“Dissemination of information for training” workshop

18-20 February 2008

Brussels

EN 1993
Eurocode 3: Design of steel structures

Organised by
European Commission: DG Enterprise and Industry, Joint Research Centre

with the support of
CEN/TC250, CEN Management Centre and Member States
**Tuesday, February 19 – Palais des Académies**

**EN 1993 - Eurocode 3: Design of steel structures**

*Prigogine room*

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<tr>
<th>Time</th>
<th>Session Title</th>
<th>Presenter</th>
<th>Institution/Institute</th>
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<tr>
<td>9:00-9:30</td>
<td>Introduction by chairman</td>
<td>F. Bijlaard</td>
<td><em>Delft University of Technology</em></td>
</tr>
<tr>
<td>9:30-10:30</td>
<td>Innovative rules in Eurocode 3</td>
<td>G. Sedlacek</td>
<td><em>RWTH Aachen</em></td>
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<tr>
<td>10:30-11:00</td>
<td>Coffee</td>
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<td></td>
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<tr>
<td>11:00-11:30</td>
<td>e-learning by Access-Steel, How to use Access Steel</td>
<td>G. Owens</td>
<td><em>The Steel Construction Institute</em></td>
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<td>11:30-12:45</td>
<td>Conceptual design and determination of actions effects for single storey buildings</td>
<td>M. Oppe</td>
<td><em>RWTH Aachen</em></td>
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<td>12:45-14:00</td>
<td>Lunch</td>
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<tr>
<td>14:00-15:30</td>
<td>Structural detailing and connections for single storey buildings</td>
<td>P. Le Chaffotec &amp; A. Bureau</td>
<td><em>CTICM</em></td>
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<td>15:30-15:45</td>
<td>Coffee</td>
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<tr>
<td>15:45-17:15</td>
<td>Conceptual design and design examples for multi-storey buildings</td>
<td>C. Müller</td>
<td><em>RWTH Aachen</em></td>
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<td>17:15-17:45</td>
<td>Cost-effective fire performance</td>
<td>L. Cajot</td>
<td><em>ArcelorMittal Esch</em></td>
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<td>17:45-18:00</td>
<td>Conclusions</td>
<td>F. Bijlaard</td>
<td><em>Delft University of Technology</em></td>
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All workshop material will be available at [http://eurocodes.jrc.ec.europa.eu](http://eurocodes.jrc.ec.europa.eu)
EUROCODE 3: DESIGN OF STEEL STRUCTURES

F. Bijlaard
TU Delft
Eurocode 3: Design of Steel Structures “ready for practice”

Contents of Presentation

- History and Context of Eurocode 3
- Structure of Eurocode 3
- Safety Level
- Introduction of Eurocode 3 in the Design Practice
- Conclusions

History and Context of Eurocode 3
Design of Steel Structures

- Design in one country followed by erection in another country
- Standard building rules for whole Euro-market
- Easier to work in other countries
- More efficient transfer of research results in rules
- Harmonized core material for local handbooks, design aids and educational material

History and Context of Eurocode 3
Design of Steel Structures

“CHALLENGE FOR EUROCODES”

- Ensure structurally safe and serviceable structures
- Provide rules which are sufficiently detailed to avoid disputes
- Facilitate international competition on an even playing field
- Permit innovation in accordance with essential principles
RELATION WITH OTHER EN’s

EN 1990  Basis of Design
EN 1991  Actions
EN 1993  Steel Structures
EN 1997 Geotech.
EN 1998 Earthquake
EN 1990  Execution

Structure of Eurocode 3
General Parts

• EN 1993-1-1:  General rules and rules for buildings
  Rules for strength and stability
  Rules specific for Buildings

Structure of Eurocode 3
General Parts

• EN 1993-1-2:  Structural fire design
  Stages of a natural fire - and the standard fire test curve
  ISO834 standard fire curve
  Ignition - Smouldering
  Pre-Flashover
  Heating
  Post-Flashover
  1000-1200°C
  Natural fire curve
  Time
  Temperature
  Flashover

Structure of Eurocode 3
General Parts

• prEN 1993-1-3:  Supplementary rules for cold formed members and sheeting

Structure of Eurocode 3
General Parts

• prEN 1993-1-4:  Supplementary rules for stainless steels
• prEN 1993-1-5:  Plated structural elements (in-plane loaded)

Structure of Eurocode 3
General Parts

• prEN 1993-1-6:  Strength and stability of shells
• prEN 1993-1-7:  Plated structural elements (transversely loaded)
• EN 1993-1-8:  Design of joints
Structure of Eurocode 3

General Parts
- EN 1993-1-9: Fatigue
- EN 1993-1-10: Material toughness and through-thickness properties
- prEN 1993-1-11: Design of structures with tension elements
- prEN 1993-1-12: Additional rules for the extension of EN 1993 up to steel grades S700

Application Parts
- prEN 1993-2: Steel bridges
- prEN 1993-3-1: Towers and Masts
- prEN 1993-3-2: Chimneys
- prEN 1993-4-1: Silos
- prEN 1993-4-2: Tanks
- prEN 1993-4-3: Pipelines
- prEN 1993-5: Piling
- prEN 1993-6: Crane supporting structures
Safety Level

- In applying the rules in Eurocode 3 a structural safety is reached of not less than the reliability index $\beta = 3.8$
- Member states are entitled to choose their own safety level for structures

Introduction of Eurocode 3 in the Design Practice

- Criticism: Eurocode 3 is very advanced but it is complex to use
- Not "simple rules sell steel" but "Simple TOOLS sell Steel"

Conclusions

- The process of harmonization of design standards of the member countries of CEN did take a period of about three decades. Compared to the "life time" of an existing code in a country of about 15 years, for the Eurocodes this period is not so bad.
- Eurocode 3 "Design of Steel Structures" comprises a fairly complete set of design codes for uniquely designed structures and for a wide range of structural steel products.
Conclusions

• The introduction of the Eurocodes in the design practice needs great care. Design examples, guide lines, design tools (special software) should be developed in the various countries. Explanations of differences and the justification for these changes should be supplied to support the acceptance of the Eurocodes.

• To support these local activities in the various member states, background documents need to be drafted on which local design tools and examples need to be based.

THANK YOU FOR YOUR ATTENTION
INNOVATIVE RULES IN EUROCODE 3

G. Sedlacek
RWTH Aachen
Innovative rules in Eurocode 3

Gerhard Sedlacek
Christian Müller
RWTH Aachen
Reliability basis

- **Safety index** 
  \( \beta = \text{safety index} \) 
  (reference period: 50 years)
- **Weighting factors** 
  \( \alpha_i = \text{weighting factors} \) 
  (required due to mutual influence of \( S_d \) and \( R_d \))

\[ E = \text{safety index} \]
\[ D_i = \text{weighting factors} \]

Standard system for steel structures

- **EN 1090 – Part 1“Delivery Conditions for prefabricated steel components”**
- **EN 1090 – Part 2“Execution of steel structures”**
- **EN 1090 – Part 3“Design rules for steel structures”**
- **Eurocode 1: EN 1991 – “Actions on structures”**

Definition of characteristic values of actions and action effects

<table>
<thead>
<tr>
<th>Action</th>
<th>( Q_s )</th>
<th>Definition</th>
<th>( \gamma ) = ( Q_s / Q_k )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Permanent</td>
<td>( Q_s )</td>
<td>Mean value ( T_{\text{return}} = 50 \text{ years} ) 1.35</td>
<td></td>
</tr>
<tr>
<td>Climatic Traffic</td>
<td>( s_k, w_k, \Delta T )</td>
<td>( T_{\text{return}} = 1000 \text{ years} ) 1.35</td>
<td></td>
</tr>
</tbody>
</table>

Combination \( E(Q_s + Q_d) \)

- **Climatic Traffic**
  \( E(Q_s - s_k w_k, \Delta T) \)
  \( T_{\text{return}} = 50 \text{ years} \)
  \( T_{\text{return}} = 1000 \text{ years} \)

Snow load in Munich-Riem

- **Snow Load on the Ground**
  Location Munich-Riem
  Annual Extrema on Gumbel paper

\[ s = 1.01 \text{ kN/m}^2 \]
Wind Load in Munich-Riem

Peak velocity pressure \( q_b \) (2 sec)
Location Munich-Riem
Annual extrema (h =10 m) on Gumbel paper

\[
q_{b0} = 0.99 \text{ kN/m}^2
\]

