EU-Russia cooperation on standardisation for construction

EUROCODES
a tool for building safety and reliability assessment

Actions on bridges

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This presentation benefits from slides created by:

- Dr. Carvalho (Eurocode 8)
- Prof. Frank and Dr. Schuppener (Eurocode 7)
- Dr. Tschumi (Rail traffic loads)
EUROCODES
A tool for building safety and reliability enhancement

Design of Bridges with the Eurocodes

EN 1991
Self-weights +
Traffic loads +
Climatic actions +
Accidental actions +
Actions during execution

Design Eurocodes
EN 1992, EN 1993
EN 1994, EN 1995

EN 1990
Basis of Structural design
Combinations of actions

Product Standards
EN 1337
Bearings...

EN 1997
Design of foundations

EN 1998
Design of structures for earthquake resistance

Execution Standards
EN 13670
Concrete
EN 1090
Steel

Material Standards
EN 201-1
Concrete
EN 10025
Steel
EN 1991-2 « Traffic Loads on Bridges »

Eurocode 1 : Actions on structures – Part 2: Traffic Loads on Bridges
FOREWORD

SECTION 1 GENERAL

SECTION 2 CLASSIFICATION OF ACTIONS

SECTION 3 DESIGN SITUATIONS

SECTION 4 ROAD TRAFFIC ACTIONS AND OTHER ACTIONS SPECIFICALLY FOR ROAD BRIDGES

SECTION 5 ACTIONS ON FOOTWAYS, CYCLE TRACKS AND FOOTBRIDGES

SECTION 6 RAIL TRAFFIC ACTIONS AND OTHER ACTIONS SPECIFICALLY FOR RAILWAY BRIDGES
<table>
<thead>
<tr>
<th>Annex</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>A (I)</td>
<td>Models of special vehicles for road bridges</td>
</tr>
<tr>
<td>B (I)</td>
<td>Fatigue life assessment for road bridges – Assessment method based on recorded traffic</td>
</tr>
<tr>
<td>C (N)</td>
<td>Dynamic factors $1+\phi$ for real trains</td>
</tr>
<tr>
<td>D (N)</td>
<td>Basis for the fatigue assessment of railway structures</td>
</tr>
<tr>
<td>E (I)</td>
<td>Limits of validity of load model HSLM and the selection of the critical universal train from HSLM-A</td>
</tr>
<tr>
<td>F (I)</td>
<td>Criteria to be satisfied if a dynamic analysis is not required</td>
</tr>
<tr>
<td>G (I)</td>
<td>Method for determining the combined response of a structure and track to variable actions</td>
</tr>
<tr>
<td>H (I)</td>
<td>Load models for rail traffic loads in transient situations</td>
</tr>
</tbody>
</table>
TRAFFIC LOADS FOR ROAD BRIDGES

Traffic load models

- Vertical forces: LM1, LM2, LM3, LM4
- Horizontal forces: braking and acceleration, centrifugal, transverse

Groups of loads

- gr1a, gr1b, gr2, gr3, gr4, gr5
  - characteristic, frequent and quasi-permanent values

Combination with actions other than traffic actions
ROAD BRIDGES : LOAD MODELS FOR LIMIT STATES
OTHER THAN FATIGUE LIMIT STATES

Load Model Nr. 1
Concentrated and distributed loads (main model – For general and local verifications)

Load Model Nr. 2
Single axle load (semi-local and local verifications)

Load Model Nr. 3
Set of special vehicles (general and local verifications)

Load Model Nr. 4
Crowd loading : 5 kN/m² (general verifications)
The main load model (LM1)

TS: Tandem system
UDL: Uniformly distributed load
The main load model (LM1)

Example of values for $\alpha$ factors (National Annexes)

