Introduction to The Design Example and EN 1990 - Basis of Design

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Agenda

- Introduction
- Acknowledgements
- Introduction to the design example
- Overview of EN 1990, Basis of Design

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JRC Scientific and Technical Reports

Bridge Design to Eurocodes
Worked examples

Worked examples presented at the Workshop "Bridge Design to Eurocodes", Vienna, 4-6 October 2010

Support to the implementation, harmonization and further development of the Eurocodes

Y. Bouassida, E. Bouchon, P. Crespo, P. Croce, L. Davaine, S. Denton, M. Feldmann, R. Frank, G. Hanswille, W. Hensen, B. Kolias, N. Malakatas, G. Mancini, M. Ortega, J. Raoul, G. Sedlacek, G. Tsionis

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EN 1991	Eurocode 1: Actions on structures
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EN 1998	Eurocode 8: Design for earthquake resistance
EN 1999	Eurocode 9: Design of aluminium structures

Eurocodes used in Vienna Workshop

EN 1990	Eurocode: Basis of structural design
EN 1991	Eurocode 1: Actions on structures
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Eurocodes considered here

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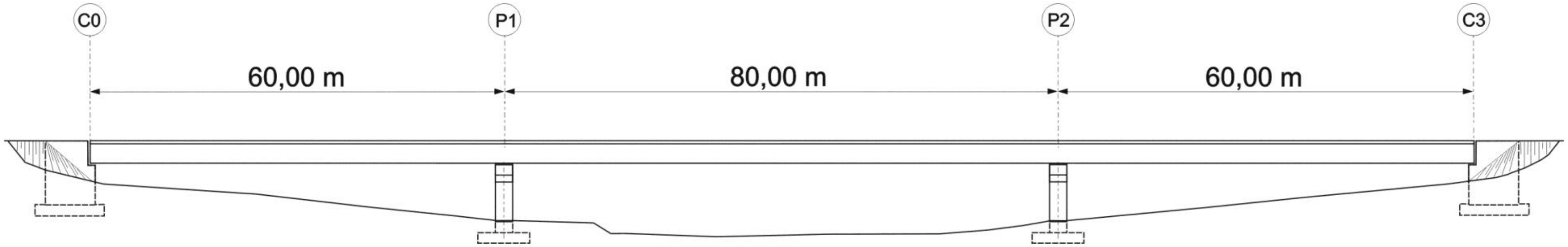
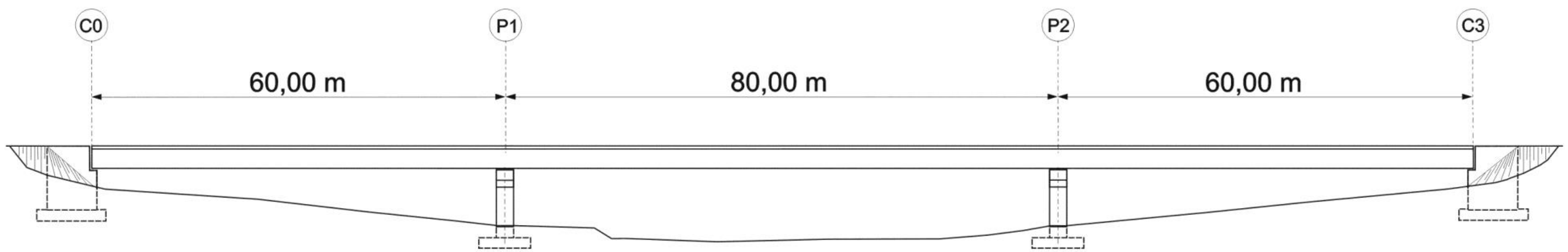
Introduction to design examples



Main example

Introduction to design examples



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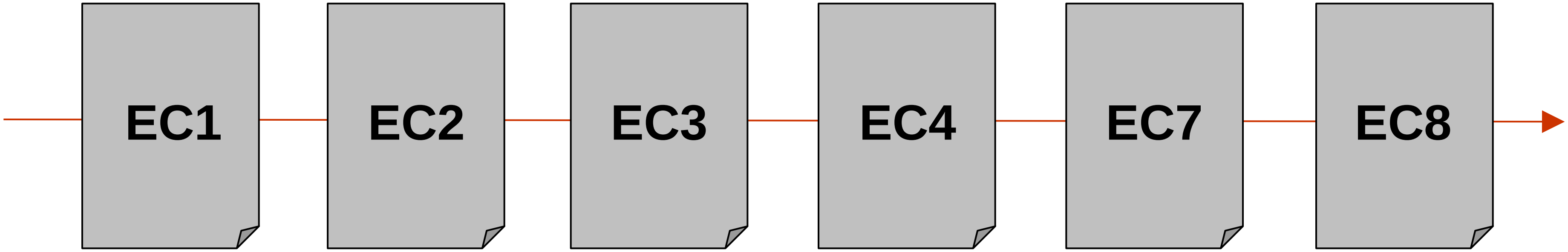

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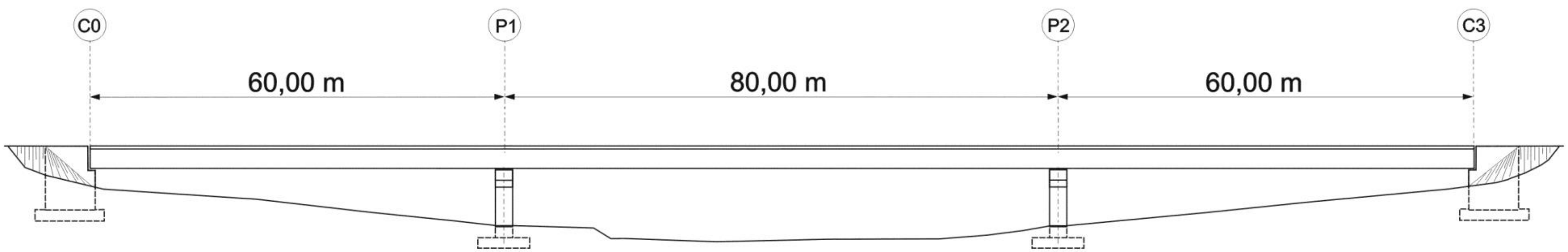

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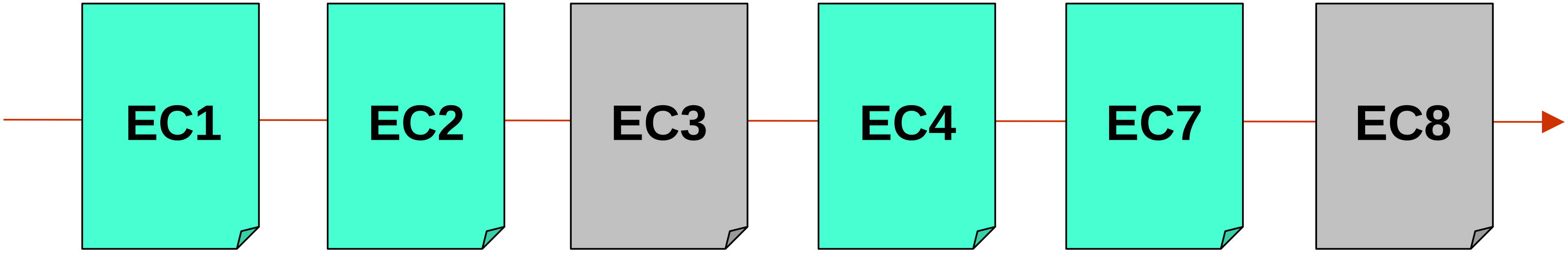

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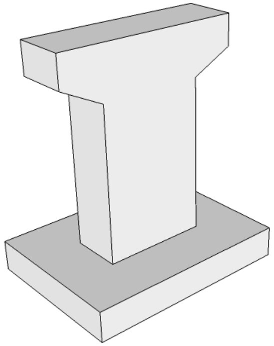
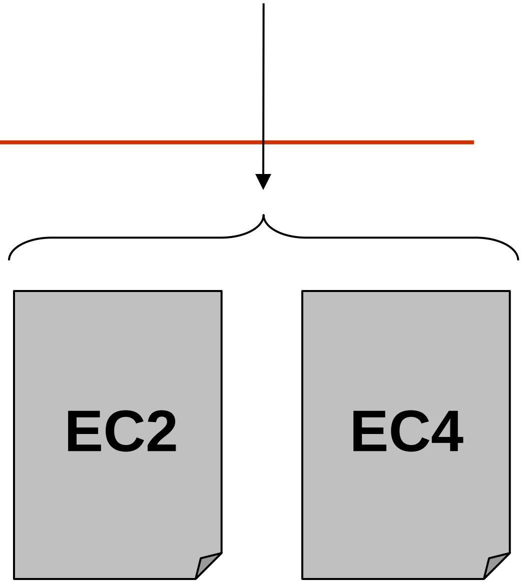


Partial alternative examples



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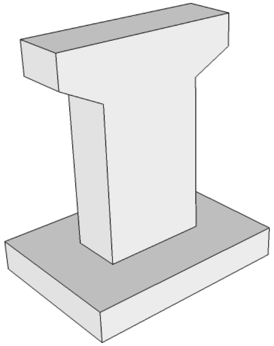
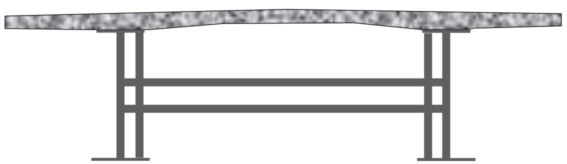


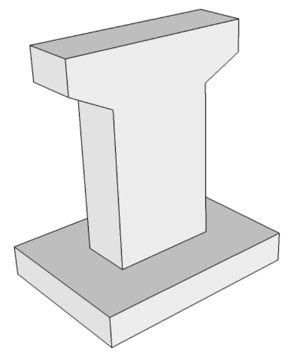
Partial alternative examples

EC1

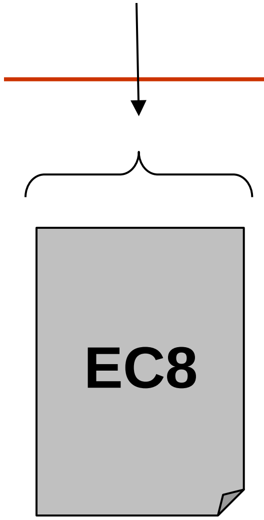
EC2

Introduction to design examples





Partial alternative examples

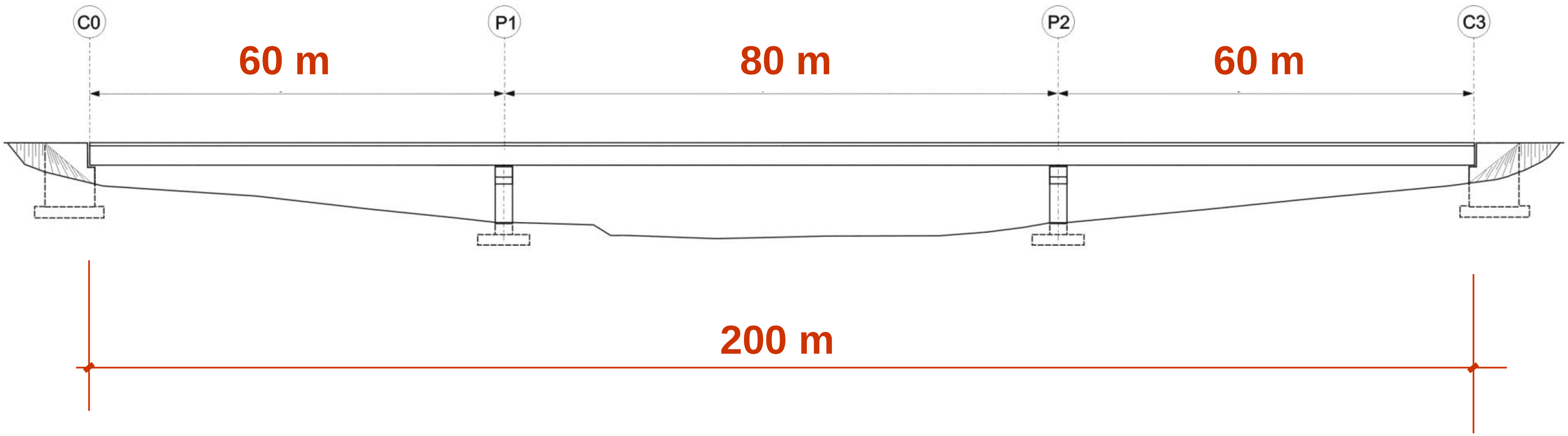


Introduction to the design example

1. Geometry of the deck
2. Geometry of the substructure
3. Design specifications
4. Materials
5. Structural details
6. Construction process