Air Temperature in Munich-Riem

Change of air temperature related to \( T_{ref} = 10 \text{ °C} \)
Location Munich-Riem
Annual Extrema on Gumbel paper

\[
\Delta T_{air, \text{min}} = -39.3 \text{ K}
\]
\[
\Delta T_{air, \text{max}} = +27.2 \text{ K}
\]

Allianz-Arena Munich

Evaluated climatic actions

<table>
<thead>
<tr>
<th>Action</th>
<th>Characteristic value</th>
<th>Design value</th>
<th>( T_0 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>snow</td>
<td>1.01 kN/m²</td>
<td>1.77 kN/m²</td>
<td>1.75</td>
</tr>
<tr>
<td>wind action ( q_{pb} )</td>
<td>0.99 kN/m²</td>
<td>1.48 kN/m²</td>
<td>1.50</td>
</tr>
<tr>
<td>( \Delta T_{\text{max}} )</td>
<td>27.2 K</td>
<td>33.1 K</td>
<td>1.22</td>
</tr>
<tr>
<td>( \Delta T_{\text{min}} )</td>
<td>-39.3 K</td>
<td>-51.7 K</td>
<td>1.32</td>
</tr>
</tbody>
</table>

Combination rule of climatic actions

\[
E_{W+S} = a_s \cdot s + a_w \cdot q_p \Rightarrow E_{W+S,k}
\]

- influence factor for wind
- influence factor for snow

Characteristic values of effects of combined actions
**EUROCODES**

**Background and Applications**

**Combination factor \( \psi_0 \)**

\[
E_{w_{i,0}} = \psi_{0,w_i} \cdot E_{w_i} \Rightarrow \psi_{0,w_i}
\]

\[
E_{w_{i,k}} = \psi_{0,w_i} \cdot E_{w_i} \Rightarrow \psi_{0,w_i}
\]

- Combination factor \( \psi_0 \) for an effect with a return period of 50 years.

**Allianz-Arena Munich**

**Standard system for steel structures**

- EN 1090 – Part 1 “Delivery Conditions for prefabricated steel components”
- EN 1090 – Part 2 “Execution of steel structures (Module 1)”
- EN 1090 – Part 3 “Execution of steel structures (Module 2)”
- EN 1090 – Part 4 “Execution of steel structures (Module 3)”
- Eurocode 1: EN 1991 – “Actions on structures”

**Historical development of production processes for rolled steel products**

**Procedure to obtain reliable values \( R_k \)**

1. Failure modes
   - Brittle failure
   - Ductile failure

   **Failure modes**
   - Mode 1: excessive deformation by yielding (e.g., tension bar)
     \( R_y \cdot \frac{R_{1,k}}{R_{1,y}} \)
   - Mode 2: fracture after yielding (e.g., bolt)
     \( R_b \cdot \frac{R_{2,k}}{R_{2,b}} \)

2. Test evaluation
   \( R_{	ext{exp}} = -0.3 \exp(1.2 \times 0.5) \cdot \sqrt{2} = -3.38 \)

3. Recommended values
   - \( \gamma_{0.9} = 1.00 \)
   - \( \gamma_{0.9} = 1.10 \)
   - \( \gamma_{0.9} = 1.25 \)

4. Characteristic value
   \( R_{k} = \gamma_{0.9} \cdot R_{	ext{exp}} \)
Charpy-V-temperature transition curves for S460ML and S690QL with S355J2 for comparison

Fracture mechanism (microscopic)

Spaltbruch

Ti Ta

Fracture mechanism (macroscopic)

Fv

Fv

Fv

Fv

elastic-plastic

Gleitbruch

Shear

Cleavage

1 2 3 4

Max fracture

K, CTOD, Jc

CTOD, Ju

CTOD, Jmax

CTOD, JRR

CTOD, Jii

Toughness [J]

Brittle fracture

Ductile fracture

Toughness-temperature-curve and related load-deformation curves for tension elements using various parameters for toughness properties

Material toughness

J, CTOD, K

Design situation for choice of material in EN 1993-1-10

Choice of material

Safety assessment based on fracture mechanics

Assumption for \( a_0 \)

\[ a_0 = a_0 \cdot f \left( \frac{\Delta a}{4} \right) \]

fatigue loading

initial crack

design crack

\[ K_{appl,d} \leq K_{mat,d} \]

Material property \( T_{Ed} \)

Applied temperature \( T_{Ed} = T_{room} + \Delta T_{c} \)

Modified Sanz-Correlation

Wallin-Toughness-curve

Safety assessment
Safety assessment based on temperature

Assessment scheme

Action side

- Lowest ambient temperature: calculation with T = -20°C
- Radiation

- Influence of strain rate

Resistance

- Additional safety element

<table>
<thead>
<tr>
<th>Grade</th>
<th>T °C</th>
<th>J</th>
<th>Charpy energy</th>
</tr>
</thead>
<tbody>
<tr>
<td>S275</td>
<td>-40</td>
<td>30</td>
<td>190</td>
</tr>
<tr>
<td>S235</td>
<td>-20</td>
<td>40</td>
<td>165</td>
</tr>
<tr>
<td>S690</td>
<td>-50</td>
<td>27</td>
<td>200</td>
</tr>
<tr>
<td>S420</td>
<td>-20</td>
<td>30</td>
<td>140</td>
</tr>
<tr>
<td>S355</td>
<td>-10</td>
<td>20</td>
<td>115</td>
</tr>
</tbody>
</table>

Table of permissible plate thicknesses

<table>
<thead>
<tr>
<th>Grade</th>
<th>Thickness (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>S275</td>
<td></td>
</tr>
<tr>
<td>S235</td>
<td></td>
</tr>
<tr>
<td>S690</td>
<td></td>
</tr>
<tr>
<td>S420</td>
<td></td>
</tr>
<tr>
<td>S355</td>
<td></td>
</tr>
</tbody>
</table>

Background and Applications

Example - Safety Assessment for a well known standard steel S355 N or M

Lowest fatigue class

<table>
<thead>
<tr>
<th>a₀</th>
<th>f₀</th>
<th>LC</th>
</tr>
</thead>
<tbody>
<tr>
<td>2,19mm</td>
<td>335N/mm²</td>
<td>&gt;100mm</td>
</tr>
</tbody>
</table>

Geometrical Parameter:

<table>
<thead>
<tr>
<th>T/s</th>
<th>K*</th>
</tr>
</thead>
<tbody>
<tr>
<td>0,15</td>
<td>15,94 mm</td>
</tr>
<tr>
<td>0,07</td>
<td>39,85 mm</td>
</tr>
</tbody>
</table>

Choice of material to EN 1993-1-10

Olympic stadium Berlin
Comparison of LTB-curves

**Columns**
- EN 1993-1-1

**Lateral torsional buckling (LTB)**
- EN 1993-1-1

**Optimised joint**

**Structural system**
- Distribution of internal forces and moments

**Common design rules for column, lateral torsional, plate and shell buckling**

**Mechanical background of column- and lateral torsional buckling**

**Strategies for optimization**
- Structural system
- Distribution of internal forces and moments
- Optimised joint

**Design Tools**
- Graphics and illustrations

**Test evaluation for buckling curves and γM-values**

- Column buckling
- Lateral torsional buckling
- Plate buckling

**Comparison of LTB-curves**
- Graphs showing LTB-curves for different conditions.
"New" lateral torsional buckling curves

Experiments

Results of test evaluations

Application of global slenderness concept for a bridge supporting frame

General method

Singly symmetrical cross-section in compression

Stress limits

Effective widths
General method bending

Small compression strains

Large compression strains

Justification of general method

Safety evaluation for all tests on plated structures examined

Input data

- \( \nu_r = 0.08 \) (geometry und yield strength)
- \( \nu_y = 0.07 \) (yield strength)

Results

- Standardnormal distribution
- log-normal distribution

\[ \begin{array}{c|c}
\text{Quantile of Standardnormal} & \text{Quantile of log-Normal} \\
-3 & -0.2 \\
-2 & 0 \\
-1 & 0.2 \\
0 & 0.4 \\
1 & 0.6 \\
2 & 0.8 \\
3 & 1 \\
\end{array} \]

\[ \begin{array}{c|c}
\text{re/rt} & \ln \text{re/rt} \\
0.9 & -0.2 \\
1.1 & 0 \\
1.3 & 0.2 \\
1.5 & 0.4 \\
1.7 & 0.6 \\
1.9 & 0.8 \\
2.1 & 1 \\
2.3 & 1.2 \\
\end{array} \]

\[ \begin{array}{c|c}
b &= 1.195 \\
s_G &= 0.106 \\
b &= 1.221 \\
s_G &= 0.130 \\
v_G &= 0.0888 \text{ (model)} \\
v_R &= 0.1196 \text{ (total)} \\
v_G &= 0.1065 \text{ (model)} \\
v_R &= 0.1332 \text{ (total)} \\
J_M &= 1.263 \\
k &= 0.890 \\
J^*_M &= 1.123 \\
J_M &= 1.204 \\
k &= 0.890 \\
J^*_M &= 1.072 \\
\end{array} \]