1\textsuperscript{st} class : international heavy vehicle traffic

2\textsuperscript{nd} class : « normal » heavy vehicle traffic

<table>
<thead>
<tr>
<th>Classes</th>
<th>$\alpha_{Q1}$</th>
<th>$\alpha_{Qi}$ \quad \text{i} \geq 2</th>
<th>$\alpha_{q1}$</th>
<th>$\alpha_{qi}$ \quad \text{i} \geq 2</th>
<th>$\alpha_{qr}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1\textsuperscript{st} class</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>2\textsuperscript{nd} class</td>
<td>0,9</td>
<td>0,8</td>
<td>0,7</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>
Example of influence surface (transverse bending moment) for a deck slab
Load model Nr. 2 (LM2)

Recommended value: \( \beta_Q = \alpha_{Q1} \) (National Annex)
HORIZONTAL FORCES: BRAKING AND ACCELERATION (Lane Nr. 1)

\[ Q_{lk} = 0.6Q_{Q1}(2Q_{1k}) + 0.1Q_{q1}q_{1k}w_1L \]

\[ 180\alpha_{Q1}kN \leq Q_{lk} \leq 900kN \]

\[ \alpha_{Q1} = \alpha_{q1} = 1 \]

\[ Q_{lk} = 180 + 2.7L \]

For \( 0 \leq L \leq 1.2m \)

\[ Q_{lk} = 360 + 2.7L \]

For \( L > 1.2m \)
Groups of loads

Group of loads gr1a : LM1 + « reduced » value of pedestrian load on footways or cycle tracks (3 kN/m²)

Group of loads gr1b : LM2 (single axle load)

Group of loads gr2 : characteristic values of horizontal forces, frequent values of LM1
Group of loads gr3: loads on footways and cycle tracks

Group of loads gr4: crowd loading

Group of loads gr5: special vehicles (+ special conditions for normal traffic)
FATIGUE LOAD MODELS

Load Model Nr. 1 (FLM1) : Similar to characteristic Load Model Nr. 1
\[ 0.7 \times Q_{ik} - 0.3 \times q_{ik} - 0.3 \times q_{rk} \]

Load Model Nr. 2 (FLM2) : Set of « frequent » lorries

Load Model Nr. 3 (FLM3) : Single vehicle

Load Model Nr. 4 (FLM4) : Set of « equivalent » lorries

Load Model Nr. 5 (FLM5) : Recorded traffic
Fatigue Load Model Nr.3 (FLM3)

A second vehicle may be taken into account:
Recommended axle load value $Q = 36 \text{ kN}$
Minimum distance between vehicles : 40 m
Verification procedure with Load Model FLM 3

Determination of the maximum and minimum stresses resulting from the transit of the model along the bridge

\[ \Delta \sigma_{LM} = \left| \text{Max} \sigma_{LM} - \text{Min} \sigma_{LM} \right| \]

The stress variation is multiplied by a local dynamic amplification factor in the vicinity of expansion joints

\[ \Delta \varphi_{fat} \]

The model is normally centered in every slow lane defined in the project specification.

Design value of the stress variation

\[ \Delta \sigma_{fat} = \lambda \Delta \varphi_{fat} \Delta \sigma_{LM} \]
LOAD MODELS FOR FOOTWAYS AND FOOTBRIDGES (Section 5)

LOAD MODEL Nr.1
Uniformly distributed load $q_{fk}$

LOAD MODEL Nr.2
Concentrated load $Q_{fwk}$
(10 kN recommended)

LOAD MODEL Nr.3
Service vehicle $Q_{serv}$
Recommended characteristic value for:
- footways and cycle tracks on road bridges,
- short or medium span length footbridges:

\[ q_{fk} = 5,0 \text{ kN/m}^2 \]

Recommended expression for long span length footbridges:

\[ q_{fk} = 2,0 + \frac{120}{L + 30} \text{ kN/m}^2 \]

\[ q_{fk} \geq 2,5 \text{ kN/m}^2 \quad q_{fk} \leq 5,0 \text{ kN/m}^2 \]

\( L \) is the loaded length [m]
Groups of loads for footbridges

Group of loads gr1

Group of loads gr2
Rail traffic actions

\( s : \text{gauge} \)
\( u : \text{cant} \)
\( Q_s : \text{nosing force} \)

1. Running surface
2. Longitudinal forces acting along the centreline of the track
The characteristic values are multiplied by a factor $\alpha$ on lines carrying rail traffic which is heavier or lighter than normal rail traffic.

