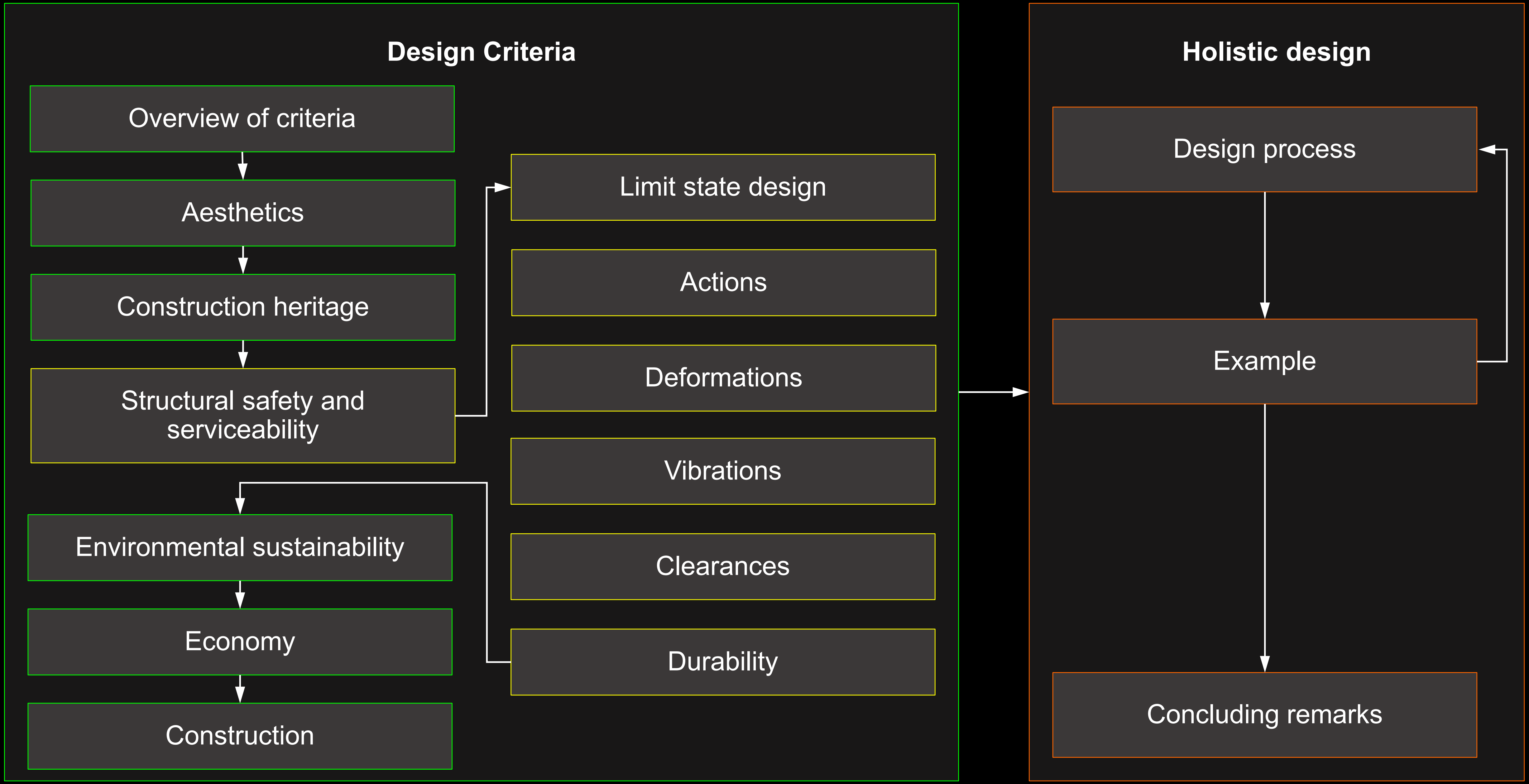
Conceptual Design
Entwurf und Bemessung


Design Criteria
Overview of criteria
Aesthetics
Construction heritage
Structural safety and serviceability
Environmental sustainability
Economy
Construction
Limit state design
Actions
Deformations
Vibrations
Clearances
Durability
Holistic design
Design process
Example
Concluding remarks

