Roofing and housing

Sandwich panels, cladding panels or corrugated sheets; steel or aluminum
<table>
<thead>
<tr>
<th>Photo: steelprofil.pl</th>
<th>Thermal isolation</th>
<th>Factory-made connecting latch</th>
<th>Anti-buckling protection for purlins according to EN</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1" alt="Thermal isolation" /></td>
<td>😊</td>
<td>😊</td>
<td>🙁</td>
</tr>
<tr>
<td><img src="image2" alt="Factory-made connecting latch" /></td>
<td>😞</td>
<td>😊</td>
<td>🙁</td>
</tr>
<tr>
<td><img src="image3" alt="Anti-buckling protection for purlins" /></td>
<td>😞</td>
<td>😞</td>
<td>😊</td>
</tr>
</tbody>
</table>

Photo: steelprofil.pl

Photo: pruszynski.com.pl

Photo: amarodachy.pl

(per 5 - 10 years from erection)
Roofing and housing can be calculated as one of three levels of accuracy:

<table>
<thead>
<tr>
<th>Accuracy of calculations</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dead weight only</td>
<td>The simples and most popular way of calculations (each type)</td>
</tr>
<tr>
<td>Dead weight + anti-buckling protection</td>
<td>According to EN 1993-1-3 (corrugated sheet only; →Lecture #15)</td>
</tr>
<tr>
<td></td>
<td>or FEM calculations according to results of tests and experiments (sandwich panels, cladding panels)</td>
</tr>
<tr>
<td>Dead weight + anti-buckling protection + cooperation with structure in bearing of loads</td>
<td>FEM calculations according to results of tests and experiments (each type);</td>
</tr>
</tbody>
</table>
Calculations of roofing (and housing) - we must choose from table thickness of sandwich or thickness of sheet and high of waves for value of loads and distance between purlins.

<table>
<thead>
<tr>
<th>Grubość rdzenia</th>
<th>Obc. ze względu na</th>
<th>Maksymalne obciążenia, daN/m² przy rozpiętości przęsła, m</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2,1</td>
<td>2,4</td>
</tr>
<tr>
<td>60</td>
<td>139</td>
<td>107</td>
</tr>
<tr>
<td></td>
<td>100</td>
<td>78</td>
</tr>
<tr>
<td>75</td>
<td>211</td>
<td>162</td>
</tr>
<tr>
<td></td>
<td>183</td>
<td>148</td>
</tr>
<tr>
<td>100</td>
<td>283</td>
<td>223</td>
</tr>
<tr>
<td></td>
<td>199</td>
<td>166</td>
</tr>
<tr>
<td>125</td>
<td>355</td>
<td>281</td>
</tr>
<tr>
<td></td>
<td>265</td>
<td>224</td>
</tr>
<tr>
<td>150</td>
<td>338</td>
<td>274</td>
</tr>
<tr>
<td></td>
<td>284</td>
<td>244</td>
</tr>
<tr>
<td>200</td>
<td>365</td>
<td>302</td>
</tr>
<tr>
<td></td>
<td>351</td>
<td>308</td>
</tr>
<tr>
<td>250</td>
<td>458</td>
<td>379</td>
</tr>
<tr>
<td></td>
<td>459</td>
<td>406</td>
</tr>
</tbody>
</table>

Photo: pruszynski.com.pl

Photo: concretescrews.org

For joints between roofing / housing and structure we use special self-tapping screw.

Photo: plyty-abo.pl
Modern type of roofing - sandwich panels - very light.

Old type of roofing - concrete channel slab - very heavy.
Example - comparison of loads:

<table>
<thead>
<tr>
<th>Load</th>
<th>Old type</th>
<th>Modern type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Roofing (sandwich</td>
<td>~ 3,70 kN / m²</td>
<td>~ 0,15 kN / m²</td>
</tr>
<tr>
<td>panels or channel</td>
<td></td>
<td></td>
</tr>
<tr>
<td>slab + additional</td>
<td></td>
<td></td>
</tr>
<tr>
<td>layers</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Snow</td>
<td>~ 1,44 kN / m²</td>
<td>~ 1,44 kN / m²</td>
</tr>
<tr>
<td>Wind</td>
<td>~ 0,60 kN / m²</td>
<td>~ 0,60 kN / m²</td>
</tr>
<tr>
<td>Sum</td>
<td>~ 5,74 kN / m²</td>
<td>~ 2,19 kN / m²</td>
</tr>
</tbody>
</table>