ECCS – New tasks – Responsibilities and activities

<table>
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<tr>
<th>Responsibilities</th>
<th>Maintenance</th>
<th>Harmonisation</th>
<th>Promotion</th>
<th>Further development</th>
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<tr>
<td>Leading org.</td>
<td>CEN / TC 250 JRC</td>
<td>Commission / JRC</td>
<td>CEN / TC 250 JRC</td>
<td>CEN / TC 250 JRC</td>
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<tr>
<td>Support from</td>
<td></td>
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<table>
<thead>
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<th>Information</th>
<th>Realisation</th>
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<td>Member States</td>
<td>Nat. Auth. / NSBs</td>
<td>CEN / TC 250</td>
</tr>
<tr>
<td></td>
<td>Member States</td>
<td>Commission / JRC</td>
</tr>
<tr>
<td></td>
<td>Nat. Auth. / NSBs</td>
<td>CEN / TC 250</td>
</tr>
</tbody>
</table>

Details of new tasks

CEN / TC 250 – Evolution Paper

1. Envolvement in reaction to problems of use of ECs
   - Background informations to National and CEN help desks

2. Envolvement in mechanism for convergence of NDPs
   - Background informations to JRC information platform

3. Envolvement in promotion
   - Technical guidance, design aids, seminars, workshops

4. Envolvement in further developments:
   - starter drafts + background documents for
     - extension of EN-Eurocodes to the assessment and refurbishment of existing buildings and engineering structures
     - new Eurocodes for new materials as glass and FRP
     - reduction of alternative methods by developing a unique European solution
     - unified testing procedures
     - rules for zinc coating
     - new materials for composite actions
     - pedestrian bridges

Hop dip galvanized structures

Modern glass structures

Tribunal de Grande Instance (TGI) de Bordeaux
E-LEARNING BY ACCESS-STEEL
HOW TO USE ACCESS STEEL

G. Owens
The Steel Construction Institute
E Learning by Access Steel: How to use Access Steel

Graham Owens, SCI

Contents

Introduction to Access Steel
Overview of the engineering design process
How Access Steel helps the engineer
How to use Access Steel
A Coda on e-learning

www.access-steel.com

240 detailed technical resources on steel design and construction
Quality assured
Printable
User friendly IT system
Fast, structured search
“Google” type search query
Index of contents
…and it is all free!

Types of information in Access steel

Case studies – examples of best European practice
Scheme development – turning the initial concept into an outline design
Non-contradictory, complementary information (NCCI)
  • Initial sizing
  • Completing the Eurocodes
Flow charts
Worked examples
  • Static worked examples
  • Active worked examples – simple software

Scope of Access Steel

Single storey
Multi-storey
Residential
Fire safety
Translations of Access Steel

Interface: common – with text files in four languages
Home page
Search functionality

Technical resources – in four languages
Metadata: description and key words
Full content
350,000 words

Additional languages
- Greek
- Czech
- ?

Industry investment in harmonisation

Our sponsors

Transfer of best value solutions
Safety and risk management

Steel is the only sector to invest in an integrated approach to the Eurocodes.

Access Steel Team

The Access Steel project team
France, Germany, Ireland, Luxembourg, Spain, Sweden and UK
Contributors from Czech Republic and Romania

Access Steel maintenance

Access Steel maintenance and user support
Internet service
Tracking of user queries
Maintenance, upgrades and extensions

Feedback and usage to date

Usage since launch in June 2006
104,000 distinct hosts
70% corporate users
Target 250,000 users
75,000 page requests in November 2007
166 countries worldwide (79%)

"The information on Access Steel is nothing short of spectacular"  
NUCONSteel Commercial Corp., USA
Design process: Engineering inputs

**Conceptual design:** With the architect, developing overall concepts and structural forms

**Scheme development:** Developing structural schemes to the extent that defines general geometry – grids and approximate element sizes - and, potentially, costs

**Detailed design:** finalising all sizes and geometry and verifying the adequacy of the overall structure, its stability, and the strength and stability of all elements and connections – to a specific code.

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Technical resources

<table>
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<tr>
<th>Conceptual Design</th>
<th>Scheme Development</th>
<th>Detailed Design</th>
</tr>
</thead>
<tbody>
<tr>
<td>Multi-storey buildings</td>
<td>Single-storey buildings</td>
<td>Residentia l buildings</td>
</tr>
<tr>
<td>Flow Charts</td>
<td>NCCI</td>
<td>Worked Examples</td>
</tr>
<tr>
<td>8</td>
<td>5</td>
<td>9</td>
</tr>
<tr>
<td>17</td>
<td>9</td>
<td>12</td>
</tr>
<tr>
<td>17</td>
<td>14</td>
<td>5</td>
</tr>
<tr>
<td>30</td>
<td>17</td>
<td>0</td>
</tr>
<tr>
<td>18</td>
<td>11</td>
<td>7</td>
</tr>
</tbody>
</table>

Totals: 240

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Case Studies (35)

**Example: Le Sequana**
Demonstrate European best practice
Inspire clients
Inspire architects and engineers
Useful source of:
- Ideas
- What has been done before
- Concepts
- Details
**Design process**

Conceptual design  
Scheme development  
Type of frame  
Floor layout  
Services strategy  
Choice of beam type and initial size  
Choice of column type and initial size  
Floor construction  
Fire strategy  
Detailed design

**Choice of frame type**

Braced frame  
Simple joints (simple construction)  
Un-braced frame

**Initial sizing**

Beams, Columns

<table>
<thead>
<tr>
<th>Beam spacing B (m)</th>
<th>Beam span L (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2,00</td>
<td>2,50</td>
</tr>
<tr>
<td>3,00</td>
<td>3,50</td>
</tr>
<tr>
<td>4,00</td>
<td>4,50</td>
</tr>
<tr>
<td>5,00</td>
<td></td>
</tr>
</tbody>
</table>

**Choice of sections and steel**

Classification  
Sub-grade for fracture toughness

**Scheme development (58)**

Example: Intermediate floors in residential construction  
Initial design issues  
Structural engineering  
Non-structural topics: check lists  
What might the building look like  
Layouts  
Initial sizing

**Design process**

Conceptual design  
Scheme development  
Detailed design
### Design process
- Conceptual design
- Scheme development
- Detailed design (to the Eurocodes)
  - Flow charts
  - NCCI
  - Worked examples both static and dynamic

### Flow Charts (48)
- Example: Fin plate connection
  - Where to start
  - What to do
  - When you have completed the design activity
  - ‘Maps’ to linked resources

### NCCI: Initial sizing (7)
- Example: Column sizes in multi-storey buildings
  - Guidance on element and connection sizes for initial selection
  - Easy, graphical approaches

### NCCI: Completing the Eurocodes (43)
- Example: Buckling lengths of columns: rigorous approach
  - Eurocodes are missing:
    - Essential guidance necessary for design
    - ‘Text book’ material

### Static worked examples (52)
- Example: End plate beam-to-column-flange simple connection
  - Realistic
  - Complete
  - Rigorous
  - Excellent introduction to design to the Eurocodes:
    - Practising engineers
    - Undergraduates

### Interactive worked examples (11)
- Example: Simple column design
  - 11 Examples
  - Need to download the parent software, TEDDS LITE
  - Carries out design to the users’ parameters and prepares calculation sheets
Key messages

**CONTENT**
- Authoritative
- Practical
- Collaborative
- Fills gaps in Eurocodes
- Harmonised

**SYSTEM**
- Inclusive
- Interactive
- User friendly

Fast and easy route to maximising opportunities from the Eurocodes

Access Steel in summary

A very rich set of resources
A major step towards harmonised best practice in Europe
Wide potential beyond Europe
Use it!
Its free!

www.access-steel.com

A Coda on e-learning 1 role of A-S

Material prepared for use by practising engineers - in design practice
Very high pedagogical content
Will automatically be used for 'informal' e-learning
Can readily be adapted for formal e-learning with:
  - Enhanced explanation, perhaps using existing electronic resources, e.g. SteelCAL
  - Formal assessment

A Coda on e-learning 2

Traditional course market is declining
Employers want their engineers to be able to access their training:
- When they need it – for an immediate business need
- Where they want it – at their workplace or at home
- How they want it – at their own pace
Employers will therefore increasingly want their staff to use e-learning
The big difficulty is to replace the interaction with lecturers and fellow students of a traditional course, by:
- E-meetings
- E-tutorials
- Etc

A Coda on e-learning 3

Leonardo programme is sponsoring a pilot project on e-learning for steel design and construction
It will deliver:
- 12 modules
- Guidance on best practice for preparation of e-learning content
A simple questionnaire is available to guide the direction of this project
Input is needed, especially from practising engineers
CONCEPTUAL DESIGN AND DETERMINATION OF ACTIONS EFFECTS FOR SINGLE STOREY BUILDINGS

M. Oppe
RWTH Aachen
Conceptual Design and Determination of Action Effects for Single-Storey Buildings

Dipl.-Ing. Matthias Oppe
RWTH Aachen

Client Guide

The client guide presents the benefits that steel construction can provide to the owners and occupiers of single storey buildings. It offers guidance to clients on how to obtain best value from steel construction.