Geometry of the deck

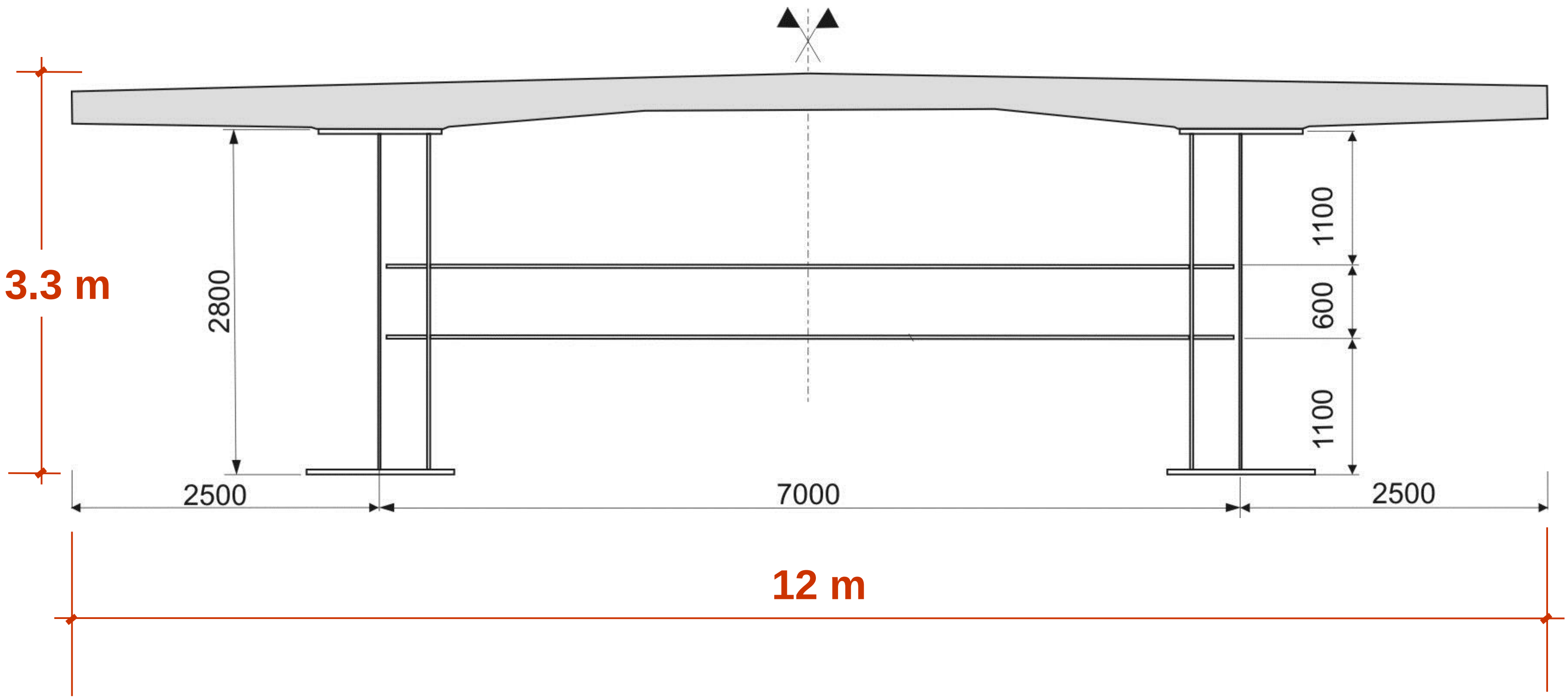
Main example



- Continuous three span
- Composite steel-concrete deck
- Constant depth
- Longitudinal axis: straight and horizontal

Geometry of the deck

Main example



Two girder composite deck

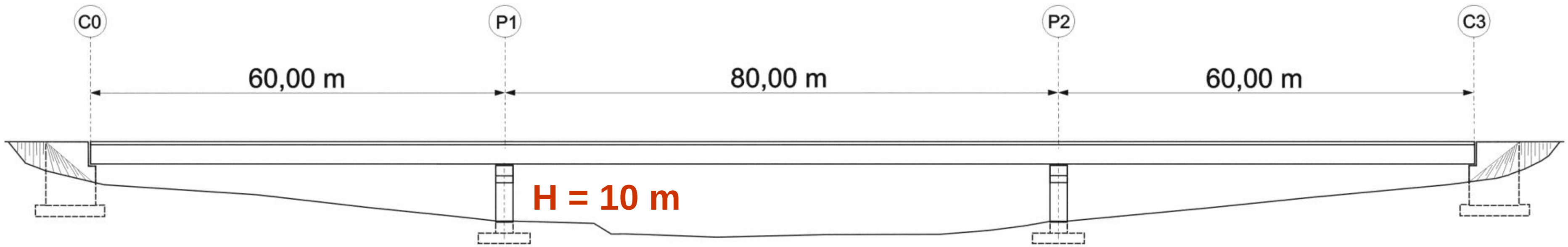
Geometry of the deck

Main example

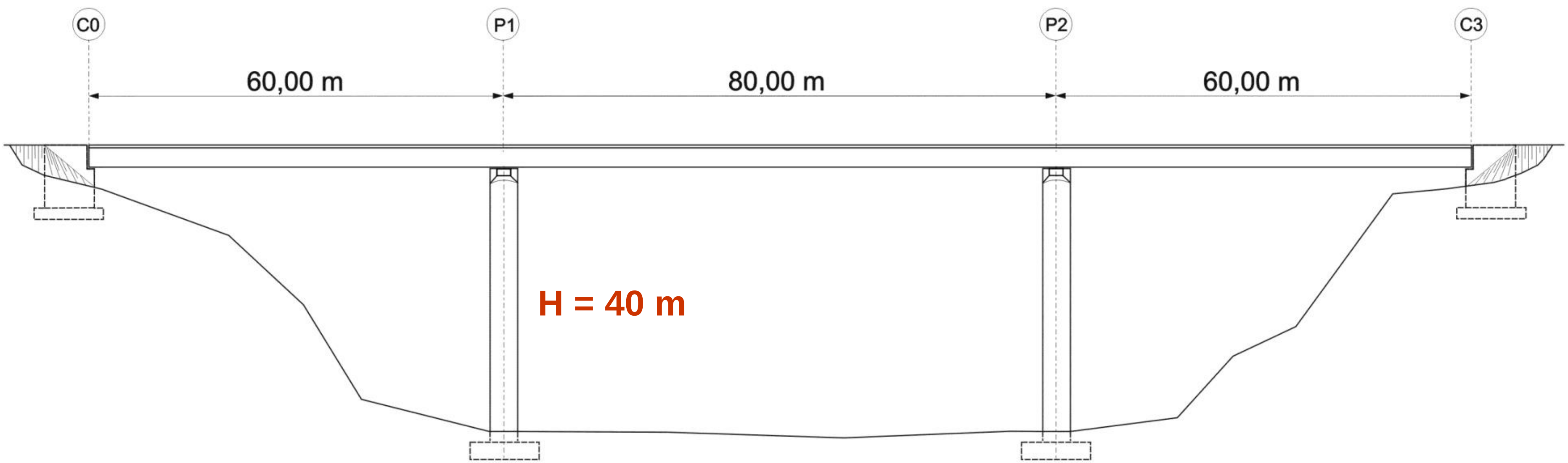
Two girder composite deck

Geometry of the substructure

Piers



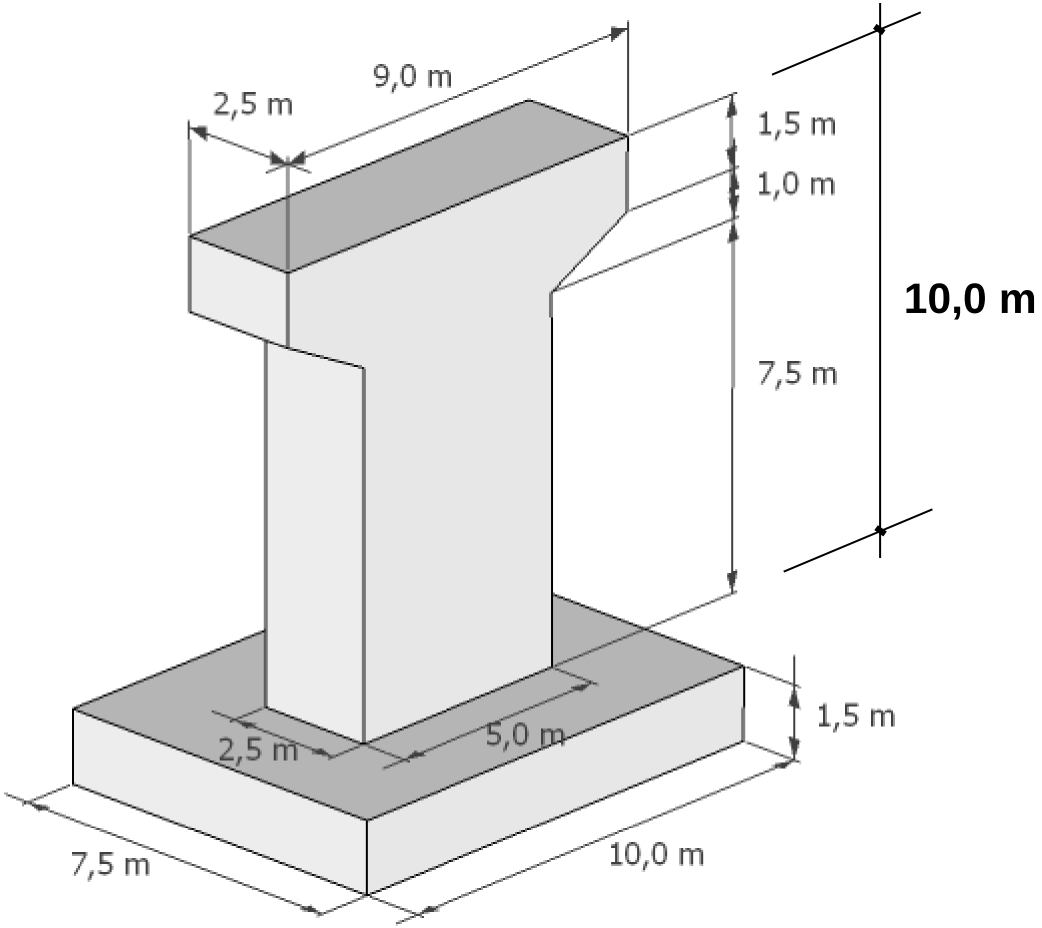
Squat pier case



High pier case

Geometry of the substructure

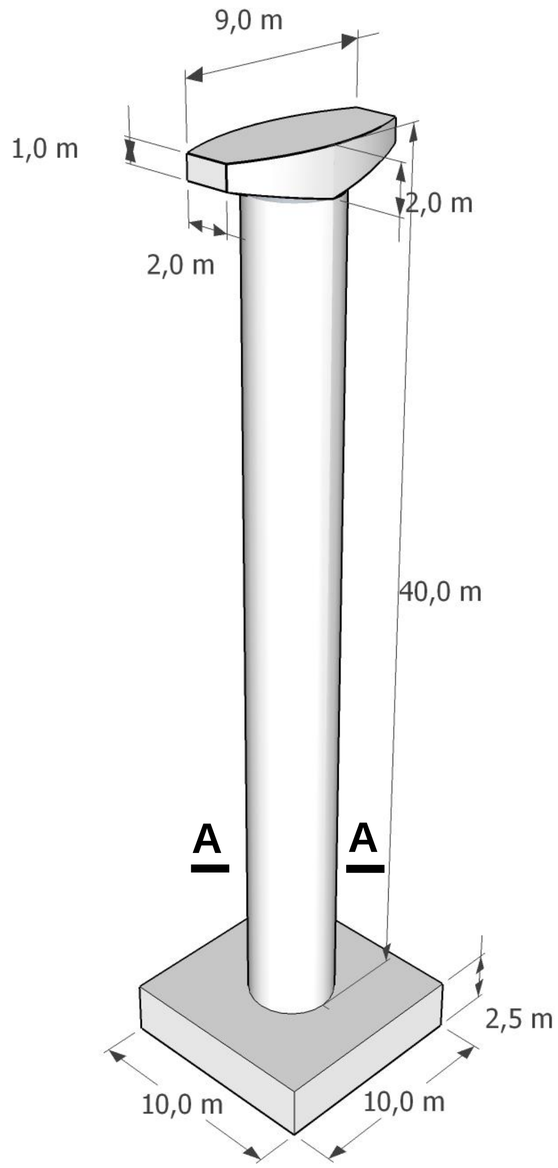
Piers (I)