Conceptual Design

Design Criteria – Overview

Entwurfskriterien – Übersicht

Design Criteria – Overview

- Designing a bridge means developing its Structural Concept (Tragwerkskonzept), based on the given boundary conditions

- According to SIA 260, the Structural Concept defines
  - → the chosen structural system
  - → the most important
    … dimensions
    … construction material properties
    … constructional details
  - → the envisaged methods of construction

The choice of the structural system must not be seen as a task limited to purely technical aspects (neither in bridges nor in buildings).

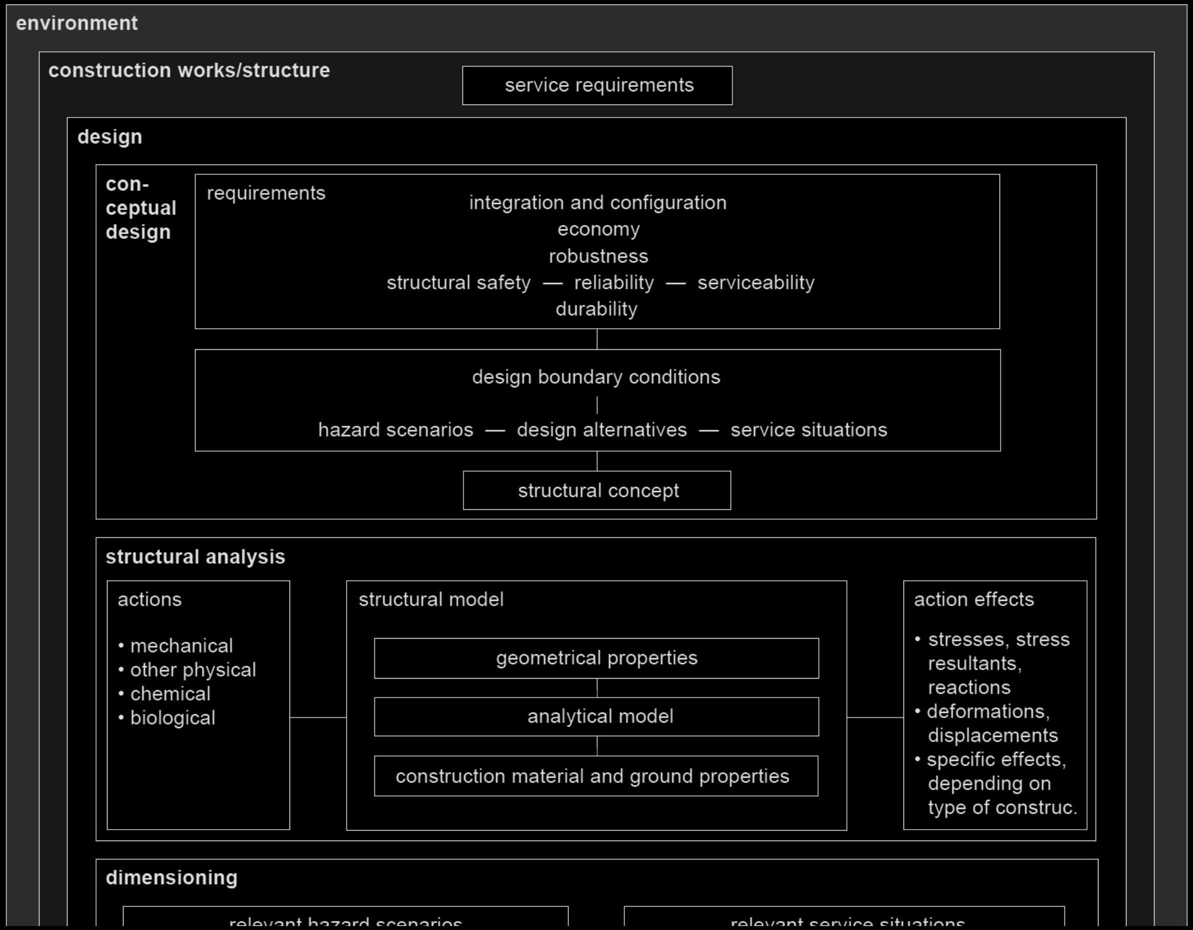
In the following, the bridge-specific aspects of structural design are dealt with.