1. Introduction
2. The European market for single story steel buildings
3. Advantages of steel for single storey buildings
4. Achieving value from the whole: Form of contract and choice of suppliers
5. Overall design issues
6. Conclusions

Introduction

Single storey buildings contribute substantially to the built environment of Europe. They accommodate manufacturing, warehousing, transport, sports, retail and leisure activities.

Steel construction can offer the occupants, owners and developers for these wide ranging activities exceptional value, as evidenced by the overwhelming market shares that it achieves in some European countries.

The purpose of this document is to:

- Demonstrate the benefit that steel construction can bring to its customers
- Highlight the success of steel single storey construction in major national markets
- Illustrate the wide range of steel solutions that are available.
- Give some guidance on how to obtain best value from the market place.

Market size and distribution

The European market for steel for single storey industrial buildings comprises approximately 100 million square metres of covered space per annum, with a value of about 6 billion euros.

Factors influencing choice of material

- Presence of large developers who repeatedly procure single storey buildings
- Development of supply chain teams of main frame manufacturers, purlin and side rail system suppliers, cladding manufacturers and equipment (e.g. doors) suppliers who work efficiently together in long term relationships.
- Wide spread use of forms of contract that suit this form of construction (e.g. Design and Build in the UK).
- Strong industry infrastructure that support the supply chain, for example by ensuring that design, construction and contractual guidance is readily available and that the regulatory framework is benign for steel.

Advantages

- Speed of construction
- Flexibility in use
- Maintenance
- Sustainability
- Value for money
- Examples

Kingswood Lakeside Business park, Cannock
In a single storey building, the contributions to the overall value of the superstructure are typically:
• Primary frames 35%
• Secondary structure, purlins and side rails 15%
• Cladding 50%

All three components are clearly important individually. As discussed in more detail below, there are also very significant structural and performance interactions between these three components. All components are supplied by specialists.

Whatever form of contract is adopted, it is therefore essential that all significant suppliers have an opportunity to contribute to the development of the design and construction specification, if client value is to be maximised.

For single storey buildings, steel offers:
• Cost efficiency in construction
• Low maintenance throughout a building’s life
• Long spans that can accommodate changes in building occupancy and activity, thus extending a building’s economic life.
• Highly sustainable contributions to Europe’s Built Environment.
• Single storey steel buildings are one of the most efficient sectors in the construction industry, with optimised approaches to the primary frames, secondary structure and cladding from specialist suppliers.
• Single storey steel buildings should be provided in a way that ensures that all the specialist suppliers can make maximum contributions to overall client value.
• Clients should interact with both the design and supply teams to ensure best value for their projects.

Access Steel highlights the benefits of steel as the primary construction material through detailed short case studies of successful buildings
• New Air Cargo Hub for DHL at Nottingham East Midlands Airport, UK
• ELUZ Building in Croissy-Beaubourg, France
• Airforge building, Pamiers, France
Overview of structural systems

This document describes the range of structural systems that are commonly used for long span single storey buildings. The descriptions include the main structural frames, secondary systems such as a bracing and the purlins and rails to support the cladding.

1. Overview of applications for single storey buildings
2. Basics for design
3. Typical structural frame solutions
4. Connections
5. Acknowledgement

Scheme Development

Concise information on proposal development guides the architect and engineer through all the decisions that have to be made to develop a best practice design.

- Overview of structural system and form and function of mainframes
- Conceptual design (roofs, walls etc.)
- Form and function of purlins and side rails
- Conceptual design of portal frames from fabricated sections
- Conceptual design of truss and column solutions
- Eaves details / Apex (ridge) details
- Valley details for multiple bay roofs
- Overview of fire
- Movement joints / Expansion joints
- Corrosion

Overview of applications

- wide range of buildings, from small homes to the largest covered spaces, such as exhibition halls and stadia.
- Large buildings will use multi-span structures and may, on occasion, cover 100 000 m².
- origin of building form in industrial building and this description is still often applied but it is misleading
- uses are many and varied with considerable usage by the general public.
- Typical end uses
  - retail
  - distribution centres,
  - call centres,
  - leisure facilities
  - indoor sports facilities.
- greater focus on the envelope in terms of aesthetics, insulation, airtightness etc.
- title of industrial buildings has therefore been replaced by the broader term, single storey buildings.

While there has been considerable change in the appearance the basic structural forms have changed little other than to evolve in the details needed to support more varied cladding forms as described in later sections.
Each design activity is described separately by a flow chart:

- Plastic analysis of a portal frame
- Global analysis and overall cross-section checks
- Global analysis (elastic) of class 2,3 or 4 sections
- Verifying out of plane stability
- Elastic design, uniform sections (rafter or column)
- Design of eaves / apex connections
- Design of fixed / pinned base connections
- Design model for welded joints in trusses using structural hollow sections
- Design of compression chord splices
- Purlin / side rail design

Flow Charts – Plastic Analysis

Determine member design forces for sway frames

The flowchart illustrates the process of plastic analysis for portal frames. The output of the analysis is the design forces and moments in members and connections.
This flow chart presents the design procedure for uniform sections (rafter or column) in portal frames.

- **Flow Chart – Element elastic design**
  - This flow chart outlines the verification procedure for welded, uniplanar unreinforced joints in trusses using structural hollow section alone or in combination with open sections.
  - **NOTE:** May conservatively be taken equal to 1,0.
**Non-contradictory, complementary information (NCCI) is presented that addresses all the information that the Eurocodes do not cover that is essential for design**

- Analytical models for trusses
- Design of asymmetric members under M&N
- Foundation stiffness for global analysis
- Practical analytical models for portal frames
- Design model for eaves / apex connections
- Design model for fixed / pinned base connections
- Deflection limits for single storey buildings
- Simple methods for second order effects
- Classification tables for rolled profiles
- General method for out of plane buckling
- Benefits of cladding
- Effective lengths of columns

---

**Deflection limits for single storey buildings**

- Chart showing deflection limits for different structures and conditions.
- Table listing deflection limits for various materials and conditions.

---

**Deflection limits for single storey buildings**

- Calculation of axial joint resistance:
  \[ N_i,Ed < N_i,Rd \]
- Determination of weld details and throat thickness:
  \[ N_i,Rd \]
  \[ D_{op},i,Rd \]

---

**Flow Chart – Design model for welded joints**

- Overview
- Client Guide
- Case Studies
- Scheme Development
- Flow Charts
- NCCI
- Examples

---

**Deflection limits for single storey buildings**

- Chart showing deflection limits for different structures and conditions.
- Table listing deflection limits for various materials and conditions.
3. Vertical deflections for portal frames

Figure 3.1: Definitions of vertical deflection at apex of portal frame

Recommended limiting values for vertical deflection are given in Table 3.1.