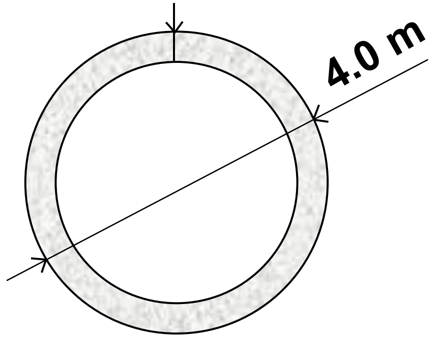


Squat pier case

Geometry of the substructure

Piers (II)



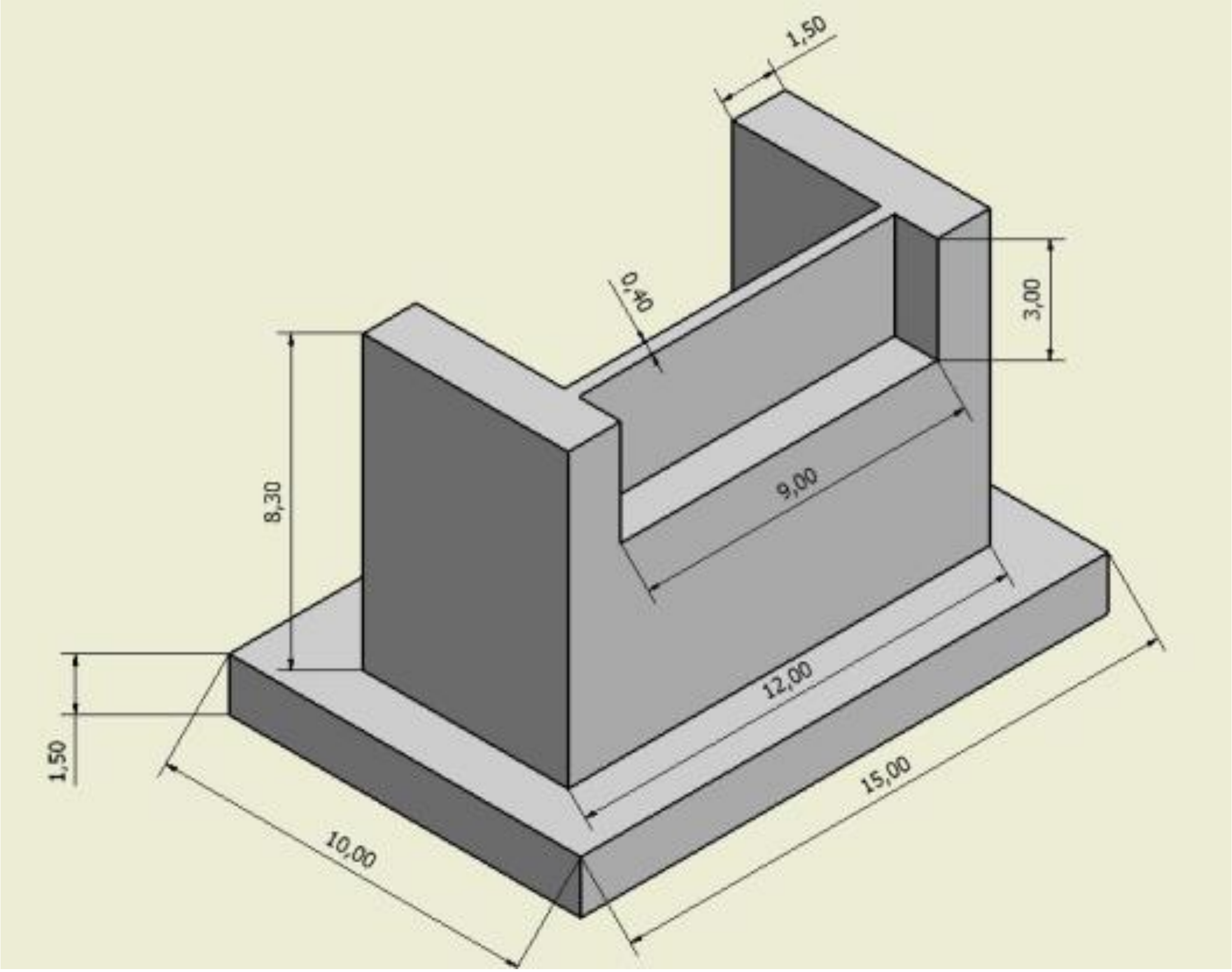


Section A-A

High pier case

Geometry of the substructure

Abutments



Design specifications

- <u>**Design working life**</u>**:** **100 years**

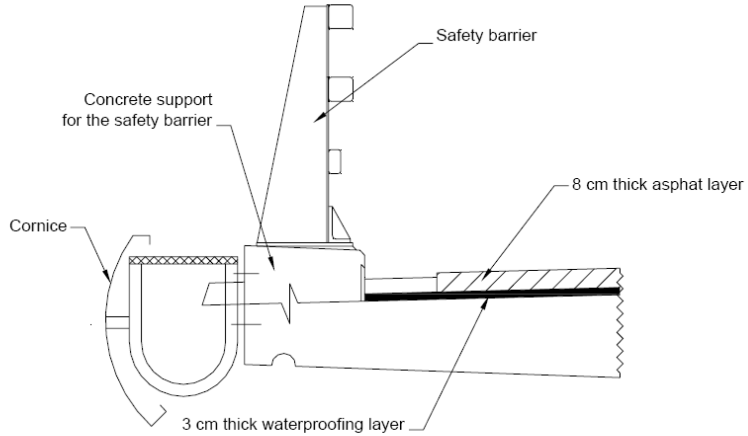
  - ***Assessment of some actions (wind, temperature)***
  - ***Minimum cover requirements for durability***
  - ***Fatigue verifications***

Design specifications

- **Design working life:** **100 years**

- **Non-structural elements**

  - ***Parapets + cornices***
  - ***Waterproofing layer (3cm)***
  - ***Asphalt layer (8cm)***

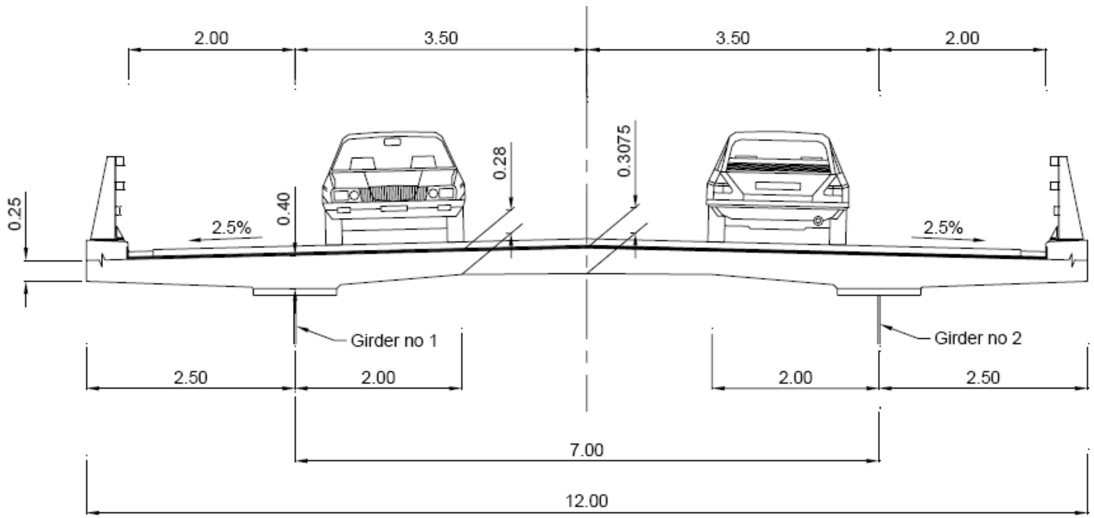


Design specifications

- **Design working life:** **100 years**

- **Non-structural elements**

- **Traffic data**



· *Two traffic lanes (3.5m)*
· *Two hard strips (2.0m)*
· *LM1:* $\alpha_{Qi} = \alpha_{qi} = \alpha_{qr} = 1.0$
· *No abnormal vehicles*

For fatigue verifications:

· *Two slow lanes (same position as actual lanes)*
· *Vehicle centrally placed on the lane*

} For assessment of general action effects

· *Slow lane close to the parapet* → For assessment of transverse reinforcement
· *Medium flow rate of lorries*

Design specifications

- **Shade air temperature**: T_{min} = -20ºC T_{max} = 40ºC

  Selection of steel quality

- **Humidity**: RH = 80%

- **Wind**: Flat valley with little isolated obstacles

  Fundamental value of basic wind velocity $v_{b,0}$ = 26 m/s

  Maximum wind for launching v = 50 km/h = 14 m/s

- **Exposure Class**: XC3 (top face of concrete slab)

  XC4 (bottom face of concrete slab)

  $c_{min,dur}$

  Limiting crack width

Design specifications

- **Soil conditions**: No deep foundation is needed

  Settlement P1: 30 mm

Materials

a) Structural steel

Thickness	Subgrade
$t \leq 30$ mm	S 355 K2
$30 \leq t \leq 80$ mm	S 355 N
$80 \leq t \leq 135$ mm	S 355 NL

b) Concrete C35/45

c) Reinforcing steel Class B high bond bars f_{sk}=500 MPa

d) Shear connectors S235J2G3 f_u=450 MPa

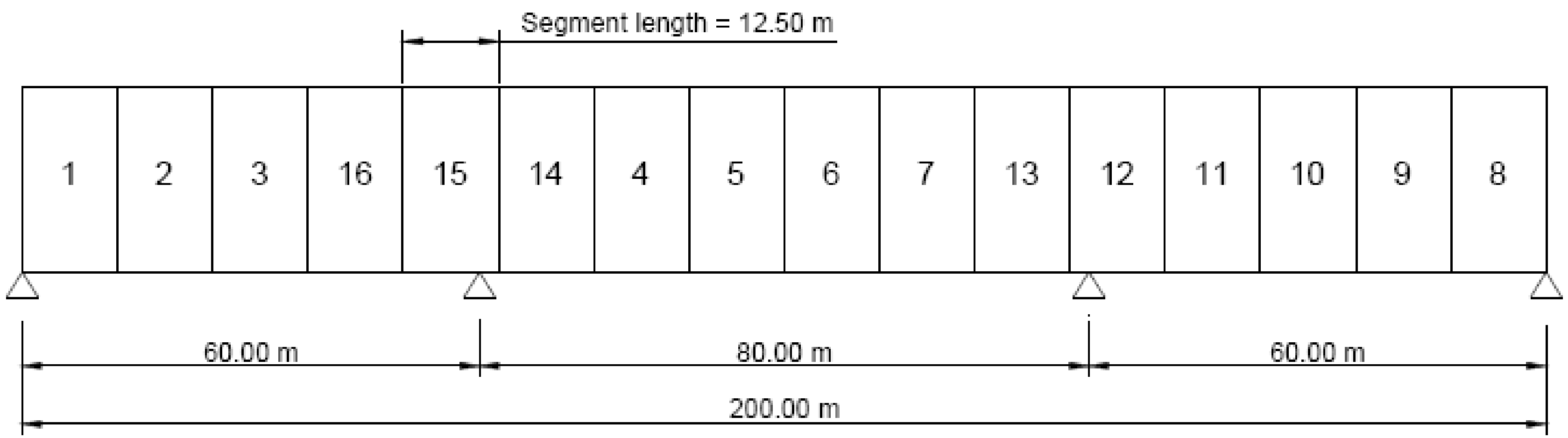
Construction process

- Launching of the steel girders

Construction process

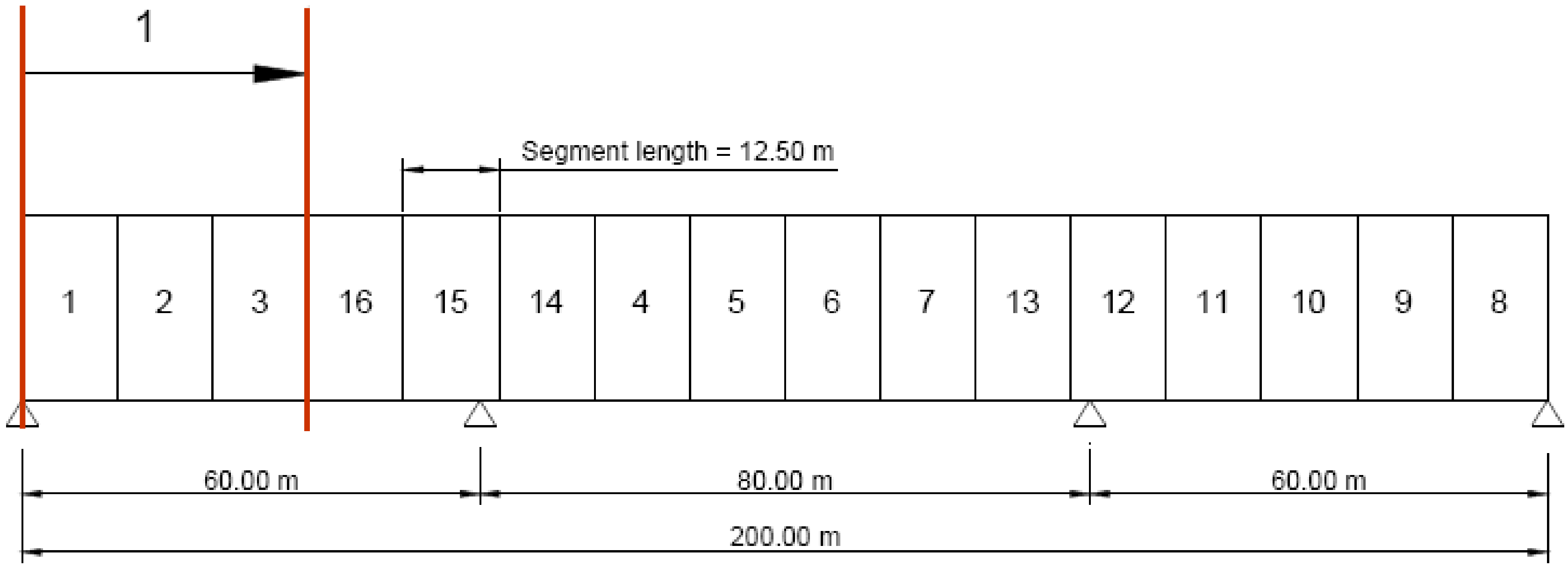
- **Cast in-place slab**

(a segment every three days)