Structural concept

(Tragwerks-konzept)

Design Criteria – Overview

- Recommended reference: SIA 260 *Basis of Structural Design*



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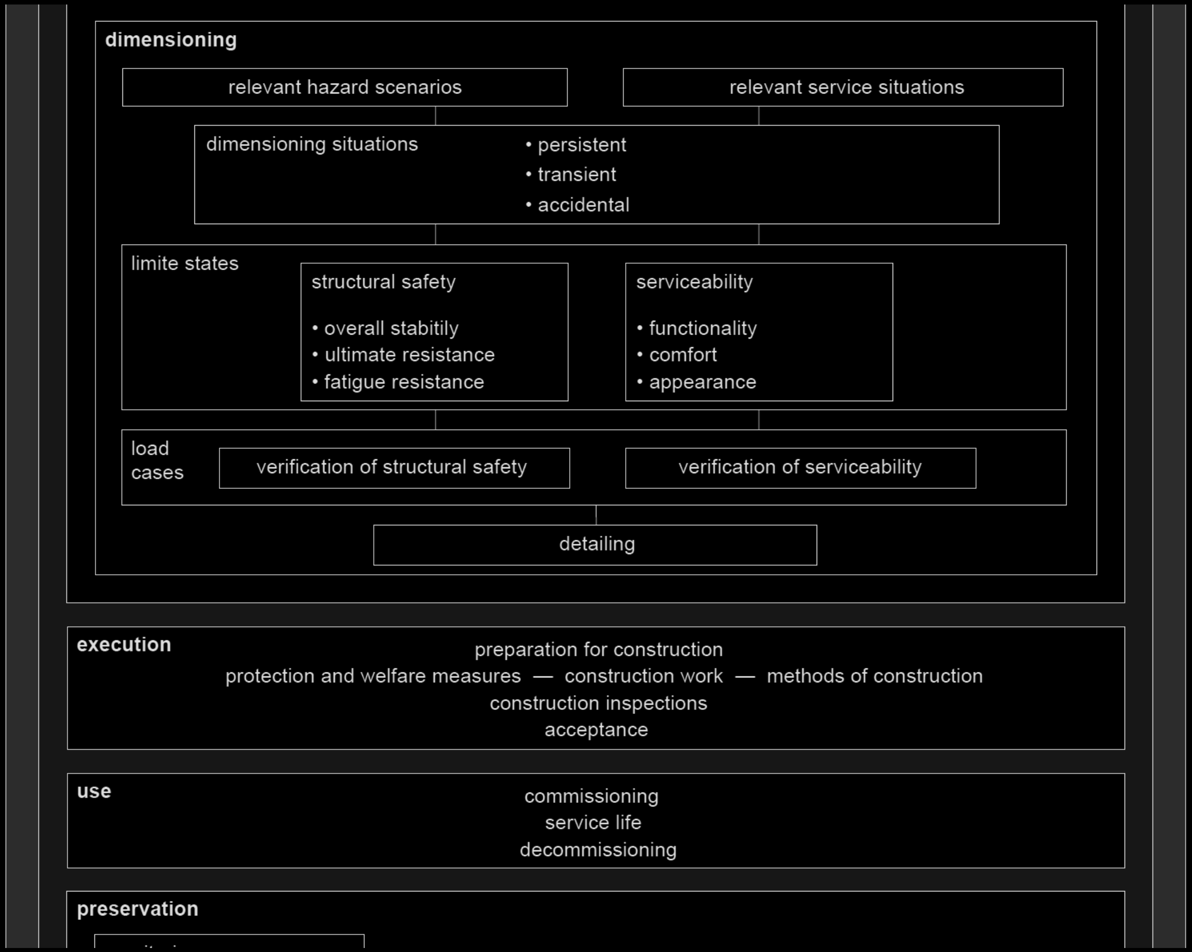