4. Vertical deflections for horizontal roof members

4.1 Serviceability limit states

Guidance for the deflection limits are given in Table 4.1, for a selection of countries. Deflections of vertical deflection in Annex A to EN 1990 is shown in Figure 4.1.

\[
\text{w}_{\text{p}}: \text{preamer in the unloaded structural member} \\
\text{w}_{\text{i}}: \text{initial part of the deflection under permanent loads of the relevant combination of actions} \\
\text{w}_{\text{p}}: \text{long term part of the deflection under permanent loads, not to be considered for single storey steel buildings,} \\
\text{w}_{\text{d}}: \text{additional part of the deflection due to the variable actions of the relevant combination of actions} \\
\text{w}_{\text{d}} = 
\]

\[
\text{w}_{\text{d}} = \text{w}_{\text{i}} + \text{w}_{\text{p}} + \text{w}_{\text{d}} \\
\text{w}_{\text{d}}: \text{remained total deflection taking into account the preamer}
\]

4.2 Ultimate limit state: Ponding

Where the roof slope is less than 5%, additional calculations should be made to check that collapse cannot occur due to the weight of water:

- either collected in pools which may be formed due to the deflection of structural members or existing materials, or retained by means.

These additional checks should be based on the combinations at the Ultimate Limit States. Proportioning of analyses may reduce the likelihood of rainwater collecting in pools, provided that rainwater outlets are appropriately located.

---

### 11 documents

**Examples**

- Determination of loads on building envelope
- Plastic design of single bay portal frame – class 2 & 3 rolled sections
- Elastic design of a portal frame – class 4 sections
- Truss and post single bay, low pitch roof
- Portal frame eaves connection – end plate and haunch
- Portal frame pinned base connection
- Truss/post end connection
- Bracing/wind frame connections
- Rolled section purlin
- Design of gable wind posts
STRUCTURAL DETAILING AND CONNECTIONS FOR SINGLE STOREY BUILDINGS

P. Le Chaffotec & A. Bureau
CTICM
Eurocode tools for structural detailing and connections of Single Storey Buildings

Alain Bureau
Patrick Le Chafotoc

Introduction

- Detailed design with Access Steel
- Design of members
- Design of connections
- Different types of available documents
- Other design tools to apply the Eurocodes

Typical single storey building

The current single storey buildings have generally a structural Class II according to EN 1993-1-3. Steel sheeting (roof and/or walls) generally contributes to the strength and stability of individual structural elements.

EUROPEAN STANDARD EN 1993-1-3 - October 2006
Eurocode 3 - Design of steel structures - Part 1-3: General rules
Supplementary rules for cold-formed members and sheeting

2. Basis of design
3. For the design of structures made of cold-formed members and sheeting a distinction should be made between "structural classes" associated with failure consequences according to EN 1990 - Annex B defined as follows:
Structural Class I: Construction where cold-formed members and sheeting are not designed to contribute to the overall strength and stability of the structure.
Structural Class II: Construction where cold-formed members and sheeting are designed to contribute to the strength and stability of individual structural elements.
Structural Class III: Construction where cold-formed sheeting is used as an element that only transfers loads to the elements.
N.B. 1. The requirements for execution of sheeting in EN 1990...
DESIGN OF MEMBERS with steel

Complementary Information (NCCI)
- Buckling lengths of columns
- Elastic critical moment for LTB
- Elastic critical moment of cantilevers
- Critical axial force for torsional buckling modes
- Stability of mono-symmetrical uniform members
- Torsion
- Sizing guidance for columns
- ...

Elastic critical moment for LTB

LTBeam software:
Calculation of the elastic critical moment

Available on www.cticm.com

Different types of available documents
- Extracts from the standards
- Complementary information to Eurocodes (NCCI)
- Code commentaries
- Flowcharts
- Design data
- Worked examples
- “Active” worked examples

No National Annex is considered.
Design data: Classification of cross-sections

- Data: Section classification tables for European hot rolled beam profiles (IPE and HE profiles)

Flowcharts ...for designers

- Design of columns
- Beam under uniform loading
- Design of a wind transverse girder
- Buckling verification of non-uniform members
- Design of cold formed members
- ...

Worked examples

- Buckling resistance of a column
- Simply supported beam, laterally restrained
- Simply supported beam, unrestrained
- Design of a purlin (hot rolled profile)
- Design of cold formed members
- Elastic analysis of a portal frame
- ...

Elastic analysis of a portal frame

Example: Elastic analysis of a single bay portal frame
A single bay portal frame made of rolled profiles is designed according to EN 1993-1-1. This worked example includes the elastic analysis of the frame using frame theory, and all the calculations of the members and their connections.
Calculation of steel beams according EN 1993 and EN 1994

ArcelorMittal Beams Calculator
- Composite and non composite beams
- ULS and SLS calculations
- LTB verification based on $M_{cr}$ calculated by the $LTBeam$ engine
- Detailed calculated sheet
- Available on the web site

www.arcelormittal.com/sections

DESIGN OF CONNECTIONS

List of contents of EN 1993-1-8
1 - Introduction
2 - Basis of design
3 - Connections made with **bolts**, rivets or pins
4 - **Welded** connections
5 - Analysis, classification and modelling
6 - Structural joints connecting H or I sections
7 - Hollow section joints

All types of connections are covered by application or interpretation of EN 1993-1-8.

The general principle to determine the resistance and stiffness of any connection is to consider the connection as a series of components. The resistance of the connection is obtained from the failure modes of each component.

But a liable calculation is not sufficient to ensure the good behaviour of a connection; a careful execution is also necessary !!! See EN 1090-2.
Connections of the main structure of a typical single storey building

In general cases:

- Eave connection: RIGID CONNECTION – CONNECTION BY BOLTED RAFTER END PLATE – CHAPTER 6 OF EN 1993-1-4 – NCCI (+ ASCAP)
- Column base connection: EITHER PINNED OR RIGID CONNECTION (RIGID WHERE DEFORMATIONS HAVE TO BE LIMITED: PRESENCE OF A CRANE...) – CHAPTER 6 OF EN 1993-1-4 (6.2.8 – 6.3.4) – FLOW CHART (PINNED)
- Connection of a bracing on a gusset plate: PINNED CONNECTION – CHAPTER 3 OF EN 1993-1-4 – EXAMPLE
- Crane bracket: RIGID CONNECTION – EITHER WELDED CONNECTION (CHAPTER 4 OF EN 1993-1-4) OR CONNECTION BY BOLTED BRACKET END PLATE (CHAPTER 6)
- Mezzanine floor beam connection: PINNED CONNECTION – EITHER BY 2 BOLTED ANGLES, OR BY FIN PLATE (NCCI – FLOW CHART – EXAMPLE), OR BY THIN PARTIAL END PLATE (NCCI – FLOW CHART)
  (+ ASCAP FOR CONNECTIONS BY 2 BOLTED ANGLES)

NCCI (Non Contradictory Complementary Information)

- Design of a portal frame apex connection
- Design of a portal frame eave connection
- Tying resistance of a fin plate connection
- Shear resistance of a fin plate connection
- Initial sizing of fin plate connections
- Initial sizing of fin plate connections
- Shear resistance of a simple end plate connection
- Initial sizing of simple end plate connections

Flow charts

- Design resistance of screwed connections of cold-formed members
- Pinned column base connection in portal frames
- Portal frame apex connection
- Portal frame eaves connection
- Fin plate connection
- Simple end plate connection
**Examples**

- Design resistance of a screwed connection of cold-formed members
- Bolted connection of an angle brace in tension to a gusset plate
- Fin plate beam-to-column-flange connection
- Truss/post end connection

**Other tools than Access Steel also provide resources to calculate the resistance and stiffness of connections according to Eurocode EN 1993-1-8.**

An example of such tools is the tables ASCAP developed by cticm and giving the capacity of standardized connections.

For different types of connections, paper tables are edited in a book that also contains a CD with extended tables and a research engine. In the next months, the software used to produce ASCAP tables will be available on cticm internet site [www.steelbizfrance.com](http://www.steelbizfrance.com).

**CONCLUSION**

- Various tools are now available to apply the Eurocodes
- Access Steel is the most important European web site for the applications of Eurocodes to steel structures
- Access Steel provides different types of information for common single storey buildings (NCCI, Flowcharts, examples...).
CONCEPTUAL DESIGN AND DESIGN EXAMPLES FOR MULTI-STOREY BUILDINGS

C. Müller
RWTH Aachen
Conceptual design and design examples for multi-storey buildings

Dr.-Ing. Christian Müller
Dipl.-Ing. Matthias Oppe
RWTH Aachen

1. Introduction
Commercial buildings, such as offices, shops and mixed residential-commercial buildings, account for 20% of construction output in the EU, representing over 20 million square metres of floor space per year. The commercial sector demands buildings that are rapid to construct, of high quality, flexible and adaptable in application, and energy efficient in use.

Steel and composite construction has achieved over 60% market share in this sector in some countries of Europe where the benefits of long spans, speed of construction, improved quality and reduced environmental impact have been recognised.