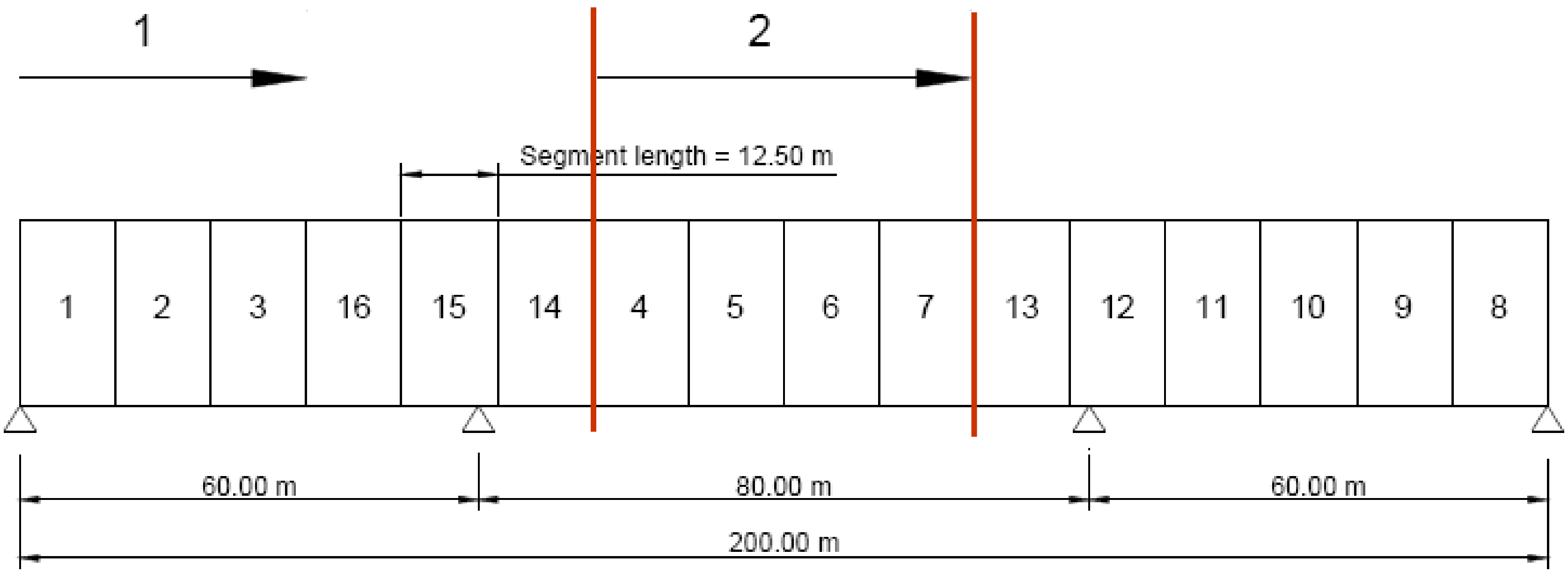
Construction process

- Cast in-place slab



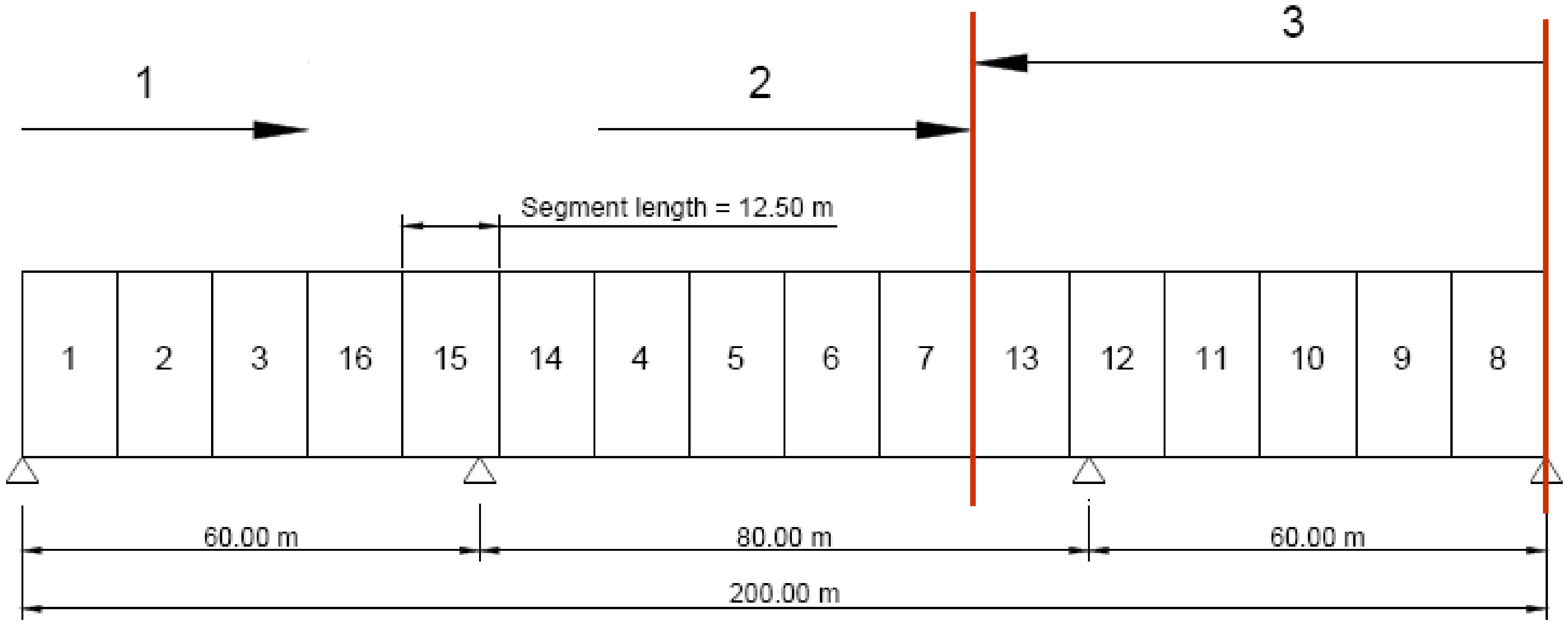
Construction process

- Cast in-place slab



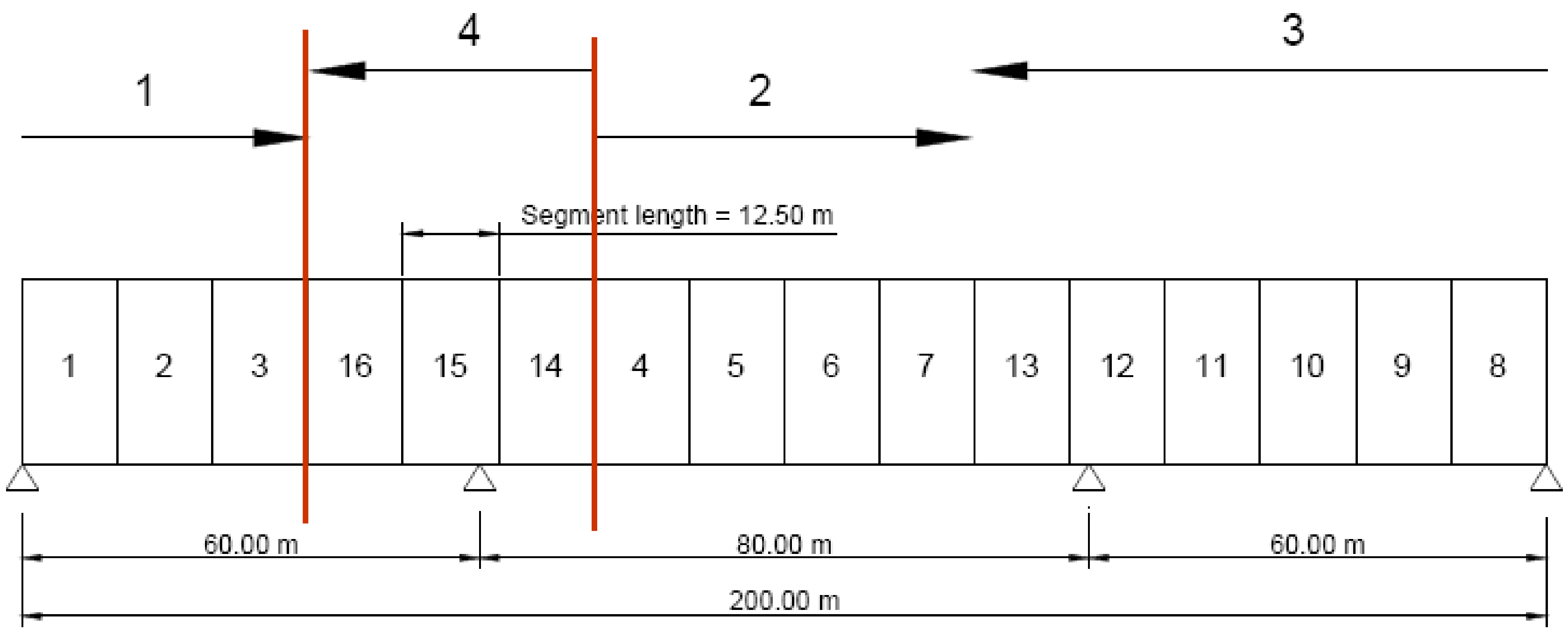
Construction process

- Cast in-place slab



Construction process

- Cast in-place slab



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- Overview of EN 1990 - Basis of Design

1. General overview of EN 1990
2. Verification of limit states and the combinations of actions

Overview of EN 1990 – Basis of Design

→ 1. **General overview of EN 1990**

2. **Verification of limit states and the combinations of actions**

EN1990 – Basis of Design: Contents

EN1990 – Basis of Design Contents

Annex A1	Application for Buildings
Annex A2	Application for Bridges
Annex An	Application for other structure types
Annex B	Management of Structural Reliability for Construction Works
Annex C	Basis for Partial Factor Design and Reliability Analysis
Annex D	Design Assisted by Testing

Role of EN1990

- Provides principles and requirements for designers
- Establishes overall framework, tools and principles used by drafters of the other Eurocode parts

Some of the EN1990 requirements are very general – specific approaches to satisfying them are often contained in other Eurocode parts, e.g.

2.1 Basic requirements

(2)P A structure shall be designed to have adequate :
- structural resistance,
- serviceability, and
- durability.

EN1990: Section 1 - General

- Scope [1.1]
- Assumptions [1.3]
- Terms and definitions [1.5]
- Symbols [1.6]

Scope

1.1 Scope

(1) EN 1990 establishes Principles and requirements for the safety, serviceability and durability of structures, describes the basis for their design and verification and gives guidelines for related aspects of structural reliability.

(2) EN 1990 is intended to be used in conjunction with EN 1991 to EN 1999 for the structural design of buildings and civil engineering works, including geotechnical aspects, structural fire design, situations involving earthquakes, execution and temporary structures.