This factor $\alpha$ shall be one of the following: 0.75 - 0.83 - 0.91 - 1.00 - 1.10 - 1.21 - 1.33 – 1.46.

The value 1.33 is normally recommended on lines for freight traffic and international lines (UIC CODE 702, 2003).
LOAD MODELS SW/0 & SW/2 (heavy traffic)

<table>
<thead>
<tr>
<th>Load model</th>
<th>$q_{vk}$ [kN/m]</th>
<th>$a$ [m]</th>
<th>$c$ [m]</th>
</tr>
</thead>
<tbody>
<tr>
<td>SW/0</td>
<td>133</td>
<td>15,0</td>
<td>5,3</td>
</tr>
<tr>
<td>SW/2</td>
<td>150</td>
<td>25,0</td>
<td>7,0</td>
</tr>
</tbody>
</table>
Example of a heavy weight waggon - Waggon DB with 32 axles, selfweight 246 t, cantilevers included, pay load 457 t, mass per axle 22 t, \( l_{\text{tot}} = 63,3 \text{ m} \)
• Dynamic factors for static calculations:
  \( \Phi_2 \) for carefully maintained track
  \( \Phi_3 \) for standard track (means: poor track)

• Dynamic enhancement for real trains
  \[ 1 + \varphi = 1 + \varphi' + (\frac{1}{2}) \varphi'' \]

• Dynamic enhancement for fatigue calculations
  \[ \varphi = 1 + \frac{1}{2}(\varphi' + (\frac{1}{2}) \varphi'') \]

• Dynamic factor \( \Phi_2(\Phi_3) \) for static calculations
  (determinant lengths \( L_\Phi \) due to table 6.2)

• Dynamic enhancement for dynamic studies
  \[ \varphi'_{dy} = \max \left| \frac{y_{dy}}{y_{st}} \right| - 1 \]
Interaction model between the bridge and the track
Example of a real train for fatigue
(Nr. 1 of 12 types of trains defined in the Eurocode)

\[ \sum Q = 6630\text{kN} \quad V = 200\text{km/h} \quad L = 262.10\text{m} \quad q = 25.3\text{kN/m'} \]
Flow chart for determining whether a dynamic analysis is required.
Maximum permissible vertical deflection $\delta$ for railway bridges with 3 or more successive simply supported spans corresponding to a permissible vertical acceleration of $b_v = 1 \text{ m/s}^2$ in a coach for speed $V$ [km/h]
Collapse of railway bridge over the river Birs in Münchenstein, Switzerland, the 14th June 1891, by buckling of the upper flange under an overloaded train, 73 persons were killed, 131 persons more or less injured. => Tetmajers law.
EUROCODE 7
‘Geotechnical design’

Section 1  General

Section 2  Basis of geotechnical design

Section 3  Geotechnical data

Section 4  Supervision of construction, monitoring and maintenance

Section 5  Fill, dewatering, ground improvement and reinforcement
Section 6  Spread foundations
Section 7  Pile foundations
Section 8  Anchorages
Section 9  Retaining structures
Section 10  Hydraulic failure
Section 11  Site stability
Section 12  Embankments
Annex A (N) : Partial and correlation factors for ultimate limit states and recommended values

Annex B (I) Background information on partial factors for Design - Approaches 1, 2 and 3

Annex C (I) Sample procedures to determine limit values of earth pressures on vertical walls

Annex D (I) A sample analytical method for bearing resistance calculation

Annex E (I) A sample semi-empirical method for bearing resistance estimation

Annex F (I) Sample methods for settlement evaluation

Annex G (I) A sample method for deriving presumed bearing resistance for spread foundations on rock

Annex H (I) Limiting values of structural deformation and foundation movement

Annex J (I) Checklist for construction supervision and performance monitoring
EN 1997- Part 2 : Ground investigation and testing

Laboratory and field tests:

* essential requirements for the equipment and tests procedures

* essential requirements for the reporting and the presentation of results

* interpretation of test results and derived values

They are NOT test standards → see TC 341
Section 1 General

Section 2 Planning and reporting of ground investigations

Section 3 Drilling, sampling and gw measurements

Section 4 Field tests in soils and rocks

Section 5 Laboratory tests on soils and rocks

Section 6 Ground investigation report

+ 24 Informative Annexes (!)
Characteristic value of geotechnical parameters

The characteristic value of a geotechnical parameter shall be selected as a cautious estimate of the value affecting the occurrence of the limit state.