Purlin - one-span, 6,00 m length, 3,00 m distance between purlins, S235:

<table>
<thead>
<tr>
<th>Calculation</th>
<th>Old type</th>
<th>Modern type</th>
</tr>
</thead>
<tbody>
<tr>
<td>I-beam</td>
<td>IPE 240</td>
<td>IPE 180</td>
</tr>
<tr>
<td>Dead-weight of purlin</td>
<td>0,36 kN / m</td>
<td>0,18 kN / m</td>
</tr>
<tr>
<td>Sum</td>
<td>~ 17,58 kN / m</td>
<td>~ 6,72 kN / m</td>
</tr>
<tr>
<td>Effort</td>
<td>~ 93 %</td>
<td>~ 84 %</td>
</tr>
</tbody>
</table>
Of course, modern roofing is much more lighter, so dead weight will be smaller and structure will be cheaper.

But...

Snow it is climatic load; there is possible, that its value can be much more greater than according to standard.

For example: unforseen 30% more snow.

<table>
<thead>
<tr>
<th>Load</th>
<th>Old type</th>
<th>Modern type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Roofing (sandwich panels or channel slab + additional layers)</td>
<td>~ 3,70 kN / m²</td>
<td>~ 0,15 kN / m²</td>
</tr>
<tr>
<td>Snow + 30%</td>
<td>~ 1,87 kN / m²</td>
<td>~ 1,87 kN / m²</td>
</tr>
<tr>
<td>Wind</td>
<td>~ 0,60 kN / m²</td>
<td>~ 0,60 kN / m²</td>
</tr>
<tr>
<td>Sum</td>
<td>~ 6,17 kN / m²</td>
<td>~ 2,62 kN / m²</td>
</tr>
</tbody>
</table>
Purlin - one-span, 6,00 m length, 3,00 m distance between purlins, S235:

<table>
<thead>
<tr>
<th>Calculation</th>
<th>Old type</th>
<th>Modern type</th>
</tr>
</thead>
<tbody>
<tr>
<td>I-beam</td>
<td>IPE 240</td>
<td>IPE 180</td>
</tr>
<tr>
<td>Dead-weight of purlin</td>
<td>0,36 kN / m</td>
<td>0,18 kN / m</td>
</tr>
<tr>
<td>Sum (snow +30%)</td>
<td>~ 18,97 kN / m</td>
<td>~ 8,01 kN / m</td>
</tr>
<tr>
<td>Effort (snow +30%)</td>
<td>~ 100 %</td>
<td>~ 100 %</td>
</tr>
<tr>
<td>Effort</td>
<td>~ 93 %</td>
<td>~ 84 %</td>
</tr>
<tr>
<td>Change of effort</td>
<td>7%</td>
<td>16%</td>
</tr>
</tbody>
</table>

Increasing of snow load up 30% means ~7% for old type and ~16% for modern type.

Structure with old type of roofing is less sensitive for unforseen change of load.
Purlins

Loads:

- Dead weight of roofing
- Dead weight of purlin
- Snow
- Wind
- Imposed loads
- Thermal actions
- Accidental actions
- Actions during execution
Static schemes of purlins:

Continuous multispans beam - rather cold-formed cross-section

One-span beam - rather hot-rolled cross-section (recommended IPE)

Photo: Author
Purlins: bi-axial bending, bi-directional shear and bi-directional deflection.

Three types of loads applied to the roof:
• vertical related to horizontal plane (snow);
• vertical related to surface of roof (dead-weight);
  • perpendicular to roof (wind);

Photo: M. Łubiński, W. Żółtowski, Konstrukcje Metalowe t. II, Arkady, Warszawa 2004
"Normal" purlin - in both direction the same length ($l_y = l_z = l$)

$$M_{Ed, y} \approx q_z l^2 \quad M_{Ed, z} \approx q_y l^2$$

$$q_z < q_y \rightarrow M_{Ed, z} < M_{Ed, y} \quad \text{but}$$

$$J_z << J_y \rightarrow W_z << W_y \rightarrow M_{Rd, z} << M_{Rd, y}$$

there is possible, that $M_{Ed, z} / M_{Rd, z} > M_{Ed, y} / M_{Rd, y}$

$$f_y \approx q_y l^4 / EJ_z \approx f_z \approx q_z l^4 / EJ_y$$

Big efforts in both directions, big deflections in both directions. Is possible, that cross-section must be very massive because of problems with weak axis.
Suspended purlin: hangers = additional support on y-direction (weak axis is supported).