NOTE For the design of special construction works (*e.g.* nuclear installations, dams, etc.), other provisions than those in EN 1990 to EN 1999 might be necessary.

Some Important Assumptions

1.3 Assumptions

(2) The general assumptions of EN 1990 are :

- the choice of the structural system and the design of the structure is made by appropriately qualified and experienced personnel;
- execution is carried out by personnel having the appropriate skill and experience;
- adequate supervision and quality control is provided during execution of the work, i.e. in design offices, factories, plants, and on site;
- the construction materials and products are used as specified in EN 1990 or in EN 1991 to EN 1999 or in the relevant execution standards, or reference material or product specifications;
- the structure will be adequately maintained;
- the structure will be used in accordance with the design assumptions.

EN1990: Section 2 - Requirements

- Basic requirements [2.1]
- Design working life [2.3]

EN1990: Section 2 - Requirements

2.1 Basic requirements

(2)P A structure shall be designed to have adequate :

- structural resistance,
- serviceability, and
- durability.

(4)P A structure shall be designed and executed in such a way that it will not be damaged by events such as :

- explosion,
- impact, and
- the consequences of human errors,

to an extent disproportionate to the original cause.

EN1990: Section 3 – Principles of limit state design

- General [3.1]
- Design situation [3.2]
- Ultimate limit states [3.3]
- Serviceability limit states [3.4]
- Limit state design [3.5]

EN1990: Section 3 – Principles of limit state design

3.1 General

(1)P A distinction shall be made between ultimate limit states and serviceability limit states.

NOTE In some cases, additional verifications may be needed, for example to ensure traffic safety.

(2) Verification of one of the two categories of limit states may be omitted provided that sufficient information is available to prove that it is satisfied by the other.

(3)P Limit states shall be related to design situations, see 3.2.

(4) Design situations should be classified as persistent, transient or accidental, see 3.2.

(5) Verification of limit states that are concerned with time dependent effects (*e.g.* fatigue) should be related to the design working life of the construction.

EN1990: Section 3 – Principles of limit state design

Key Concept 1

3.1 General

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Key Concept 1 – Design Situations

- **Design situations** are categorised as **persistent**, **transient**, **accidental** or **seismic**.
- These categorisations draw together families of circumstances or conditions that the structure might experience during its life:
  - **Persistent** design situations refer to conditions of normal use. As such, for a highway bridge, they will include the passage of heavy vehicles since the ability to carry heavy vehicles is a key functional requirement.
  - **Transient** design situations refer to circumstances when the structure is itself in some temporary configuration, such as during execution or repair.
  - **Accidental** design situations refer to exceptional circumstances when a structure is experiencing an extreme accidental event.
  - **Seismic** design situations concern conditions applicable to the structure when subjected to seismic events

EN1990: Section 3 – Principles of limit state design

3.3 Ultimate limit states

(1)P The limit states that concern :

– the safety of people, and/or
– the safety of the structure

shall be classified as ultimate limit states.

EN1990: Section 3 – Principles of limit state design

3.4 Serviceability limit states

(1)P The limit states that concern :

– the functioning of the structure or structural members under normal use ;
– the comfort of people ;
– the appearance of the construction works,

shall be classified as serviceability limit states.

(2)P A distinction shall be made between reversible and irreversible serviceability limit states.

EN1990: Section 3 – Principles of limit state design

3.4 Serviceability limit states

(1)P The limit states that concern :

- the functioning of the structure or structural members under normal use ;
- the comfort of people ;
- the appearance of the construction works,

shall be classified as serviceability limit states.

(2)P A distinction shall be made between reversible and irreversible serviceability limit states.

Key Concept 2

Key Concept 2 – Reversible and Irreversible Serviceability Limit States

- The Eurocodes differentiate between **reversible** and **irreversible** serviceability limit states.
- Irreversible serviceability limit states are of greater concern than reversible serviceability limit states.
  - The acceptable probability of an irreversible serviceability limit state being exceeded is lower than that for a reversible serviceability limit state.
- As will be seen later, a more onerous **combination of actions** is used for irreversible serviceability limit states than reversible serviceability limit states.

EN1990: Section 4 – Basic variables

- Actions and environmental influences [4.1]
- Material and product properties [4.2]
- Geometric data [4.3]

EN1990: Section 4 – Basic variables

4.1.1 Classification of actions

(1)P Actions shall be classified by their variation in time as follows :

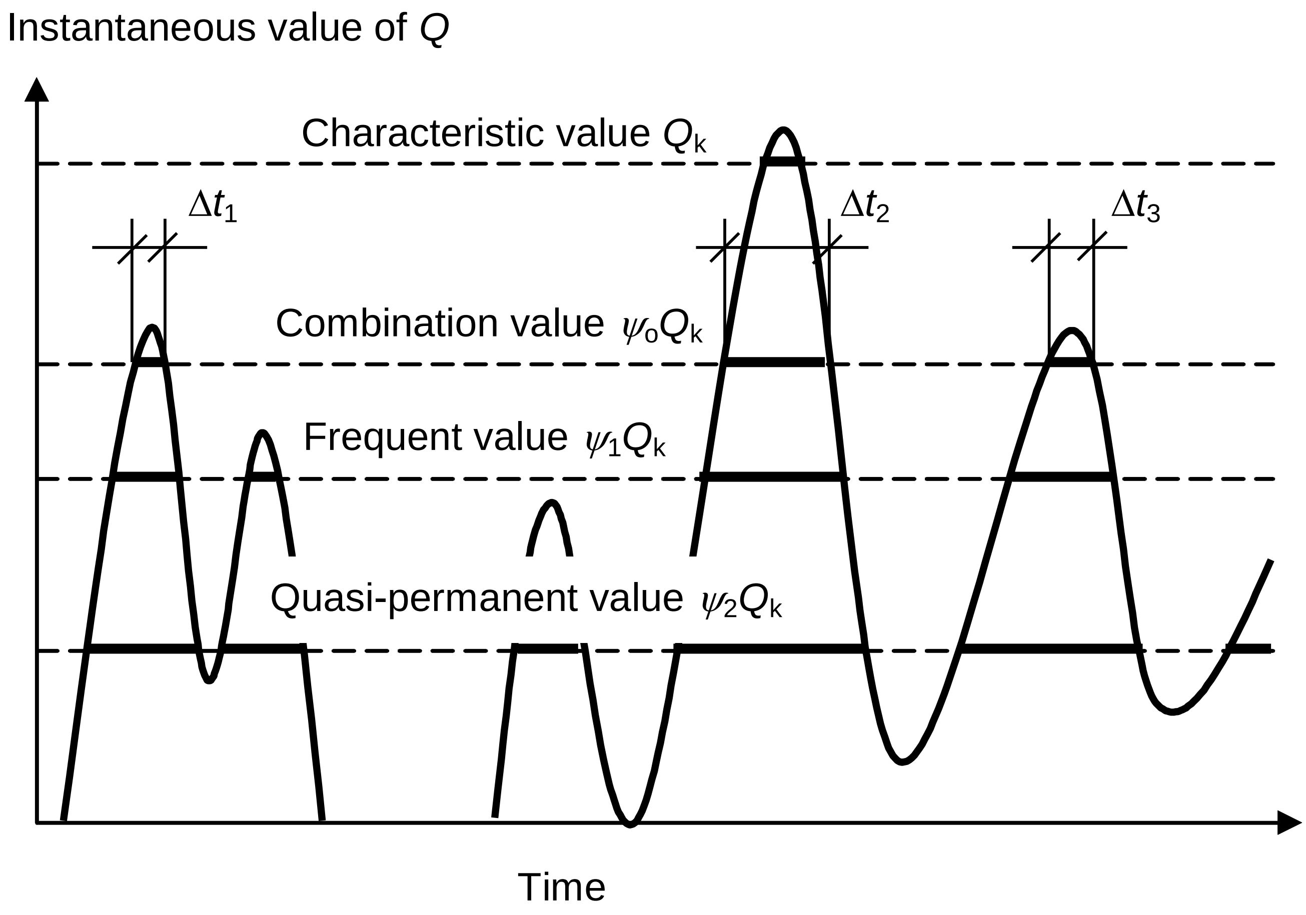
- permanent actions *(G)*, e.g. self-weight of structures, fixed equipment and road surfacing, and indirect actions caused by shrinkage and uneven settlements ;
- variable actions *(Q)*, e.g. imposed loads on building floors, beams and roofs, wind actions or snow loads ;
- accidental actions *(A)*, e.g. explosions, or impact from vehicles.

Representative values of variable actions

- EN1990 established four representative values of a variable action
  - Characteristic Value (Q_k) [1.5.3.14]
  - Combinations Value of a Variable Action ($\psi_0 Q_k$) [1.5.3.16]
  - Frequent Value of a Variable Action ($\psi_1 Q_k$) [1.5.3.17]
  - Quasi-permanent Value of a Variable Action ($\psi_2 Q_k$) [1.5.3.18]

Key Concept 3

Representative Values of a Variable Action



Key Concept 3 – Representative values of variable actions

- There are four different **representative values** of a Variable Action.
- The **characteristic** value is a statistically extreme value. It is the main representative value, and the value generally defined in EN1991.
- The other representative values are called the combination value, **frequent** value and **quasi-permanent** value. They are determined by multiplying the characteristic value by ψ_0, ψ_1 and ψ_2 respectively.
- The combination, frequent and quasi-permanent values are less statistically extreme than the characteristic value, so ψ_0, ψ_1 and ψ_2 are always less than 1.

Material Properties

4.2 Material and product properties

(1) Properties of materials (including soil and rock) or products should be represented by characteristic values (see 1.5.4.1).

(2) When a limit state verification is sensitive to the variability of a material property, upper and lower characteristic values of the material property should be taken into account.

EN1990: Section 5 – Structural analysis and design assisted by testing

Section 5 Structural analysis and design assisted by testing

5.1 Structural analysis

5.1.1 Structural modelling

(1)P Calculations shall be carried out using appropriate structural models involving relevant variables.

(2) The structural models selected should be those appropriate for predicting structural behaviour with an acceptable level of accuracy. The structural models should also be appropriate to the limit states considered.

(3)P Structural models shall be based on established engineering theory and practice. If necessary, they shall be verified experimentally.

EN1990: Section 6 – Verification by the partial factor method

- <u>Key section – will return to it further later</u>

- Design values [6.3]
  - Actions, materials, geometric data, (effects of actions, resistances)
- Ultimate limit states [6.4]
  - ULS's to be verified, verification rules, combination rules
- Serviceability limit states [6.5]
  - Verification rules, combinations of actions

Ultimate Limit States

6.4 Ultimate limit states

6.4.1 General

(1)P The following ultimate limit states shall be verified as relevant :

a) EQU : Loss of static equilibrium of the structure or any part of it considered as a rigid body, where :
   - minor variations in the value or the spatial distribution of actions from a single source are significant, and
   - the strengths of construction materials or ground are generally not governing ;

b) STR : Internal failure or excessive deformation of the structure or structural members, including footings, piles, basement walls, etc., where the strength of construction materials of the structure governs ;

c) GEO : Failure or excessive deformation of the ground where the strengths of soil or rock are significant in providing resistance ;

d) FAT : Fatigue failure of the structure or structural members.