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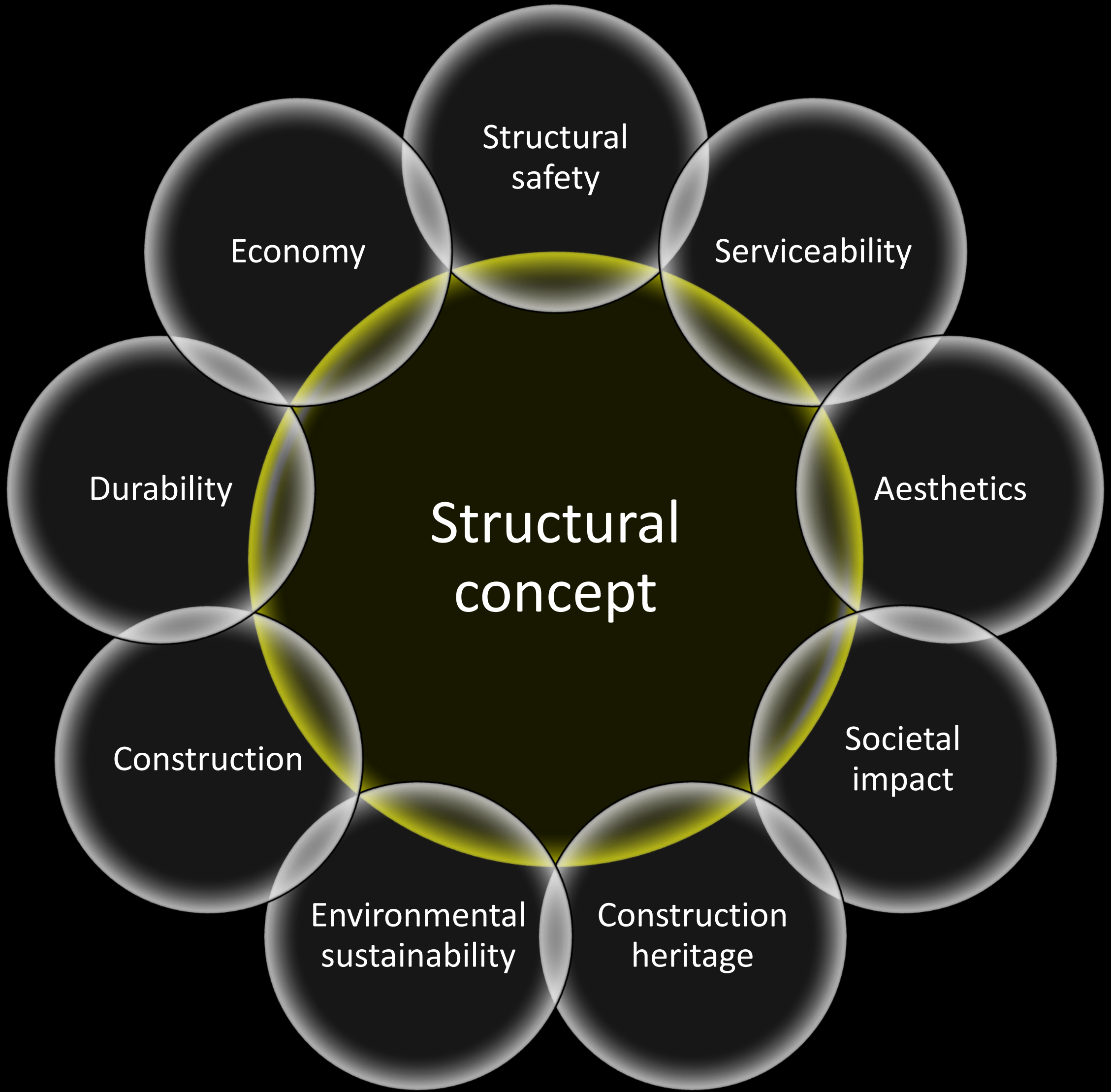
Design Criteria – Overview