At now, for weak axis \( l_1 = 1 / 2 \)

\[ M_{Ed, y_1} \approx q_z l_1^2 = q_z l_2^2 / 4 = M_{Ed, y} / 4 \]

\[ f_{y1} \approx q_y l_1^4 / EJ_z = q_y l_4^4 / EJ_z / 16 = f_y / 16 \]

Much smaller bending moments and deflections about weak axis. Very economical design project: big effort for strong axis, small effort for weak axis.
Compression and tension in hangers for:

wind pressure  wind suction
There is possible compression in part of hangers. There will be permanently deformations as the effect of buckling.

We need rigging screws to repair hangers.
The same dead weight; much greater moment of inertia and sectional modulus about strong axis; no change about weak axis.
"Normal" truss - forces are applied in nodes; there are axial forces in chords and cross-bars only.

Truss purlin - continuous load from roofing; there are axial forces in chords and cross-bars; in addition top chord is bending.
I-beam purlin: bi-axial bending.

\[ (D + S + I) \cos \alpha + W \]

\[ (D + S + I) \sin \alpha \]

Truss purlin: horizontal force

\[ W \sin \alpha \]

has very small value and can be neglected (acts on roofing, not purlins). All loads act in plane of truss. There is need wedge to install truss purlin in vertical position.

Photo: Author
Recommended types of purlins for different length of span (distance between supports):

<table>
<thead>
<tr>
<th>Length</th>
<th>Continuous, cold-formed</th>
<th>Continuous, suspended, cold formed</th>
<th>One-span hot-rolled</th>
<th>Castellated</th>
<th>Truss</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3 − 4</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>4 − 6</td>
<td></td>
<td>✓</td>
<td>✓</td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>6 − 8</td>
<td></td>
<td></td>
<td></td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>8 − 12</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>12 − 18</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>✓</td>
</tr>
</tbody>
</table>
Support for purlins

Hot-rolled

Snow + dead-weight + wind pressure: by contact between bottom flange and girder; web and support plate

Wind suction bigger than dead-weight: by contact between web and support plate; shear of bolt
Support for purlins

Cold-formed

Snow + dead-weight + wind pressure:
by contact between bottom flange and girder; web and support plate

Wind suction bigger than dead-weight:
by contact between web and support plate; shear of bolt
Loads:

- Dead weight of housing
- Dead weight of girt
- Wind
- Imposed loads
- Thermal actions
- Accidental actions
- Actions during execution

Photo: cobouw.pl
There is no snow load for girts; cross-sections of girts is much more lighter than for purlins.

<table>
<thead>
<tr>
<th>Horizontal elements</th>
<th>Photo: newsteelconstruction.com</th>
<th>Photo: everfaithsteel.cn</th>
<th>Photo: calgor.com.pl</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="newsteelconstruction.com" alt="Image" /></td>
<td><img src="everfaithsteel.cn" alt="Image" /></td>
<td><img src="calgor.com.pl" alt="Image" /></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Vertical elements (for example additional columns)</th>
<th>Photo: wggstal.pl</th>
<th>Photo: wistal.pl</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="wggstal.pl" alt="Image" /></td>
<td><img src="wistal.pl" alt="Image" /></td>
<td></td>
</tr>
</tbody>
</table>
Wall girts, purlins, roof bracings and side wall bracings make specific system for wind action. Front wall housing columns must be connected with purlins and roof bracings at one point. The same, girts on front and side walls.
Wind acts on housing \((p, \text{ [kN} / \text{m}^2])\). Housing is support on wall girts; loads from housing act on girts as continuous loads \((q, \text{ kN} / \text{m})\). Girts are under bending (mono- or bi-axial). Loads from girts act on main frames as forces, applied in points of connection girts - main columns.

\[
p = qa \\
q = qa \\
F = ql
\]

Wind acts on front wall: the same way of recalculation \(p \rightarrow q \rightarrow F\). Forces are applied to main frames (perpendicularly to theirs plane) and to housing columns. In case of doors (in front / side wall), wind action from door is applied to girts and housing columns around doors.
Loads from housing columns finally act on bases of housing column and main frames (main columns, roof girders), perpendicularly to theirs planes. It potentially makes bi-axial bending in main frames.