Ultimate Limit States

- Ultimate Limit States
  - EQU – Equilibrium
  - STR – Structural
  - GEO – Geotechnical
  - FAT - Fatigue
  - UPL – Uplift
  - HYD – Hydraulic heave

Ultimate Limit States

- Ultimate Limit States
  - EQU – Equilibrium
  - STR – Structural
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Key Concept 4

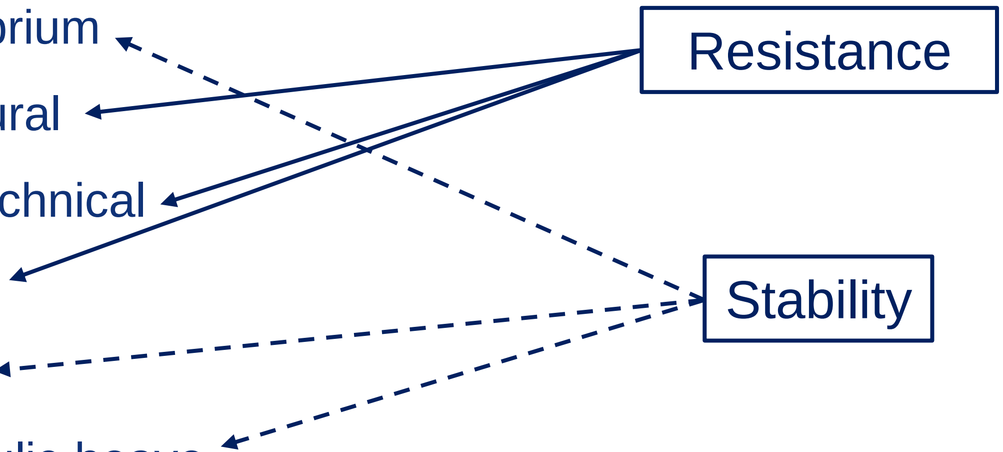
Ultimate Limit States

- Ultimate Limit States
  - EQU – Equilibrium
  - STR – Structural
  - GEO – Geotechnical
  - FAT - Fatigue
  - UPL – Uplift
  - HYD – Hydraulic heave

Resistance

Ultimate Limit States

- Ultimate Limit States
  - EQU – Equilibrium
  - STR – Structural
  - GEO – Geotechnical
  - FAT - Fatigue
  - UPL – Uplift
  - HYD – Hydraulic heave



Ultimate Limit States

- Ultimate Limit States
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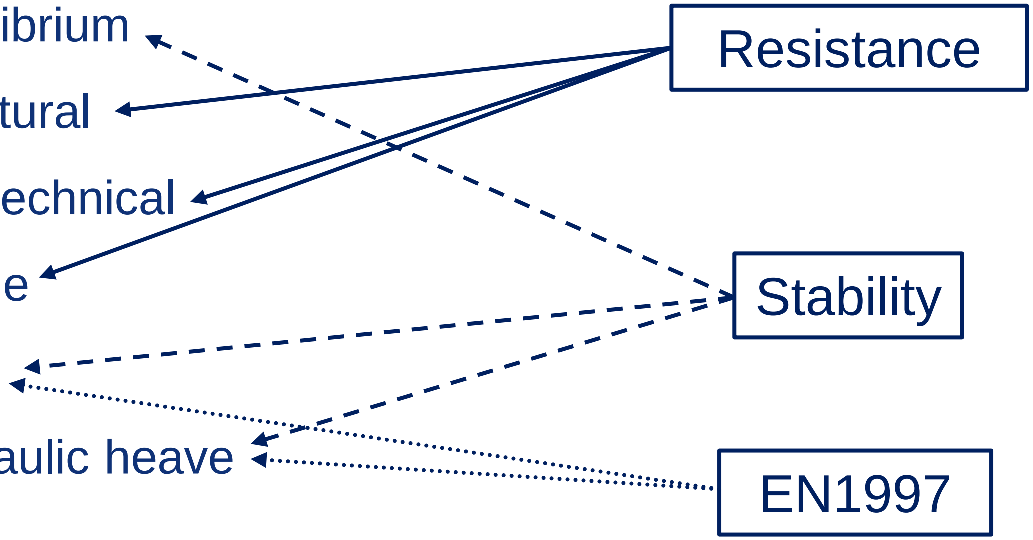
  - HYD – Hydraulic heave



Key Concept 4 – Six different Ultimate Limit States

- The Eurocodes explicitly establish **six different ultimate limit states**.
- Two of these, **UPL** and **HYD**, are specific to EN1997.
- Two are concerned with resistances: **STR** when verifying structural resistance and **GEO** when verifying the resistance of the ground.
- **FAT** is concerned with fatigue.
- **EQU** is principally concerned with ultimate limit states involving a loss of overall equilibrium. However, it has an important relationship with the single source principle (see Key Concept 5)
- Different **partial factors** on **actions** and **geotechnical material properties** are used for different ultimate limit states

EN1990: Annex A2 – Application for bridges

- **Another key section for bridge design**
- Combinations of action [A2.2]

  General, rules for different bridge types, values of ψ factors
- Ultimate limit states [A2.3]

  Design values, design approaches, partial factors on actions
- Serviceability limit states [A2.4]

  Design values, deformation, vibrations

EN1990: Annex A2 – Application for bridges

A2.2 Combinations of actions

A2.2.1 General

(1) Effects of actions that cannot occur simultaneously due to physical or functional reasons need not be considered together in combinations of actions.

EN1990: Annex A2 – Application for bridges

A2.2.2 Combination rules for road bridges

(3) Neither snow loads nor wind actions need be combined with:

– braking and acceleration forces or the centrifugal forces or the associated group of loads gr2,
– loads on footways and cycle tracks or with the associated group of loads gr3,
– crowd loading (Load Model 4) or the associated group of loads gr4.

NOTE The combination rules for special vehicles (see EN 1991-2, Annex A, Informative) with normal traffic (covered by LM1 and LM2) and other variable actions may be referenced as appropriate in the National Annex or agreed for the individual project.

(6) Wind actions and thermal actions need not be taken into account simultaneously unless otherwise specified for local climatic conditions.

NOTE Depending upon the local climatic conditions a different simultaneity rule for wind and thermal actions may be defined either in the National Annex or for the individual project.

A1

Partial factors on actions

A2.3.1 Design values of actions in persistent and transient design situations

(3) Static equilibrium (EQU, see 6.4.1 and 6.4.2(2)) for bridges should be verified using the design values of actions in Table A2.4(A).

(4) Design of structural members (STR, see 6.4.1) not involving geotechnical actions should be verified using the design values of actions in Table A2.4(B).

Partial factors on actions

A2.3.1 Design values of actions in persistent and transient design situations

(3) Static equilibrium (EQU, see 6.4.1 and 6.4.2(2)) for bridges should be verified using the design values of actions in Table A2.4(A).

(4) Design of structural members (STR, see 6.4.1) not involving geotechnical actions should be verified using the design values of actions in Table A2.4(B).

ULS Partial Factors – Set A - Bridges

A1 **Table A2.4(A) - Design values of actions (EQU) (Set A)**

Persistent and transient design situation	Permanent actions		Prestress	Leading variable action (*)	Accompanying variable actions (*)	
	Unfavourable	Favourable			Main (if any)	Others
(Eq. 6.10)	$\gamma_{Gj,sup} G_{kj,sup}$	$\gamma_{Gj,inf} G_{kj,inf}$	$\gamma_P P$	$\gamma_{Q,1} Q_{k,1}$		$\gamma_{Q,i} \psi_{0,i} Q_{k,i}$

(*) Variable actions are those considered in Tables A2.1 to A2.3.

NOTE 1 The γ values for the persistent and transient design situations may be set by the National Annex.

For persistent design situations, the recommended set of values for γ are:

$\gamma_{G,sup} = 1{,}05$

$\gamma_{G,inf} = 0{,}95^{(1)}$

γ_Q = 1,35 for road and pedestrian traffic actions, where unfavourable (0 where favourable)

γ_Q = 1,45 for rail traffic actions, where unfavourable (0 where favourable)

γ_Q = 1,50 for all other variable actions for persistent design situations, where unfavourable (0 where favourable).

γ_P = recommended values defined in the relevant design Eurocode.

For transient design situations during which there is a risk of loss of static equilibrium, $Q_{k,1}$ represents the dominant destabilising variable action and $Q_{k,i}$ represents the relevant accompanying destabilising variable actions.

Partial factors on actions

A2.3.1 Design values of actions in persistent and transient design situations

(3) Static equilibrium (EQU, see 6.4.1 and 6.4.2(2)) for bridges should be verified using the design values of actions in Table A2.4(A).

(4) Design of structural members (STR, see 6.4.1) not involving geotechnical actions should be verified using the design values of actions in Table A2.4(B).

ULS Partial Factors – Set B - Bridges

A1

Table A2.4(B) - Design values of actions (STR/GEO) (Set B)

Persistent and transient design situation	Permanent actions		Prestress	Leading variable action (*)	Accompanying variable actions (*)	
	Unfavourable	Favourable			Main (if any)	Others
(Eq. 6.10)	$\gamma_{Gj,sup}G_{kj,sup}$	$\gamma_{Gj,inf}G_{kj,inf}$	$\gamma_P P$	$\gamma_{Q,1}Q_{k,1}$		$\gamma_{Q,i}\psi_{0,i}Q_{k,i}$

Persistent and transient design situation	Permanent actions		Prestress	Leading variable action (*)	Accompanying variable actions (*)	
	Unfavourable	Favourable			Main (if any)	Others
(Eq. 6.10a)	$\gamma_{Gj,sup}G_{kj,sup}$	$\gamma_{Gj,inf}G_{kj,inf}$	$\gamma_P P$		$\gamma_{Q,1}\psi_{0,1}Q_{k,1}$	$\gamma_{Q,i}\psi_{0,i}Q_{k,i}$
(Eq. 6.10b)	$\xi\gamma_{Gj,sup}G_{kj,sup}$	$\gamma_{Gj,inf}G_{kj,inf}$	$\gamma_P P$	$\gamma_{Q,1}Q_{k,1}$		$\gamma_{Q,i}\psi_{0,i}Q_{k,i}$

(*) Variable actions are those considered in Tables A2.1 to A2.3.

NOTE 1 The choice between 6.10, or 6.10a and 6.10b will be in the National Annex. In the case of 6.10a and 6.10b, the National Annex may in addition modify 6.10a to include permanent actions only.

NOTE 2 The γ and ξ values may be set by the National Annex. The following values for γ and ξ are recommended when using expressions 6.10, or 6.10a and 6.10b:

$\gamma_{G,sup} = 1,35$ 1)

$\gamma_{G,inf} = 1,00$

$\gamma_Q = 1,35$ when Q represents unfavourable actions due to road or pedestrian traffic (0 when favourable)

$\gamma_Q = 1,45$ when Q represents unfavourable actions due to rail traffic, for groups of loads 11 to 31 (except 16, 17, 26 3) and 27 3)), load models LM71, SW/0 and HSLM and real trains, when considered as individual leading traffic actions (0 when favourable)

$\gamma_Q = 1,20$ when Q represents unfavourable actions due to rail traffic, for groups of loads 16 and 17 and SW/2 (0 when favourable)

$\gamma_Q = 1,50$ for other traffic actions and other variable actions 2)

$\xi = 0,85$ (so that $\xi\gamma_{G,sup} = 0,85 \times 1,35 \cong 1,15$).

$\gamma_{Gset} = 1,20$ in the case of a linear elastic analysis, and $\gamma_{Gset} = 1,35$ in the case of a non linear analysis, for design situations where actions due to uneven settlements may have unfavourable effects. For design situations where actions due to uneven settlements may have favourable effects, these actions are not to be taken into account.

See also EN 1991 to EN 1999 for γ values to be used for imposed deformations.

γ_P = recommended values defined in the relevant design Eurocode.

1) This value covers: self-weight of structural and non structural elements, ballast, soil, ground water and free water, removable loads, etc.

2) This value covers: variable horizontal earth pressure from soil, ground water, free water and ballast, traffic load surcharge earth pressure, traffic aerodynamic actions, wind and thermal actions, etc.

3) For rail traffic actions for groups of loads 26 and 27 $\gamma_Q = 1,20$ may be applied to individual components of traffic actions associated with SW/2 and $\gamma_Q = 1,45$ may be applied to individual components of traffic actions associated with load models LM71, SW/0 and HSLM, etc.

Table continued on next page

Design situations – cases where geotechnical actions or resistance present

A2.3.1 Design values of actions in persistent and transient design situations

(5) Design of structural members (footings, piles, piers, side walls, wing walls, flank walls and front walls of abutments, ballast retention walls, etc.) (STR) involving geotechnical actions and the resistance of the ground (GEO, see 6.4.1) should be verified using one only of the following three approaches supplemented, for geotechnical actions and resistances, by EN 1997:

– Approach 1: Applying in separate calculations design values from Table A2.4(C) and Table A2.4(B) to the geotechnical actions as well as the actions on/from the structure;

– Approach 2: Applying design values of actions from Table A2.4(B) to the geotechnical actions as well as the actions on/from the structure;

– Approach 3: Applying design values of actions from Table A2.4(C) to the geotechnical actions and, simultaneously, applying design values of actions from Table A2.4(B) to the actions on/from the structure.

NOTE The choice of approach 1, 2 or 3 is given in the National Annex.

ULS Partial Factors – Set C - Bridges

A1 **Table A2.4(C) - Design values of actions (STR/GEO) (Set C)**

Persistent and transient design situation	Permanent actions		Prestress	Leading variable action (*)	Accompanying variable actions (*)	
	Unfavourable	Favourable			Main (if any)	Others
(Eq. 6.10)	$\gamma_{Gj,sup}G_{kj,sup}$	$\gamma_{Gj,inf}G_{kj,inf}$	$\gamma_P P$	$\gamma_{Q,1}\ Q_{k,1}$		$\gamma_{Q,i}\psi_{0,i}Q_{k,i}$
(*) Variable actions are those considered in Tables A2.1 to A2.3						

NOTE The γ values may be set by the National Annex. The recommended set of values for γ are:

$\gamma_{G,sup} = 1{,}00$

$\gamma_{G,inf} = 1{,}00$

$\gamma_{Gset} = 1{,}00$

$\gamma_Q = 1{,}15$ for road and pedestrian traffic actions where unfavourable (0 where favourable)

$\gamma_Q = 1{,}25$ for rail traffic actions where unfavourable (0 where favourable)

$\gamma_Q = 1{,}30$ for the variable part of horizontal earth pressure from soil, ground water, free water and ballast, for traffic load surcharge horizontal earth pressure, where unfavourable (0 where favourable)

$\gamma_Q = 1{,}30$ for all other variable actions where unfavourable (0 where favourable)

$\gamma_{Gset} = 1{,}00$ in the case of linear elastic or non linear analysis, for design situations where actions due to uneven settlements may have unfavourable effects. For design situations where actions due to uneven settlements may have favourable effects, these actions are not to be taken into account.