A wide range of steel technologies may be used in commercial buildings. Specific technologies are chosen to match client requirements. Many long span steel solutions provide service integration within their depth, which saves on building height. Cellular beams combine an efficient manufacturing process with opportunities for service integration. Integrated beams minimise the floor zone while allowing services uninterrupted access below the floor slab.

2. Maximum Value from Steel Construction
- Speed of Construction
- Flexibility and adaptability
- Service integration
- Reduced disruption to the locality
- Quality
- Safer Construction
- Environmental Benefits

3. Construction Systems and their Ranges of Application
- Composite construction using steel decking
  - Span range 6 to 15 m
  - Structure depth 400 to 800 mm
- Cellular beams in composite construction
  - Span range 9 to 18 m
  - Structure depth 600 to 1000 mm
- Fabricated or rolled beams with large web openings
  - Span range 9 to 20 m
  - Structure depth 600 to 1200 mm
- Integrated beams with deep decking
  - Span range 5 to 9 m
  - Structure depth 300 to 400 mm
- Integrated beams supporting precast concrete slabs
  - Span range 5 to 9 m
  - Structure depth 300 to 400 mm
- Steel beams supporting precast concrete slabs
  - Span range 5 to 10 m
  - Structure depth 500 to 900 mm
4. Specific Technologies for Commercial Buildings

Commercial buildings require a range of specific technologies that have been developed to meet client needs:

- **Service Integration:**
  - Cellular beams with regular openings for services
  - Fabricated beams with variety of shapes of openings

- **Fire Resistance:**
  - Tubular columns exposed for fire resistance

- **Cladding and Infill Walls:**
  - Large variety of cladding systems: traditional brickwork, curtain walling and glazing
  - Light steel infill walls as sub-structure to all types of facades
  - Double skin glazed facades to reduce solar gain

- **Energy Efficiency:**
  - Energy efficient design at GLA building, London
  - Double façade in the Kone Building, Finland

---

**Access Steel highlights the benefits of steel as the primary construction material through detailed short case studies of successful buildings**

- Le Sequana, Paris
- Kista Science Tower, Stockholm
- Place d'lena, Paris
- Office Building, Palestra, London
- Luxembourg Chamber of Commerce's
- ING Headquarters, Amsterdam
- Sheraton Hotel, Bilbao
25,000 m² of exceptional quality office accommodation in the heart of the new commercial centre, Ville de Paris
• Column free spaces of 18 m x 36 m overlooking the Seine
• Full double-glazed ventilated façade with shading with serigraphed glass shields.
• A shallow construction depth of 310 mm was achieved using Slimdek for a structural grid of approximately 7 m. Slimdek consists of asymmetric steel beams (ASB) support a deep composite slab.
• These operating conditions for the water-cooled slab are:
  - Summer-night-time; Summer-day-time and winter.
  - Heating and cooling is provided
  - Diaphragm action of composite slabs and stability through the lift shaft.
  - Erection of the 3500 tonnes of steelwork in only 10 months
  - Pairs of cellular beams were placed either side of the 4 inclined tubular columns. The cellular beams were designed for an eccentric load transfer which carried bending in the columns. The columns used innovative double circular hollow sections filled with cement grout to achieve 120 minutes fire resistance.
  - The inclined columns support the entire weight of the building and provide overall stability.
  - Fully glazed façade, which was directly attached to the composite slab
  - The floor-floor zone is a minimum of 3.65 m and the structure and services zone is only 850 mm. The cellular beams permit passage of 400 mm diameter circular service ducts
  - The 'nose' of the building provides an auditorium and cantilevers 26 m from the adjoining structure.
  - Diaphragm action of composite slabs and stability through the lift shaft.
  - Full double-glazed ventilated facade with shading with serigraphed glass shields.
  - Water-cooled composite slab using stainless steel façade, which acted as framework to the concrete slab of 300 mm depth. No temporary propping was required.
  - Integrated 180 beams with under-deck hollow sections to create a span of 12.5 m, which is 30% larger than is possible with integrated beams. These beams are exposed usually.
  - Fire engineering, using natural fire approach, led to a fully unprotected steel structure.
  - These operating conditions for the water-cooled slab are:
    - 12 storey building of 31.5 to 36 m width and 90 m length with a 9 m projection of the upper 4 floors.
    - Pairs of cellular beams were placed either side of the 4 inclined tubular columns. The cellular beams were designed as continuous over a span of 15 m in order to reduce their depth.
    - The inclined tubular columns support the entire weight of the building and provide overall stability.
    - The inclined tubular columns and shear connections were designed for an eccentric load transfer which carried bending in the columns. The columns used innovative double circular hollow sections filled with cement grout to achieve 120 minutes fire resistance.
    - Erection of the 3500 tonnes of steelwork in only 10 months

Kista Science Tower:
Kista Science Tower: 42000 m² of high quality office space in six buildings, 158 meters tall with 32 storeys. Long span steel trusses create open space overlooking northern Stockholm.

Office Building Palestra, London
12 storey building of 31.5 to 36 m width and 90 m length with a 9 m projection of the upper 4 floors.

ING Headquarters, Amsterdam
9 storey steel structure of 20 000 m² floor area supported on inclined columns.

Le Sequana, Paris
25,000 m² of exceptional quality office accommodation in the heart of the new commercial centre, Ville de Paris
INTRO

Background and Applications

Steelwork was supplied by a consortium of 3 fabricators. Erection of the 1 000 tonnes of steelwork took only 28 weeks.

Slimdek minimised the visual impact of the structure, which was important for the architectural concept.

Minimum ground works were required by concentrating loads at discrete points.

A double skin glass façade was used to control ‘solar gain’ and regulate internal temperatures.

20 000 m² multi-storey luxury hotel in Bilbao: 11 above-ground storeys of 13 000 m² floor area; and 4 below ground floors of 7 000 m² floor area.

211 rooms: one presidential suite, 20 suites and 190 double rooms.

1 100 tonnes of structural steelwork were used in the form of I and H sections, tubes and plates.

Only 7 months for the erection of the steel structure.

1 100 tonnes of structural steelwork were used in the form of I and H sections, tubes and plates.

20 000 m² multi-storey luxury hotel in Bilbao: 11 above-ground storeys of 13 000 m² floor area; and 4 below ground floors of 7 000 m² floor area.

211 rooms: one presidential suite, 20 suites and 190 double rooms.

1 100 tonnes of structural steelwork were used in the form of I and H sections, tubes and plates.

Only 7 months for the erection of the steel structure.

The Sheraton hotel has a high level of building services comprising:

• Full air conditioning system in all rooms and in common areas, and radiant flooring in the atrium.
• Architectural design for optimised energy requirements, such as natural cooling, solar gains or natural ventilation.
• Emergency electric power plant for essential facilities, such as the fire protection, safety and communication systems.
• UPS-supported computer network installations.
• Service systems have been used. These are outside the scope of this information.
• 4 below ground floors of 7 000 m² floor area.

The Sheraton Hotel, Bilbao

SHERATON

Hotel

Bilbao

Building Height

The building height has a strong influence on the:

• Structural system that is adopted.
• Foundation system.
• Fire resistance requirements and means of escape.
• Access (by lifts) and circulation space.
• Cladding system.
• Speed of construction and site productivity.

The structural system is primarily influenced by the means of stabilizing the building. For buildings up to 8 storeys high, vertical bracing is preferred, but for taller buildings, strategically placed concrete or braced steel cores are usually adopted. For ultra-tall buildings, many types of external bracing systems have been used. These are outside the scope of this information.

Sizes of lifts and their speed of movement also become important considerations for tall buildings. Depending on the Regulations for fire safety in the particular country, the use of sprinklers may be required or buildings of more than 8 storeys.

Building Height
Horizontal coordination / Position of cores

Positioning of cores is influenced by:

- Horizontal distribution systems for mechanical services.
- Fire rating requirements, which may lead to shortened evacuation routes, and to reduced compartment sizes.
- The need to distribute the structural stabilizing systems more-or-less symmetrically throughout the building plan.