Main frames are supported in perpendicular direction by bracings, purlins and side wall girts. It prevent from bi-axial bending.

Roof bracings and purlins make horizontal truss. Roof girders are chords of truss. The effect is, that loads perpendicular to main frames make additional axial forces in roof girders. Additionally, there are axial forces in purlins.
Roof: loads are transported through longitudinal roof bracings.

Wall: loads are transported by side wall girts.

Finally, loads act on vertical bracings on side walls, vertical trusses. Main columns are chords of truss. Depending on location of girts on side walls, there is possible bi-axial bending in these four of columns (loads out of nodes of truss).
Bracings - recommended cross-sections
(→ Lec # 15)

Photo: calgor.com.pl

Photo: rafstal-inox.pl

Photo: rafstal-inox.pl

Photo: EN 1993-1-1 fig. 6.13

Photo: stalhart.pl

Photo: stalhart.pl
Modern trusses
(→ Lec # 13, 14)

Chords: hot-rolled I-beams or pipes
Truss bracing: pipes
Each element at I\textsuperscript{st} or II\textsuperscript{nd} classs of cross-section

Photo: wikipedia
Beams, girders and columns
(→ Lec # 16-19)
Hot rolled:

\[ \text{IPN, IPE, IPE-A, IPE-AA, IPE-O} \]

\[ \text{HEB, HEA, HEAA, HEM} \]
Proportion of cross-sections

<table>
<thead>
<tr>
<th>Cross-sections</th>
<th>$J_z / J_y$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>100 - 300</td>
</tr>
<tr>
<td>IP</td>
<td>~ 1 / 13</td>
</tr>
<tr>
<td>HE</td>
<td>~ 1 / 3</td>
</tr>
</tbody>
</table>

Photo: hmsteel.pl
For which type of loads are recommended different types of cross-sections:

<table>
<thead>
<tr>
<th></th>
<th>IP</th>
<th>HE</th>
</tr>
</thead>
<tbody>
<tr>
<td>$N_{Ed}$</td>
<td></td>
<td>![thumb-up]</td>
</tr>
<tr>
<td>$M_{y, Ed}$</td>
<td>![thumb-up]</td>
<td></td>
</tr>
<tr>
<td>$M_{z, Ed}$</td>
<td>![thumb-down]</td>
<td></td>
</tr>
<tr>
<td>$M_{y, Ed} + M_{z, Ed}$</td>
<td>![thumb-up]</td>
<td>![thumb-up]</td>
</tr>
<tr>
<td>$N_{Ed} + M_{y, Ed}$</td>
<td>![thumb-up]</td>
<td>![thumb-up]</td>
</tr>
<tr>
<td>$N_{Ed} + M_{z, Ed}$</td>
<td>![thumb-down]</td>
<td>![thumb-up]</td>
</tr>
<tr>
<td>$N_{Ed} + M_{y, Ed} + M_{z, Ed}$</td>
<td>![thumb-up]</td>
<td>![thumb-up]</td>
</tr>
</tbody>
</table>
Frames for steel halls

L < 25 - 30 m → hot rolled I-beam IP
L > 25 - 30 m → welded I-beam IK
Steel skeletons (3d frames)

Beams, girders → hot rolled IP, welded IK
Columns → hot rolled IP, HE, welded IK, HK
Joints

For joints important is their stiffness (relationship $M$–$\phi$)

\[ M = 0 - \infty \]
\[ \phi = 0 \]

Real:

\[ M \]
\[ \phi \]

Photo: Author

Theory:

\[ M = 0 \]
\[ \phi = 0 - \infty \]

Photo: Author
Calculations (→ Lec # 20, 21):
What are limits 1-2 and 2-3?
What is stiffness of analysed joint?
What about comparison between limits and stiffness?