γ_P = recommended values defined in the relevant design Eurocode.

Single Source Principle

EN 1990, Annex A2:

A1 Table A2.4(B) - Design values of actions (STR/GEO) (Set B)

Persistent and transient design situation	Permanent actions		Prestress	Leading variable action (*)	Accompanying variable actions (*)	
	Unfavourable	Favourable			Main (if any)	Others
(Eq. 6.10)	$\gamma_{Gj,sup}G_{kj,sup}$	$\gamma_{Gj,inf}G_{kj,inf}$	$\gamma_P P$	$\gamma_{Q,1}Q_{k,1}$		$\gamma_{Q,i}\psi_{0,i}Q_{k,i}$

Persistent and transient design situation	Permanent actions		Prestress	Leading variable action (*)	Accompanying variable actions (*)	
	Unfavourable	Favourable			Main (if any)	Others
(Eq. 6.10a)	$\gamma_{Gj,sup}G_{kj,sup}$	$\gamma_{Gj,inf}G_{kj,inf}$	$\gamma_P P$		$\gamma_{Q,1}\psi_{0,1}Q_{k,1}$	$\gamma_{Q,i}\psi_{0,i}Q_{k,i}$
(Eq. 6.10b)	$\xi\gamma_{Gj,sup}G_{kj,sup}$	$\gamma_{Gj,inf}G_{kj,inf}$	$\gamma_P P$	$\gamma_{Q,1}Q_{k,1}$		$\gamma_{Q,i}\psi_{0,i}Q_{k,i}$

(*) Variable actions are those considered in Tables A2.1 to A2.3.

NOTE 1 The choice between 6.10, or 6.10a and 6.10b will be in the National Annex. In the case of 6.10a and 6.10b, the National Annex may in addition modify 6.10a to include permanent actions only.

NOTE 3 The characteristic values of all permanent actions from one source are multiplied by $\gamma_{G,sup}$ if the total resulting action effect is unfavourable and $\gamma_{G,inf}$ if the total resulting action effect is favourable. For example, all actions originating from the self-weight of the structure may be considered as coming from one source; this also applies if different materials are involved. See however A2.3.1(2).

Key Concept 5

Single Source Principle

A1

Table A2.4(B) - Design values of actions (STR/GEO) (Set B)

Persistent and transient design situation	Permanent actions		Prestress	Leading variable action (*)	Accompanying variable actions (*)	
	Unfavourable	Favourable			Main (if any)	Others
(Eq. 6.10)	$\gamma_{Gj,sup}G_{kj,sup}$	$\gamma_{Gj,inf}G_{kj,inf}$	$\gamma_P P$	$\gamma_{Q,1}Q_{k,1}$		$\gamma_{Q,i}\psi_{0,i}Q_{k,i}$

Persistent and transient design situation	Permanent actions		Prestress	Leading variable action (*)	Accompanying variable actions (*)	
	Unfavourable	Favourable			Main (if any)	Others
(Eq. 6.10a)	$\gamma_{Gj,sup}G_{kj,sup}$	$\gamma_{Gj,inf}G_{kj,inf}$	$\gamma_P P$		$\gamma_{Q,1}\psi_{0,1}Q_{k,1}$	$\gamma_{Q,i}\psi_{0,i}Q_{k,i}$
(Eq. 6.10b)	$\xi\gamma_{Gj,sup}G_{kj,sup}$	$\gamma_{Gj,inf}G_{kj,inf}$	$\gamma_P P$	$\gamma_{Q,1}Q_{k,1}$		$\gamma_{Q,i}\psi_{0,i}Q_{k,i}$

(*) Variable actions are those considered in Tables A2.1 to A2.3.

NOTE 1 The choice between 6.10, or 6.10a and 6.10b will be in the National Annex. In the case of 6.10a and 6.10b, the National Annex may in addition modify 6.10a to include permanent actions only.

NOTE 3 The characteristic values of all permanent actions from one source are multiplied by $\gamma_{G,sup}$ if the total resulting action effect is unfavourable and $\gamma_{G,inf}$ if the total resulting action effect is favourable. For example, all actions originating from the self-weight of the structure may be considered as coming from one source; this also applies if different materials are involved. See however A2.3.1(2).

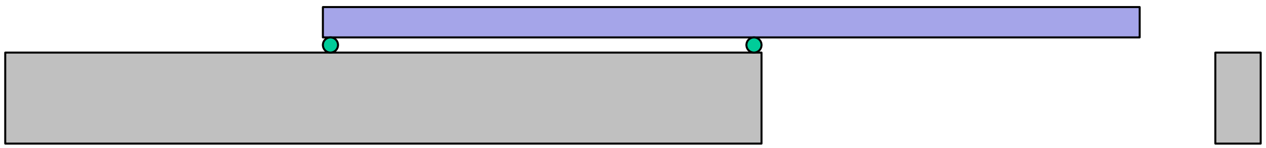
Key Concept 5

NOTE 3 The characteristic values of all permanent actions from one source are multiplied by $\gamma_{G,sup}$ if the total resulting action effect is unfavourable and $\gamma_{G,inf}$ if the total resulting action effect is favourable. For example, all actions originating from the self weight of the structure may be considered as coming from one source; this also applies if different materials are involved. See however A2.3.1(2)

Key Concept 5 – Single Source Principle

- Application of the **single source principle** allows a single partial factor to be applied to the whole of an action arising from a single source.
- The value of the partial factor used depends on whether the resulting action effect is favourable or unfavourable.
- EN1990 allows the **single source principle** to be used for **STR** and **GEO** verifications.
- **EQU** addresses cases when **minor variations** in the magnitude or spatial distribution of a permanent **action** from a **single source** is **significant**.

Illustration of STR and EQU: Verification of launched structure



6.4 Ultimate limit states

6.4.1 General

(1)P The following ultimate limit states shall be verified as relevant :

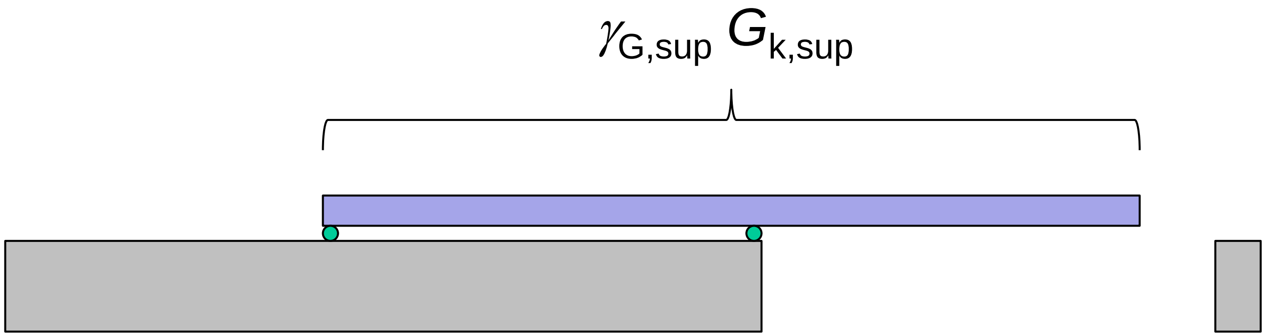
a) EQU : Loss of static equilibrium of the structure or any part of it considered as a rigid body, where :
   - minor variations in the value or the spatial distribution of actions from a single source are significant, and
   - the strengths of construction materials or ground are generally not governing ;

b) STR : Internal failure or excessive deformation of the structure or structural members, including footings, piles, basement walls, etc., where the strength of construction materials of the structure governs ;

c) GEO : Failure or excessive deformation of the ground where the strengths of soil or rock are significant in providing resistance ;

d) FAT : Fatigue failure of the structure or structural members.

Illustration of STR and EQU: Verification of launched structure



STR Verification : Moment over central support

Single source principle can be applied

EN1990 Set B Partial Factors used

6.4 Ultimate limit states

6.4.1 General

(1)P The following ultimate limit states shall be verified as relevant :

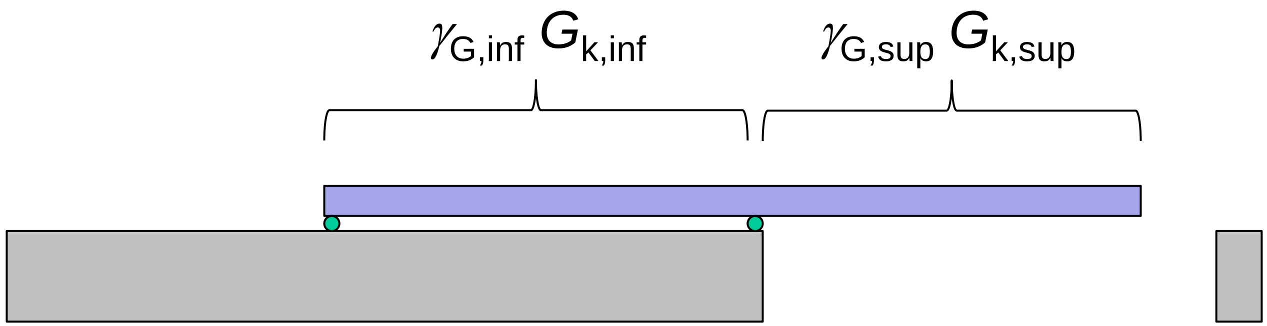
a) EQU : Loss of static equilibrium of the structure or any part of it considered as a rigid body, where :
   - minor variations in the value or the spatial distribution of actions from a single source are significant, and
   - the strengths of construction materials or ground are generally not governing ;

b) STR : Internal failure or excessive deformation of the structure or structural members, including footings, piles, basement walls, etc., where the strength of construction materials of the structure governs ;

c) GEO : Failure or excessive deformation of the ground where the strengths of soil or rock are significant in providing resistance ;

d) FAT : Fatigue failure of the structure or structural members.

Illustration of STR and EQU: Verification of launched structure



EQU Verification

Single source principle not applied

EN1990 Set A Partial Factors used

Overview of EN 1990 – Basis of Design

1. General overview of EN 1990

→ 2. Verification of limit states and the combinations of actions

Overview of EN 1990 – Basis of Design

1. General overview of EN 1990

2. Verification of limit states and the combinations of actions

Key Concept 6

Ultimate Limit States

Verification (ULS)

6.4.2 Verifications of static equilibrium and resistance

(3)P When considering a limit state of rupture or excessive deformation of a section, member or connection (STR and/or GEO), it shall be verified that :

$$E_d \leq R_d \tag{6.8}$$

where :

E_d is the design value of the effect of actions such as internal force, moment or a vector representing several internal forces or moments ;

R_d is the design value of the corresponding resistance.