Horizontal Structural Options

<table>
<thead>
<tr>
<th>Type of Beam</th>
<th>Span Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Composite beams (with composite slabs)</td>
<td>Spans of 6 to 13 m</td>
</tr>
<tr>
<td>Non-composite beams (with precast planks)</td>
<td>Spans of 6 to 9 m</td>
</tr>
<tr>
<td>Partially encased composite beams</td>
<td>Spans of 6 to 12 m</td>
</tr>
<tr>
<td>Cellular or fabricated beams (with composite slabs)</td>
<td>Spans of 8 to 18 m</td>
</tr>
<tr>
<td>Slim floor or integrated beams</td>
<td>Spans of 5 to 9 m</td>
</tr>
</tbody>
</table>

Forms of construction used in floors

1. Composite beam
2. Partially encased beam
3. Integrated beam
4. Slim floor beam

Typical long span primary beams and shorter span secondary beams

Integrated beams or slim floor
**Benefits of Long Span Construction**

Long span beams have gained in popularity in the commercial building sector because they offer the following benefits in design and construction:

- **Internal columns are eliminated, leading to more flexible and efficient use of internal space.**
- **Services can be integrated within the depth of the structure, and so the floor-to-floor depth is not increased.**
- **Fewer components are required (typically 30% fewer beams) leading to reduced construction and installation time.**
- **Fire protection costs can be reduced due to the massivity of the longer span members.**
- **For cellular beams, multiple circular ducts for services are cheaper than rectangular ducts.**
- **Steelwork costs are not increased significantly, despite the longer spans.**
- **Overall building costs are increased by a negligible amount (less than 1%).**

**Approximate Steel Quantities**

<table>
<thead>
<tr>
<th>Form of Building</th>
<th>Beams</th>
<th>Columns</th>
<th>Bracing</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>3 or 4 storey building of rectangular form</td>
<td>25–30</td>
<td>8–10</td>
<td>2–3</td>
<td>35–40</td>
</tr>
<tr>
<td>6–8 storey building of rectangular form</td>
<td>25–30</td>
<td>12–15</td>
<td>3–5</td>
<td>40–50</td>
</tr>
<tr>
<td>8–10 storey building with long spans</td>
<td>35–40</td>
<td>12–15</td>
<td>3–5</td>
<td>50–60</td>
</tr>
<tr>
<td>20 storey building with a concrete core</td>
<td>40–50</td>
<td>10–13</td>
<td>1–2</td>
<td>55–65</td>
</tr>
<tr>
<td>20 storey building with a braced steel core</td>
<td>40–50</td>
<td>20–25</td>
<td>8–10</td>
<td>70–85</td>
</tr>
</tbody>
</table>
Choosing a steel subgrade

Column design

Column design

Column design

Column design – Determination of interaction criteria for both axes
Non-contradictory, complementary information (NCCI) is presented that addresses all the information that the Eurocodes do not cover that is essential for design, e.g.:

- Calculation of $\alpha_{\text{cr}}$
- Vertical and horizontal deflection limits
- Effective lengths of columns
- Torsional Buckling (calculation of $N_{T,T}$ and $M_{T,T}$)
- Design Rules for Web Openings in Beams
- Torsion (Section Properties and stresses)
- Vibrations
- Sizing Guidance
- Horizontal and vertical Bracings
- Design Model for simple Column Splices
- Choice of Method for Frame Analysis
- Simplified Bracing Systems

Calculation of $\alpha_{\text{cr}}$

This NCCI sets out the basis for the calculation of $\alpha_{\text{cr}}$, the parameter that measures the stability of the frame.

Calculation of $\alpha_{\text{cr}}$

As an alternative to formula (5.2), in certain cases other checks may be more convenient or more appropriate. The following three alternatives may be considered:

Alternative (1)
Use formula (5.2) with $F_{\text{cr}}$ determined by the fictitious horizontal loads from the initial sway imperfections in 3.3.27 and with $\alpha_{\text{cr}}$ as the displacements arising from those fictitious horizontal loads i.e. to exclude the effects of any other horizontal loads, such as wind loads.

Alternative (2)
Calculate $\alpha_{\text{cr}}$ by computer by finding the first sway mode from an eigenvalue analysis. When using this type of analysis, it is important to study the form of each buckling mode to see if it is a frame mode or a local column mode. In frames, where sway stability is ensured by discrete bays of bracing (often referred to as “braced frames”), it is common to find that the eigenvalues of the column buckling modes are lower than the eigenvalues of the first sway mode of the frame. Local column modes may also appear in out-of-plane frames at columns. Hinged at ends, or at columns, that are much more slender than the average stiffness of columns in the same story.

Alternative (3)
$F_{\text{cr}}$ may be found from design charts appropriate to the type of building considered.

Figure 3.1 Displacement of a multi-storey frame due to horizontal loads (Deflection parameters for second storey only illustrated)
Effective lengths of columns

This NCCI gives information concerning the calculation of the buckling length for columns, to be used for the buckling verification (slenderness approach). Simple aids (e.g. tables, diagrams) are presented.

1. Basis

The buckling length $L_u$ of a compression member is the length of an otherwise similar member with "fixed ends". Limits are excused against lateral movement but free to rotate in the plane of buckling which has the same elastic critical buckling load.

In the absence of more accurate information, the theoretical buckling length for slender critical buckling may conservatively be adopted.

An equivalent buckling length may be used to relate the critical load of a member subject to non-uniform loading to that of an otherwise similar member subject to uniform loading.

An equivalent buckling length may also be used to relate the critical load of a non-uniform member to that of a uniform member under similar conditions of loading and restraint.

Overview    Client Guide    Case Studies    Scheme Development  Flow Charts  NCCI  Examples
### Effective lengths of columns

For building frames with concrete floor slabs, provided that the frame is of regular layout and the loading is uniform, it is normally sufficiently accurate to assume that the effective stiffness coefficients of the beams are as shown in Table 2.2.

<table>
<thead>
<tr>
<th>Loading condition for the beam</th>
<th>Stiffness coefficient, ( \alpha_{eff} )</th>
<th>( \beta_{eff} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beam directly supporting concrete floor slabs</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>Beam with b/c ratio ≤ 0.5</td>
<td>2.00</td>
<td>0.50</td>
</tr>
<tr>
<td>Beam with b/c ratio &gt; 0.5</td>
<td>4.00</td>
<td>0.25</td>
</tr>
</tbody>
</table>

Where: \( \alpha_{eff} \) is the effective length of the beam, \( \beta_{eff} \) is the effective length factor for the beam.

Where a beam has semi-rigid supports, its effective stiffness coefficient should be reduced accordingly.

### Calculation of \( D_{crit} \)

- Choosing a steel sub-grade
- Simply supported secondary composite beams
- Simply supported primary composite beams
- Simply supported beam with lateral restraint at load
- Pinned column with intermediate restraint
- Sway stability
- Tying and avoidance of disproportionate collapse
- Beam to beam fin plate connection
- Beam to column end plate connection
- Column splice (Non-Bearing / Bearing)
- Column base, axially loaded

### Choosing a steel sub-grade

**Example: Choosing a steel sub-grade**

This worked example on the choice of a steel sub-grade should clarify a comparable but procedure how to do Table 2.1 in EN 1993-1-8 and EN 1993-1-5. The values for the input data and material properties are based on the data presented in Table 2.2. The values for the effective stiffness coefficients are based on the data presented in Table 2.3.

<table>
<thead>
<tr>
<th>Data</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steel grade</td>
<td>S355</td>
</tr>
<tr>
<td>Yield stress</td>
<td>355 N/mm²</td>
</tr>
<tr>
<td>Ultimate strength</td>
<td>490 N/mm²</td>
</tr>
<tr>
<td>Modulus of elasticity</td>
<td>210,000 N/mm²</td>
</tr>
<tr>
<td>Poisson's ratio</td>
<td>0.3</td>
</tr>
<tr>
<td>Density</td>
<td>7850 kg/m³</td>
</tr>
<tr>
<td>Creep modulus</td>
<td>0.65</td>
</tr>
<tr>
<td>Fatigue limit</td>
<td>250 N/mm²</td>
</tr>
<tr>
<td>Creep strain rate</td>
<td>5 x 10^-5</td>
</tr>
</tbody>
</table>

**Steel section:**

- **Profile:** IPE 200
- **Material:** S355
- **Cross-sectional area:** 12.7 cm²
- **Shear area:** 9.3 cm²
- **Effective area:** 12.7 cm²
- **Moment of inertia:** 0.45 cm⁴
- **Section modulus:** 7.5 cm³

**Calculation of effective length:**

\[ L_{eff} = \frac{E \cdot I}{\sigma} \]

where:
- \( E \) = Modulus of elasticity
- \( I \) = Moment of inertia
- \( \sigma \) = Stress

**Effective length factor:**

\[ \beta_{eff} = \frac{L_{eff}}{L} \]

where:
- \( L_{eff} \) = Effective length
- \( L \) = Length of the beam

**Effective length coefficient:**

\[ \alpha_{eff} = \frac{1}{\beta_{eff}} \]

where:
- \( \alpha_{eff} \) = Effective length coefficient

### Background and Applications

EUROCODES provide a comprehensive framework for the design and assessment of structures, ensuring a consistent approach for European engineers. They cover a wide range of building types and materials, from concrete and steel to composite structures. The guidelines are based on the latest research and are regularly updated to reflect advancements in structural engineering.