If statistical methods are used, the characteristic value should be derived such that the calculated probability of a worse value governing the occurrence of the limit state under consideration is not greater than 5%.
Ultimate limit states for Geotechnical Design

- **EQU**: loss of static equilibrium of the structure
- **STR**: internal failure or excessive deformation of the structure or structural elements
- **GEO**: failure or excessive deformation of the ground
- **UPL**: loss of equilibrium due to uplift by water pressure (buoyancy) or other vertical actions
- **HYD**: hydraulic heave, internal erosion and piping caused by hydraulic gradients

Both short-term and long-term design situations shall be considered.
Examples of situations where uplift might be critical
Example of situations where heave or piping might be critical
EN 1997-1, 2.1 : Geotechnical Categories

Geotechnical Category 1 should only include small and relatively simple structures:

- for which it is possible to ensure that the fundamental requirements will be satisfied on the basis of experience and qualitative geotechnical investigations;
- with negligible risk.

Simplified design procedures may be applied.

Geotechnical Category 2 should include conventional types of structure and foundation with no exceptional risk or difficult soil or loading conditions.

Designs for structures in Geotechnical Category 2 should normally include quantitative geotechnical data and analysis to ensure that the fundamental requirements are satisfied.
Geotechnical Category 3 should include structures or parts of structures, which fall outside the limits of Geotechnical Categories 1 and 2.

Geotechnical Category 3 should normally include alternative provisions and rules to those in this standard.

NOTE Geotechnical Category 3 includes the following examples:
• very large or unusual structures;
• structures involving abnormal risks, or unusual or exceptionally difficult ground or loading conditions;
• structures in highly seismic areas;
• structures in areas of probable site instability or persistent ground movements that require separate investigation or special measures.
Load and Resistance Factor Approach

\[ E_d \leq R_d \]
\[ E_k(\varphi'_k, c'_k) \cdot \gamma_E \leq R_k(\varphi'_k, c'_k) / \gamma_R \]

- **\( E_k \):** characteristic value of the effect of action
- **\( \gamma_E \):** partial factor for the effect of action or the action
- **\( R_k \):** characteristic values of ground resistance
- **\( \gamma_R \):** partial factor for the ground resistance
- **\( \varphi'_k, c'_k \):** characteristic values of the shear parameter
Design values of shear parameter

\[ \tan \varphi'_d = \left( \tan \varphi'_k \right) / \gamma_\varphi \]
\[ c'_d = c'_k / \gamma_c \]

\( \varphi'_k, c'_k \) characteristic value of shear parameter
\( \varphi'_d, c'_d \) design values of the shear parameter
\( \gamma_\varphi \) partial factor for the angle of shearing resistance
\( \gamma_c \) partial factor for the cohesion intercept
Material Factor Approach

\[ E_d(\phi', c') \leq R_d(\phi', c') \]

- **\( E_d \)**: design value of the effects of actions of the ground
- **\( R_d \)**: design value of the ground resistance
- **\( \phi' \)**: design value of the angle of shearing resistance
- **\( c' \)**: design value of the cohesion intercept
Observational method

(1) When prediction of geotechnical behaviour is difficult, it can be appropriate to apply the approach known as "the observational method", in which the design is reviewed during construction.