Range 1

Range 2

Range 3

Photo: EN 1993-1-8 fig 5.4

Photo: Author
Information about differences between these two types of joint will be presented on lecture #7.
Quasi-welded joints (→ Lec # 8)

Soldering - additional metal only

Pressure welding - fusion in few points only

Welding - fusion and additional metal
Quasi-bolted joints (→ Lec # 10)

Photo: Author

Photo: ventia.pl

Bolt

Pin

Rivet
### Negative and positive aspects

<table>
<thead>
<tr>
<th>Aspect</th>
<th>Bolted joint</th>
<th>Welded joint</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Influence of weather</td>
<td>🌅</td>
<td>🌚</td>
<td>#t / 61</td>
</tr>
<tr>
<td>Susceptibility to worker’s qualifications</td>
<td>🌅</td>
<td>🌚</td>
<td>#t / 62–63</td>
</tr>
<tr>
<td>Combination with other materials</td>
<td>🌅</td>
<td>🌚</td>
<td>#t / 64</td>
</tr>
<tr>
<td>Possibility to disassembly</td>
<td>🌅</td>
<td>🌚</td>
<td>#t / 65</td>
</tr>
<tr>
<td>Independence from the electricity</td>
<td>🌅</td>
<td>🌚</td>
<td>#t / 66</td>
</tr>
<tr>
<td>Destruction of corrosion protection</td>
<td>🌅</td>
<td>🌚</td>
<td>#t / 67</td>
</tr>
<tr>
<td>Influence on the mechanical properties of the material</td>
<td>🌅</td>
<td>🌚</td>
<td>#t / 68</td>
</tr>
<tr>
<td>Residual deformation and stress</td>
<td>🌅</td>
<td>🌚</td>
<td>#t / 69</td>
</tr>
<tr>
<td>Fire</td>
<td>🌅</td>
<td>🌚</td>
<td>#t / 70</td>
</tr>
<tr>
<td>Versatility of the relative position of plates</td>
<td>🌚</td>
<td>🌅</td>
<td>#t / 71–73</td>
</tr>
<tr>
<td>Uniformity of connection</td>
<td>🌚</td>
<td>🌅</td>
<td>#t / 74</td>
</tr>
<tr>
<td>Time of connection</td>
<td>🌚</td>
<td>🌅</td>
<td>#t / 75</td>
</tr>
</tbody>
</table>
Weather

Work quality for welded joints is much more important, than for bolted joints.

Bad weather can significantly decreases ability of workers → and quality of welded joints. Bolted joints are not such susceptible.
Workers qualifications

Everybody can put bolts in holes and screw...
(almost everybody)
...but only a small part of people can make welds of high quality.
Other material

We can't weld steel to concrete. We can join them by bolts.
Disassembly

We can disassemble bolted joint without destruction - and use members once again in other place. There is possible only total destruction in case of welded joints.
Electricity

We can't weld without energy. But we can screw bolts.
Corrosion protection

Protection is destructed by high temperature.
Influence on the mechanical properties

Photo: M. Łubiński, W. Żółtowski, Konstrukcje Metalowe t. II, Arkady, Warszawa 2004
Residual stresses and strains (→ Lec # 8)

There are non-zero value of stress and strain after welding.
Fire

Oil tank ignites during welding

FEBRUARY 20, 2011 | BY KNEWS | FILED UNDER NEWS

Fire ignited by welders trying to dismantle a metal tank that contained remnants of lube oil caused fire to erupt inside the tank at the old GNIC wharf, Lombard and Sussex Streets, yesterday. The welders were not injured in the process since they scampered from the tank immediately after the fire started.

Fire fighters were summoned to the scene after billows of black smoke filled the air as the oil burnt inside the tank.
At the scene fire fighters did the unpredictable and tried dousing the fire with water. This caused more destruction since the oil which would always float on top of the water overflowed out of the container causing the fire to spread outside the tank.
The fire fighters then used foam to quench the flames after realizing that using water was futile.
According to a fire official, they had to assess the magnitude of the fire before the used the foam.
One man said the tank which was very old was being dismantled to be sold as scrap iron since it served no purpose. The owner said that he was unaware that any lube oil was inside the tank at the time.

Photo: safetylifethailand.com

Photo: kaieteurnewsonline.com
Relative position of plates

~100 and more years ago, I-beams were constructed as plates connected by L-sections and rivets.
L-sections enable to joint elements by angle 90° only.
Flat bars enable to joint elements by angle 0° only.
CHS can’t be connected.
Because of welding, we can connect members by various angles. We can connected CHS, too.
Uniformity

We can't notice borders between elements in well-done weld.