### Client Guide

1. **Overview**
   - Introduction to EUROCODES
   - Scope and application areas

2. **Case Studies**
   - Real-world examples demonstrating successful implementation of EUROCODES

3. **Scheme Development**
   - Step-by-step guidance on developing new structural schemes

4. **Flow Charts**
   - Visual representation of design and assessment processes

5. **Examples**
   - 13 documents

- Calculation of \( D_{crit} \)
- Choosing a steel sub-grade
- Simply supported secondary composite beams
- Simply supported primary composite beams
- Simply supported beam with lateral restraint at load
- Pinned column with intermediate restraint
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- Beam to beam fin plate connection
- Beam to column end plate connection
- Column splice (Non-Bearing / Bearing)
- Column base, axially loaded
**Conceptual design and design examples for multi-storey buildings**

*Dr.-Ing. Christian Müller  
Dipl.-Ing. Matthias Oppe  
RWTH Aachen*
COST-EFFECTIVE FIRE PERFORMANCE

L. Cajot
ArcelorMittal Esch
Cost-effective fire performance

Cost-effective fire performance
Louis-Guy Cajot
ArcelorMittal
Research & Development
Structural Long Products
Esch/Alzette GD Luxemburg
February, 19th 2008

High potential of steel in multi-storey buildings

Weak knowledge from engineers and architects of the actual performances of the steel in case of fire, still mainly assessed through knowledge from fire tests on single element.

Fire Safety Engineering not yet fully considered

One of the reasons explaining the difference: Fire Safety Approach.

The present low market share in continental Europe is more particularly due to:
- Weak knowledge from engineers and architects of the actual performances of the steel in case of fire, still mainly assessed through knowledge from fire tests on single element.
- Fire Safety Engineering not yet fully considered

Classical approach amongst “structural fire safety engineering” methods - Eurocodes 1, 3 and 4

Prescriptive Performance based
standard firenatural fire
classification
fire safety eng.

Classical approach - Quick use of the Eurocodes
- Unprotected steel structures for fire resistance ≤ 30minutes
- P30 unprotected steel structures (Overdesign [S355,S460] : benefit of the connections)

Classical approach based on ISO-834 heating curve

Steel protection for fire resistance > 30minutes

Additional cost of the protection > 40% of the finished steel cost
The protection must be optimized and applied where it is really needed.
The performance based "structural fire safety engineering" approach according to Eurocodes 1, 3 et 4

### Fire Engineering approach

#### Scientific analysis based on:
- Fire scenario
- Physical parameters influencing the fire development (fire load, ventilation, active fire fighting measures, …)

#### Standard curve

- ISO834 standard fire curve
- Ignition - Smouldering
- Pre-Flashover
- Flashover
- Post-Flashover

- Temperature
- Heating
- Cooling

#### Fire scenario

- Time
- Flashover

#### Fire Engineering approach

- Fire safety concept evaluation based on natural fire.
- Required data for the fire development calculation methods (fire load [MJ/m²], fire spread, rate of heat release [kW/m²]).
- Definition of model scenario for usual buildings (offices, schools, shops, …).
- Take into account of the active fire fighting measures (sprinkler, smoke exhaust system, …).
- Air temperature field calculation method in case of fire.
- Steel temperature calculation method.
- Simulation of the behaviour of the structure submitted to the different fire scenarios and to the static loads.
- Building systems and technical solutions to guarantee that the structure survive the considered scenario.

The implementation of the research results met the following difficulties:

- Existing regulations and standards based on standard fire.
- Habits and a priori in the minds of the professionals of construction.
- Different regulations depending on the countries and even on the regions.
- Low expertise of engineers, architects and authorities in that domain.
- Lack of training in that domain.
- No user friendly calculation tools.

solved by:

- The natural fire was introduced in the Eurocodes, particularly Eurocode 1 - Fire Part.
- The fire engineering has been dealt with in decree and regulations in different European countries.
- User friendly calculation tools were developed (Ozone), and put on the site www.arcelor.com/sections
- Trainings were, and are organized (DIFISEK).
- A network of competent and qualified engineering offices in the field of fire engineering was developed (SECURE with STEEL).
Dissemination of Fire Safety Engineering Knowledge

Treated topics
- Part 1: Thermal & Mechanical Actions
- Part 2: Thermal Response
- Part 3: Mechanical Response of Structures in Fire
- Part 4: Software for Fire Design
- Part 5-1: Worked Examples
- Part 5-2: Illustration of Completed Projects

Available tools for further dissemination
- All Presentations and Syllabus in PDF - WP1 to WP5 (17 languages)
- Database for Fire Design Software (UK)

http://www.arcelormittal.com/sections/DIFISEK/DIFISEK_welcome.html
- ACCESS STEEL
- CHOICE OF FIRE ENGINEERING STRATEGY
- The “structural fire safety engineering” approach
- Eurocodes 1, 3 et 4

Test in Cardington (UK)
- Maximum steel temperature about 1150°C
- Fire calculation by element provides a failure at 680°C
- Why did the structure survive?
Test on single elements

Existing design methods assume isolated members will perform in a similar way in actual buildings.

Real behaviour in a building

- Membrane effect
  - In a building, catenary behaviour of the steel beam acting compositely with the concrete slab.
  - Higher is the deflection, higher is the membrane effect.

Fire resistance of secondary beams calculated as single elements

<table>
<thead>
<tr>
<th>Method</th>
<th>EC4 Fire part</th>
<th>SAFIR Simulation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Critical temp</td>
<td>608 °C</td>
<td></td>
</tr>
<tr>
<td>Fire resistance</td>
<td>16'</td>
<td>20'</td>
</tr>
</tbody>
</table>

Fire Safety Concept: Protected main beams, unprotected secondary beams

The "structural fire safety engineering" approach

Eurocodes 1, 3 et 4

Prescriptive | Performance based

- Standard fire
- Natural fire
- Classification
- Fire safety eng.
- Fire safety eng.
- FRACOF

Unprotected Element
\[ R_{\text{single element}} < 30 \]

Protected Element

Test on the whole floor including connections
\[ R \geq 30 \]
Example of Design Table

<table>
<thead>
<tr>
<th>Span 1</th>
<th>Span 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>9m</td>
<td>7m</td>
</tr>
<tr>
<td>R120</td>
<td></td>
</tr>
</tbody>
</table>

FRACOF - Fire Resistance Assessment of partially Composite Floor

**Objective**

That project will be a milestone in the strategy to develop the fire engineering. It will enable any engineers to use partially unprotected steel structure by using design tables/software approved by the Authorities.

**Deliverables**

There are three main deliverables for this project:

1. **Background Technical Report**
   - To provide in-depth information on the development and verification of the design method.
2. **Design Guide**
   - The design guide will consist of approximately 50 pages and will be based on the existing publication ‘Fire Safe Design: A new approach to multi-storey steel-framed buildings’. The design guide will present the principles of the design process using this method.
3. **Design Software**
   - The design software will be made available free of charge and will be distributed via the Steel Alliance website.

**Dissemination**

Through Steel Alliance + IPO’s in Spain, Germany, Belgium, Italy, Luxembourg and the Netherlands, + DPISEK, + ‘Secure with Steel’

Economic fire design of steel beams in composite floor

**TEST SET-UP**

Within the framework of project FRACOF, a composite floor of about 60 m², supported by four protected boundary beams and two unprotected internal beams, subjected to standard fire exposure for 2 hours.

**LOADING CONDITIONS**

- Self weights of slab, steel beams, etc
- Dead load: 170 kg/m²
- Imposed load: 500 kg/m²

**MESH REINFORCEMENT**

**TEST MONITORING**
AFTER 120 MINUTES…

Cracks in concrete

AFTER 120 MINUTES...

Cracks in concrete

AFTER 120 MINUTES...

Deflected shape

Fire safety engineering is aimed at adopting a rational scientific approach which ensures that fire resistance/protection is provided where it is needed rather than accepting universal provisions which may over or under estimate the level of risk.

Institution of Structural Engineers