(2) The following requirements shall be met before construction is started:

- acceptable limits of behaviour shall be established;
- the range of possible behaviour shall be assessed and
- it shall be shown that there is an acceptable probability that the actual behaviour will be within the acceptable limits;
Observational method

• a plan of monitoring shall be devised, which will reveal whether the actual behaviour lies within the acceptable limits. The monitoring shall make this clear at a sufficiently early stage, and with sufficiently short intervals to allow contingency actions to be undertaken successfully;

• the response time of the instruments and the procedures for analysing the results shall be sufficiently rapid in relation to the possible evolution of the system;

• a plan of contingency actions shall be devised, which may be adopted if the monitoring reveals behaviour outside acceptable limits.
Geotechnical Design Report

(1) The assumptions, data, methods of calculation and results of the verification of safety and serviceability shall be recorded in the Geotechnical Design Report.

(2) The level of detail of the Geotechnical Design Reports will vary greatly, depending on the type of design. For simple designs, a single sheet may be sufficient.
EUROCODE 7:
- a tool to help European geotechnical engineers speak the same language
- a necessary tool for the dialogue between geotechnical engineers and structural engineers

EUROCODE 7 helps promoting research
it stimulates questions on present geotechnical practice from ground investigation to design models
Eurocode 8
General rules and seismic actions
• **EN1998-1:** General rules, seismic actions and rules for buildings

• **EN1998-2:** Bridges

• **EN1998-3:** Assessment and retrofitting of buildings

• **EN1998-4:** Silos, tanks and pipelines

• **EN1998-5:** Foundations, retaining structures and geotechnical aspects

• **EN1998-6:** Towers, masts and chimneys

All parts published by CEN (2004-2006)
EUROCODES
A tool for building safety and reliability enhancement

EU-Russia cooperation on standardisation for construction – Moscow, 9-10 October 2008

EN1998-1: General rules, seismic actions and rules for buildings

EN1998-1 to be applied in combination with other Eurocodes
General

• Performance requirements and compliance criteria
• Ground conditions and seismic action
• Design of buildings
• Specific rules for:
  Concrete buildings
  Steel buildings
  Composite Steel-Concrete buildings
  Timber buildings
  Masonry buildings
• Base isolation
Objectives

In the event of earthquakes:

Human lives are protected

Damage is limited

Structures important for civil protection remain operational

Special structures – Nuclear Power Plants, Offshore structures, Large Dams – outside the scope of EN 1998
Fundamental requirements

No-collapse requirement:

Withstand the design seismic action without local or global collapse

Retain structural integrity and residual load bearing capacity after the event

For ordinary structures this requirement should be met for a reference seismic action with 10 % probability of exceedance in 50 years (recommended value) i.e. with 475 years Return Period
Fundamental requirements

Damage limitation requirement:

Withstand a more frequent seismic action without damage

Avoid limitations of use with high costs

For ordinary structures this requirement should be met for a seismic action with 10% probability of exceedance in 10 years (recommended value) i.e. with 95 years Return Period
Reliability differentiation

Target reliability of requirement depending on consequences of failure

Classify the structures into importance classes

Assign a higher or lower return period to the design seismic action

In operational terms multiply the reference seismic action by the importance factor $\gamma_I$
Importance classes for buildings

Table 4.3 Importance classes for buildings

<table>
<thead>
<tr>
<th>Importance class</th>
<th>Buildings</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>Buildings of minor importance for public safety, e.g. agricultural buildings, etc.</td>
</tr>
<tr>
<td>II</td>
<td>Ordinary buildings, not belonging in the other categories.</td>
</tr>
<tr>
<td>III</td>
<td>Buildings whose seismic resistance is of importance in view of the consequences associated with a collapse, e.g. schools, assembly halls, cultural institutions etc.</td>
</tr>
<tr>
<td>IV</td>
<td>Buildings whose integrity during earthquakes is of vital importance for civil protection, e.g. hospitals, fire stations, power plants, etc.</td>
</tr>
</tbody>
</table>

NOTE Importance classes I, II and III or IV correspond roughly to consequences classes CC1, CC2 and CC3, respectively, defined in EN 1990:2002, Annex B.