Photo: roadking.riders.pl

Photo: bakertesting.com

Photo: weldingtipsandtricks.com
Time

Sometimes we need much more time to put and screw bolts than to make welds.

Photo: steelconstruction.info
From assembly room to construction site

Steel structures are made by members, welded in assembly room and connected on construction site by bolts.
<table>
<thead>
<tr>
<th>Assembly room → welded joints</th>
<th>Construction site → bolted joints</th>
</tr>
</thead>
<tbody>
<tr>
<td>no weather influence;</td>
<td>no susceptibility on weather;</td>
</tr>
<tr>
<td>specialized companies → high</td>
<td>everybody (even CEO) can connected</td>
</tr>
<tr>
<td>workers qualifications;</td>
<td>members by bolts;</td>
</tr>
<tr>
<td>possibility of accuracy</td>
<td></td>
</tr>
<tr>
<td>reconstruction of</td>
<td></td>
</tr>
<tr>
<td>corrosion protection;</td>
<td></td>
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<tr>
<td>possibility of wide range of</td>
<td></td>
</tr>
<tr>
<td>NDT of welds;</td>
<td></td>
</tr>
<tr>
<td>possibility of annealing (reduction of</td>
<td></td>
</tr>
<tr>
<td>welded stresses and strains);</td>
<td></td>
</tr>
<tr>
<td>good fire protection;</td>
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</tbody>
</table>
Structure will be transported in pieces from assembly room to construction site. This means, already at the design stage, designers must think about structure as about complex of transport members. There must be predicted and designed splice joints between transport members.
Design project should be idiot-proof.

There are two identical steel columns. Beam is attached only to one of them, but both have in the same place transverse stiffeners. It does not matter, if someone makes a mistake and turn columns places. Both will fit into the rest of the structure. Members of structures should be unified.
Design documentation:

Initial drawing - first concept of structure, important for designer (for internal use only). Based on its, designer calculate loads, length of members and splice joints.

Overall drawing - official global drawing of structure. Important for workers on construction site. There are presented most important dimensions and names of members. Generally, can look the same as initial drawing.
Workshop drawing - drawing of transport member. Important for workers in assembly room (diameter of holes for bolts, type and length of welds, dimensions of components of transport member).

Assembly drawing - drawing of splice joints. Important for workers on construction site (type of bolts, type and length of welds if there are welded splice joints).

For small structures, both information can be presented on one drawing.
List of materials:

- Total mass of structure → cost of material;
- Mass of transport members (modulus) → cost of transport;
- Mass of welds, bolts and moduluses → labor cost.

<table>
<thead>
<tr>
<th>MODULUS</th>
<th>SYMBOL OF ELEMENT</th>
<th>NAME OF ELEMENT</th>
<th>DIMENSIONS [mm]</th>
<th>UNIT MASS [kg/m²], [kg/m³], [kg/1000 pieces]</th>
<th>MASS OF ELEMENT [kg]</th>
<th>NUMBER OF ELEMENTS</th>
<th>MASS OF ELEMENTS [kg]</th>
<th>UNIT MASS [kg]</th>
<th>NUMBER OF UNITS [kg]</th>
<th>TOTAL MASS [kg]</th>
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<tbody>
<tr>
<td>Pa</td>
<td>1</td>
<td>HEA 650</td>
<td>8 097</td>
<td>190.00, 1538.43</td>
<td>1</td>
<td>1538.43</td>
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<td></td>
<td></td>
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<tr>
<td></td>
<td>3</td>
<td>pl 9</td>
<td>320x480</td>
<td>64.00, 9.83</td>
<td>2</td>
<td>19.66</td>
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<tr>
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<td>4</td>
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<td>91.20</td>
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<tr>
<td></td>
<td>6</td>
<td>pl 8</td>
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<td>10.54</td>
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<tr>
<td></td>
<td>7</td>
<td>pl 10</td>
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<td>60.00, 6.59</td>
<td>4</td>
<td>26.34</td>
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<tr>
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<td>-</td>
<td>10</td>
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<td>12</td>
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<td>pl 10</td>
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<tr>
<td>Sum</td>
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<td>18 361</td>
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<td></td>
<td></td>
<td></td>
<td>2% for welds 368</td>
<td></td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

| Bolts   |                  |                |                 |                                              |                     | 96 pieces 10     |
|         | M16 cl 4.8       | 50 mm          | 107 kg / 1000 pcs|                                              |                     | 120 pieces 13    |
|         | M16 cl 8.8       | 50 mm          | 107 kg / 1000 pcs|                                              |                     | 6 pieces 6       |
|         | M20 cl 4.8       | 420 mm         | 1,06 kg / 1 pcs  |                                              |                     | 144 pieces 50    |
|         | M24 cl 8.8       | 70 mm          | 347 kg / 1000 pcs|                                              |                     | TOTAL 18 828     |