ULS Verification
(Persistent and Transient Design Situation)

$$E_d \leq R_d$$

ULS Verification
(Persistent and Transient Design Situation)

$$E_d \leq R_d$$

Applying Equation 6.10 from EN1990:

ULS Verification
(Persistent and Transient Design Situation)

6.4.3.2 Combinations of actions for persistent or transient design situations (fundamental combinations)

(1) The general format of effects of actions should be :

$$E_d = \gamma_{Sd} E\{\gamma_{g,j} G_{k,j} ; \gamma_p P ; \gamma_{q,1} Q_{k,1} ; \gamma_{q,i} \psi_{0,i} Q_{k,i}\} \quad j \geq 1 ; i > 1 \tag{6.9a}$$

(2) The combination of effects of actions to be considered should be based on
– the design value of the leading variable action, and
– the design combination values of accompanying variable actions :

NOTE See also 6.4.3.2(4).

$$E_d = E\{\gamma_{G,j} G_{k,j} ; \gamma_P P ; \gamma_{Q,1} Q_{k,1} ; \gamma_{Q,i} \psi_{0,i} Q_{k,i}\} \quad j \geq 1 ; i > 1 \tag{6.9b}$$

(3) The combination of actions in brackets { }, in (6.9b) may either be expressed as :

$$\sum_{j \geq 1} \gamma_{G,j} G_{k,j} \text{"+"} \gamma_P P \text{"+"} \gamma_{Q,1} Q_{k,1} \text{"+"} \sum_{i > 1} \gamma_{Q,i} \psi_{0,i} Q_{k,i} \tag{6.10}$$

ULS Verification
(Persistent and Transient Design Situation)

$$E_d \leq R_d$$

Applying Equation 6.10 from EN1990:

$$E_d = E\ \{\ \Sigma_{j\geq1}\gamma_{G,j}G_{k,j}\ \text{“+”}\ \gamma_p P\ \text{“+”}\ \gamma_{Q,1}Q_{k,1}\ \text{“+”}\ \Sigma_{i>1}\gamma_{Q,i}\ \psi_{0,i}\ Q_{k,i}\ \}$$

ULS Verification
(Persistent and Transient Design Situation)

$$E_d = E\{ \Sigma_{j\geq 1}\gamma_{G,j}G_{k,j} \text{ "+" } \gamma_p P \text{ "+" } \gamma_{Q,1}Q_{k,1} \text{ "+" } \Sigma_{i>1}\gamma_{Q,i}\,\psi_{0,i}\,Q_{k,i} \}$$

ULS Verification
(Persistent and Transient Design Situation)

Design effect

$$E_d = E\ \{\ \Sigma_{j\geq 1}\gamma_{G,j}G_{k,j}\ \text{“+”}\ \gamma_p P\ \text{“+”}\ \gamma_{Q,1}Q_{k,1}\ \text{“+”}\ \Sigma_{i>1}\gamma_{Q,i}\ \psi_{0,i}\ Q_{k,i}\ \}$$

ULS Verification
(Persistent and Transient Design Situation)

Design effect

$$E_d = E\{ \Sigma_{j\geq1}\gamma_{G,j}G_{k,j} \text{ "+" } \gamma_p P \text{ "+" } \gamma_{Q,1}Q_{k,1} \text{ "+" } \Sigma_{i>1}\gamma_{Q,i}\,\psi_{0,i}\,Q_{k,i} \}$$

Effect of

ULS Verification
(Persistent and Transient Design Situation)

Design effect

Permanent actions

$$E_d = E\{\Sigma_{j\geq 1}\gamma_{G,j}G_{k,j} \text{ "+" } \gamma_p P \text{ "+" } \gamma_{Q,1}Q_{k,1} \text{ "+" } \Sigma_{i>1}\gamma_{Q,i}\,\psi_{0,i}\,Q_{k,i}\}$$

Effect of

ULS Verification
(Persistent and Transient Design Situation)

Design effect

Permanent actions

$$E_d = E\{\textstyle\sum_{j\geq 1}\gamma_{G,j}G_{k,j} \text{ "+" } \gamma_p P \text{ "+" } \gamma_{Q,1}Q_{k,1} \text{ "+" } \sum_{i>1}\gamma_{Q,i}\,\psi_{0,i}\,Q_{k,i}\}$$

Effect of

Combined with

ULS Verification
(Persistent and Transient Design Situation)

Design effect

Permanent actions

$$E_d = E\{ \Sigma_{j\geq1}\gamma_{G,j}G_{k,j} \text{“+”} \gamma_p P \text{“+”} \gamma_{Q,1}Q_{k,1} \text{“+”} \Sigma_{i>1}\gamma_{Q,i}\,\psi_{0,i}\,Q_{k,i} \}$$

Effect of

Prestress

Combined with

ULS Verification
(Persistent and Transient Design Situation)

$$E_d = E\{ \Sigma_{j\geq 1}\gamma_{G,j}G_{k,j} \text{ "+" } \gamma_p P \text{ "+" } \gamma_{Q,1}Q_{k,1} \text{ "+" } \Sigma_{i>1}\gamma_{Q,i}\,\psi_{0,i}\,Q_{k,i} \}$$

Design effect

Permanent actions

Leading variable action

Effect of

Prestress

Combined with

ULS Verification
(Persistent and Transient Design Situation)

$$E_d = E\{\Sigma_{j\geq 1}\gamma_{G,j}G_{k,j} \text{ “+” } \gamma_p P \text{ “+” } \gamma_{Q,1}Q_{k,1} \text{ “+” } \Sigma_{i>1}\gamma_{Q,i}\,\psi_{0,i}\,Q_{k,i}\}$$

- E_d: Design effect
- E: Effect of
- $\Sigma_{j\geq 1}\gamma_{G,j}G_{k,j}$: Permanent actions
- “+”: Combined with
- $\gamma_p P$: Prestress
- $\gamma_{Q,1}Q_{k,1}$: Leading variable action
- $\Sigma_{i>1}\gamma_{Q,i}\,\psi_{0,i}\,Q_{k,i}$: Accompanying variable actions

ψ factors for highway bridges

A1 **Table A2.1 – Recommended values of ψ factors for road bridges**

Action	Symbol		ψ_0	ψ_1	ψ_2
Traffic loads (see EN 1991-2, Table 4.4)	gr1a (LM1+pedestrian or cycle-track loads) 1)	TS	0,75	0,75	0
		UDL	0,40	0,40	0
		Pedestrian+cycle-track loads 2)	0,40	0,40	0
	gr1b (Single axle)		0	0,75	0
	gr2 (Horizontal forces)		0	0	0
	gr3 (Pedestrian loads)		0	0	0
	gr4 (LM4 – Crowd loading))		0	0,75	0
	gr5 (LM3 – Special vehicles))		0	0	0
Wind forces	F_{Wk} - Persistent design situations - Execution		0,6 0,8	0,2 -	0 0
	F_W^*		1,0	-	-
Thermal actions	T_k		0,6 3)	0,6	0,5
Snow loads	$Q_{Sn,k}$ (during execution)		0,8	-	-
Construction loads	Q_c		1,0	-	1,0

1) The recommended values of ψ_0, ψ_1 and ψ_2 for gr1a and gr1b are given for road traffic corresponding to adjusting factors α_{Qi}, α_{qi}, α_{qr} and β_Q equal to 1. Those relating to UDL correspond to common traffic scenarios, in which a rare accumulation of lorries can occur. Other values may be envisaged for other classes of routes, or of expected traffic, related to the choice of the corresponding α factors. For example, a value of ψ_2 other than zero may be envisaged for the UDL system of LM1 only, for bridges supporting severe continuous traffic. See also EN 1998.

2) The combination value of the pedestrian and cycle-track load, mentioned in Table 4.4a of EN 1991-2, is a "reduced" value. ψ_0 and ψ_1 factors are applicable to this value.

3) The recommended ψ_0 value for thermal actions may in most cases be reduced to 0 for ultimate limit states EQU, STR and GEO. See also the design Eurocodes.

Combinations of Actions – Treatment of variable actions

	Leading		Accompanying	
	γ_Q (1)	ψ	γ_Q (1)	ψ
ULS Persistent and Transient Design Situations	γ_Q	1.0	γ_Q	ψ_0

Notes:

(1) Values of γ_Q are obtained from tables A2.4(A) – (C) of EN 1990.

ULS Verification (Accidental Design Situation)

$$E_d = E \{ \Sigma_{j\geq 1} G_{k,j} \text{ "+" } P \text{ "+" } A_d \text{ "+" } (\psi_{1,1} \text{ or } \psi_{2,1}) Q_{k,1} \text{ "+" } \Sigma_{i>1} \psi_{2,i} Q_{k,i} \}$$

Combinations of Actions – Treatment of variable actions

	Leading		Accompanying	
	γ_Q (1)	ψ	γ_Q (1)	ψ
ULS Persistent and Transient Design Situations	γ_Q	1.0	γ_Q	ψ_0
ULS Accidental Design Situation	1.0	$\psi_{1 \text{ or } 2}$ (2)	1.0	ψ_2

Combination also includes A_d

Notes:

(1) Values of γ_Q are obtained from tables A2.4(A) – (C) of EN 1990.

(2) Expression 6.11 allows the use of either or ψ_1 or ψ_2

Serviceability Limit States

SLS Verification Combinations of Actions

Characteristic Combination

– Normally used for irreversible limit states

$$E_d = E \{ \Sigma_{j\geq 1} G_{k,j} \text{ "+" } P \text{ "+" } Q_{k,1} \text{ "+" } \Sigma_{i>1} \psi_{0,i} Q_{k,i} \}$$

Example from EN1992-1-1

7.2 Stress limitation

(4)P Tensile stresses in the reinforcement shall be limited in order to avoid inelastic strain, unacceptable cracking or deformation.

(5) Unacceptable cracking or deformation may be assumed to be avoided if, under the characteristic combination of loads, the tensile stress in the reinforcement does not exceed $k_3 f_{yk}$. Where the stress is caused by an imposed deformation, the tensile stress should not exceed $k_4 f_{yk}$. The mean value of the stress in prestressing tendons should not exceed $k_5 f_{pk}$

Note: The values of k_3, k_4 and k_5 for use in a Country may be found in its National Annex. The recommended values are 0,8, 1 and 0,75 respectively.

Combinations of Actions – Treatment of variable actions

	Leading		Accompanying	
	γ_Q (1)	ψ	γ_Q (1)	ψ
ULS Persistent and Transient Design Situations	γ_Q	1.0	γ_Q	ψ_0
ULS Accidental Design Situation	1.0	$\psi_{1 \text{ or } 2}$ (2)	1.0	ψ_2
(SLS) Characteristic Combination	1.0	1.0	1.0	ψ_0

Combination also includes A_d

Notes:

(1) Values of γ_Q are obtained from tables A2.4(A) – (C) of EN 1990.

(2) Expression 6.11 allows the use of either or ψ_1 or ψ_2

(3) Guidance on which combination should be used for specific verifications is given in the relevant Parts of EN 1992 to EN 1999 for SLS, and is dependent upon the design situation at ULS.

SLS Verification Combinations of Actions

<u>Frequent Combination</u>

– Normally used for reversible limit states

$$E_d = E \{ \Sigma_{j\geq 1} G_{k,j} \text{“+”} P \text{“+”} \psi_{1,1} Q_{k,1} \text{“+”} \Sigma_{i>1} \psi_{2,i} Q_{k,i} \}$$

SLS Verification Combinations of Actions

Quasi-Permanent Combination

– Normally used for long term effects

$$E_d = E \{ \Sigma_{j\geq1} G_{k,j} \text{ “+” } P \text{ “+” } \Sigma_{i\geq1} \psi_{2,i} Q_{k,i} \}$$

Example from EN1992-1-1

EN 1992-2:2005 (E)

Table 7.101N — Recommended values of w_{max} and relevant combination rules

Exposure Class	Reinforced members and prestressed members without bonded tendons	Prestressed members with bonded tendons
	Quasi-permanent load combination	Frequent load combination
X0, XC1	0,3[a]	0,2
XC2, XC3, XC4	0,3	0,2[b]
XD1, XD2, XD3 XS1, XS2, XS3		Decompression

[a] For X0, XC1 exposure classes, crack width has no influence on durability and this limit is set to guarantee acceptable appearance. In the absence of appearance conditions this limit may be relaxed.

[b] For these exposure classes, in addition, decompression should be checked under the quasi-permanent combination of loads.

Combinations of Actions – Treatment of variable actions

	Leading		Accompanying	
	γ_Q (1)	ψ	γ_Q (1)	ψ
ULS Persistent and Transient Design Situations	γ_Q	1.0	γ_Q	ψ_0
ULS Accidental Design Situation	1.0	$\psi_{1\ \text{or}\ 2}$ (2)	1.0	ψ_2
(SLS) Characteristic Combination	1.0	1.0	1.0	ψ_0
(SLS) Frequent combination	1.0	ψ_1	1.0	ψ_2
(SLS) Quasi permanent Combination (also used for long term effects)	1.0	ψ_2	1.0	ψ_2

Combination also includes A_d

Notes:

(1) Values of γ_Q are obtained from tables A2.4(A) – (C) of EN 1990.

(2) Expression 6.11 allows the use of either or ψ_1 or ψ_2

(3) Guidance on which combination should be used for specific verifications is given in the relevant Parts of EN 1992 to EN 1999 for SLS, and is dependent upon the design situation at ULS.

Key Concept 6 – Five Combinations of Actions

- **EN1990** establishes **five** different **combinations of actions**.
- Different combinations of actions are used for verifying different **limit states**. They have different statistical likelihoods of occurring.
- The **quasi-permanent** combination is also used when analysing **long-term effects**.
- The differences between the combinations of actions concern: whether partial factors are applied; which representative values of variable actions are used; and, whether there is an accidental action included.
- The different combinations of actions are used in conjunction with the Eurocode 'material parts'. The Eurocode part generally states explicitly which combination is to be used in each SLS verification.

Six key concepts of EN 1990 - summary

- Design situations
- Reversible and irreversible serviceability limit states
- Representative values of variable actions
- Six ultimate limit states
- Single source principle
- Five combinations of actions