Importance factors for buildings (recommended values):

\[ \gamma_I = 0.8; 1.0; 1.2 \text{ and } 1.4 \]
Fundamental requirements

Compliance criteria (design verifications):

**Ultimate limit state**
- Resistance and Energy dissipation capacity
- Ductility classes and Behaviour factor values
- Overturning and sliding stability check
- Resistance of foundation elements and soil

**Second order effects**
- Non detrimental effect of non structural elements

Simplified checks for **low seismicity** cases ($a_g < 0.08$ g)
No application of EN 1998 for **very low seismicity** cases ($a_g < 0.04$ g)
Fundamental requirements

Compliance criteria (design verifications):

Damage limitation state

Deformation limits (Maximum interstorey drift due to the “frequent” earthquake):

- 0.5% for brittle non structural elements attached to the structure
- 0.75% for ductile non structural elements attached to the structure
- 1.0% for non structural elements not interfering with the structure

Sufficient stiffness of the structure for the operationality of vital services and equipment

DLS may control the design in many cases
Fundamental requirements

Compliance criteria (design verifications):

**Specific measures**

**Simple and regular forms (plan and elevation)**

**Control the hierarchy of resistances and sequence of failure modes (capacity design)**

**Avoid brittle failures**

**Control the behaviour of critical regions (detailing)**

**Use adequate structural model (soil deformability and non structural elements if appropriate)**

In zones of high seismicity formal Quality Plan for Design, Construction and Use is recommended
Ground conditions

Five ground types:

A - Rock
B - Very dense sand or gravel or very stiff clay
C - Dense sand or gravel or stiff clay
D - Loose to medium cohesionless soil or soft to firm cohesive soil
E - Surface alluvium layer C or D, 5 to 20 m thick, over a much stiffer material

2 special ground types $S_1$ and $S_2$ requiring special studies

Ground conditions defined by shear wave velocities in the top 30 m and also by indicative values for $N_{SPT}$ and $c_u$
Seismic zonation

Competence of National Authorities

Described by $a_{gR}$ (reference peak ground acceleration on type A ground)

Corresponds to the reference return period $T_{NCR}$

Modified by the Importance Factor $\gamma_I$ to become the design ground acceleration (on type A ground) $a_g = a_{gR} \cdot \gamma_I$

Objective for the future updating of EN1998-1: European zonation map with spectral values for different hazard levels (e.g. 100, 500 and 2,500 years)
Basic representation of the seismic action

Elastic response spectrum

Common shape for the ULS and DLS verifications

2 orthogonal independent horizontal components

Vertical spectrum shape different from the horizontal spectrum (common for all ground types)

Possible use of more than one spectral shape (to model different seismo-genetic mechanisms)

Account of topographical effects (EN 1998-5) and spatial variation of motion (EN1998-2) required in some special cases
Normalised elastic response spectrum (standard shape)

Control variables
- $S$, $T_B$, $T_C$, $T_D$ (NDPs)
- $\eta \geq 0.55$ damping correction for $\xi \neq 5\%$

Fixed variables
- Constant acceleration, velocity & displacement spectral branches
- acceleration spectral amplification: 2.5

Different spectral shape for vertical spectrum (spectral amplification: 3.0)
Elastic response spectrum

**Two types of (recommended) spectral shapes**

Depending on the characteristics of the most significant earthquake contributing to the local hazard:

- **Type 1** - High and moderate seismicity regions ($M_s > 5,5$)
- **Type 2** - Low seismicity regions ($M_s \leq 5,5$); near field earthquakes

Optional account of deep geology effects (NDP) for the definition of the seismic action
Recommended elastic response spectra

Type 1 - $M_s > 5.5$

Type 2 - $M_s \leq 5.5$
Alternative representations of the seismic action

**Time history representation** (essentially for NL analysis purposes)

Three simultaneously acting accelerograms

- **Artificial accelerograms**
  Match the elastic response spectrum for 5% damping
  Duration compatible with Magnitude ($T_s \geq 10$ s)
  Minimum number of accelerograms: 3

- **Recorded or simulated accelerograms**
  Scaled to $a_g \cdot S$
  Match the elastic response spectrum for 5% damping
Thank you for your attention

Lady Fedoroff