Photo: Author
Complex of the most important information of information on system safety assurance at the design and assembly stage (values of the safety factors, accuracy of supervision, quality levels of the welds and imperfections: CC, RC, DSL, IL, SC, PC, EXC, IC), bolted joints (category, klass and grade), corrosion protection and fire protection.
Trial erection in assembly room before transport to construction site: check geometry.

Errors or mistakes are repaired after this step.
Transport:
- by road
- by rail
- by ship
- by helicopter
- on foot
We can transport even enormous huge structures, but it is very, very expensive (closing road for normal traffic, organisation bypass, monitoring of transport). Because of this, better way is transport not very big members of structure.
There are three types of limits according to loading gauge:

- max width of member;
- max length of member;
- max mass of member;

Max width of member depends on class of road or railroad:

Max length for rail and road is defined by few law rules.

Max mass depends, first of all, on capacity of truck or rail platform.
Transport by rail is more popular than transport by ship, air, or on foot. But, because only a part of assembly rooms and construction sites are next to railroad, the most popular is transport by cars.

Additionally, there are important many local limits.
According Road Traffic Law, we no need additional permissions, when each total dimensions (structure + vehicle) are not exceeded:

- width $\leq 3,20$ m;
- length $\leq 15,0$ m (one vehicle) or $\leq 23,0$ m (team of two vehicles);
- height $\leq 4,0$ m;
- axle load $\leq 11,5$ t;

Generally, there’s no problem, when transport members is no longer than 12,0 m in road transport and 18,0 in rail transport.
Why this type of joint is used?

→ Des #1 / 7

Road loading gauge 12,00 m

Length of the I-beams produced 12,00 (sometimes 15,00) m

Rail loading gauge 18,00 m

Length of elements: beams - to few dozens m;
columns - to few hundreds m
Construction site: there must be analyse, how many cranes and what kind we need to erected structure. Two most important information about crane are length of arm and lifting capacity.
Assembly anchoring of steel column: stabilization and plumbing on bolts or steel wedges and plates.

Then the gap between structure and concrete base is primed by mortar.
Assembly of structure – first step: mounting the first and the second segment with the temporary supports.
Second step: two adjacent frames (first and second segments) connected by bracings form of a rigid body, to which are being added to next frames.

Last step: hall is enclosed by roofing and housing.
There is possible of change static scheme during execution of structure.

For example: vertical longitudinal bracings work for wind load in execution stage. Final area of wind action (covered structure) and temporary - not covered truss - there are two completely different areas.
The element is often not protected against instability during lifting by crane. Clumsy transport can lead to flexural, torsional and lateral buckling.

\[ R = \frac{g \cdot L}{2 \sin \alpha} \]

\[ M_{\text{max}} = \frac{g \cdot L^2}{8} \]

\[ N_c = \frac{(g \cdot L \cdot \cos \alpha)}{2 \sin \alpha} \]
Examination issues

Negative and positive aspects of bolted and welded joints
Transport members, ways of transport and their limitations for transport
Problems of assembly of steel structures
Pilings - palowanie, grodze
Roofing - poktycie dachu
Housing - obudowa ścian
Wall laminboard / sandwich panel - panel obudowy ściennjej
Self-tapping screw - wkręty samogwintujące
Purlin - płatew
Rigging screw - śruba rzymska
Girt - rygiel obudowy
Castellated beam - belka ażurowa
Closely spaced build-up members - pręt wielogałęziowy
Frame - rama
Girder - dźwigar
Pinned joint - węzeł przegubowy
Rigid joint - węzeł sztywny
Semi-rigid joint - węzeł podatny
Welding - spawanie
Pressure welding - zgrzewanie
Soldering - lutowanie
Bolt - śruba
Rivet - nit
Pin - sworzeń
Anchor bolt - kotew
Plumbing - wypionowanie
Mortar - zaprawa
Thank you for attention