- Designing a bridge means developing its Structural Concept, based on the given boundary conditions
- Designing a bridge is a multi-faceted task, where many different topics are to be mastered by structural engineers



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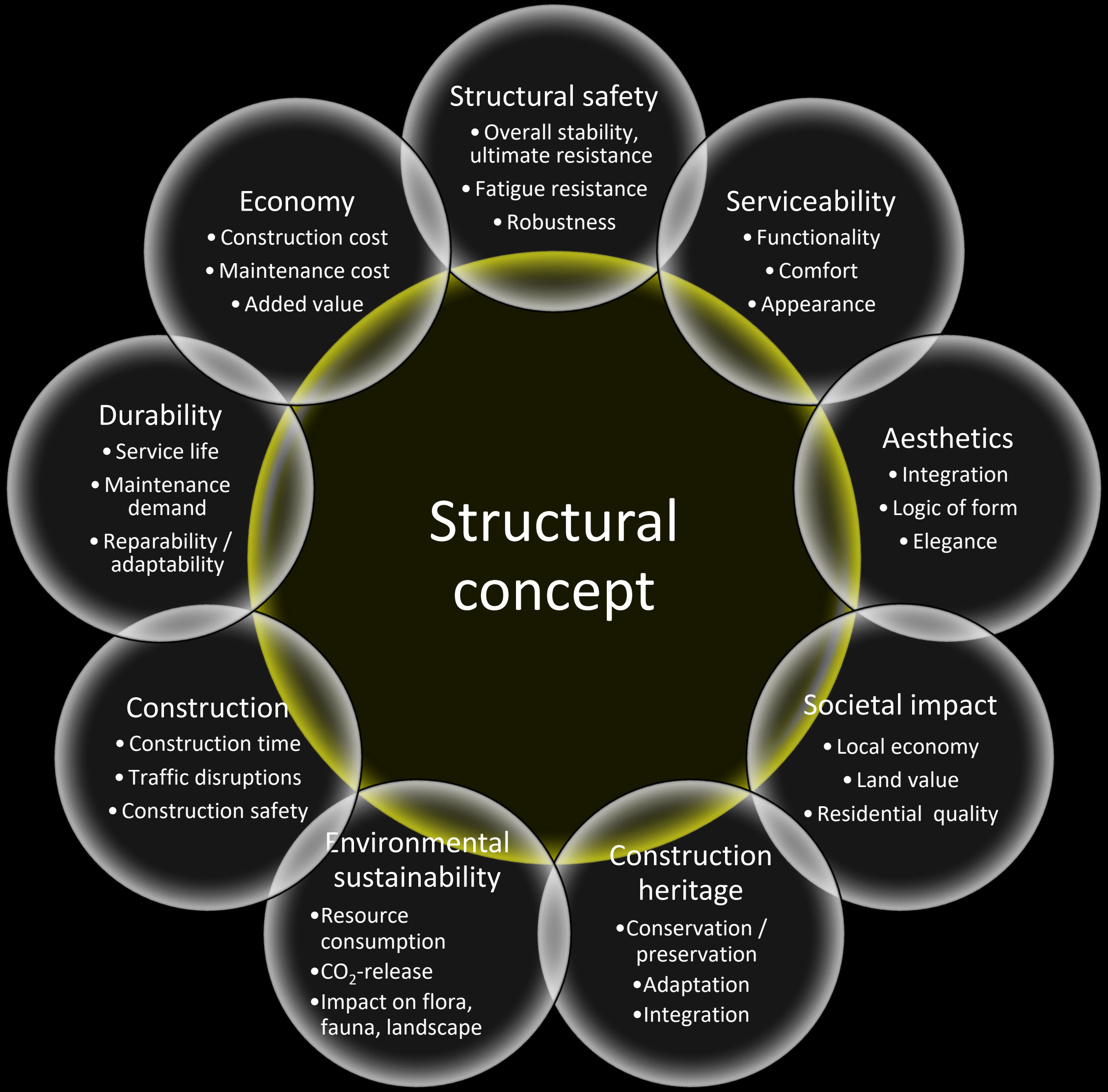


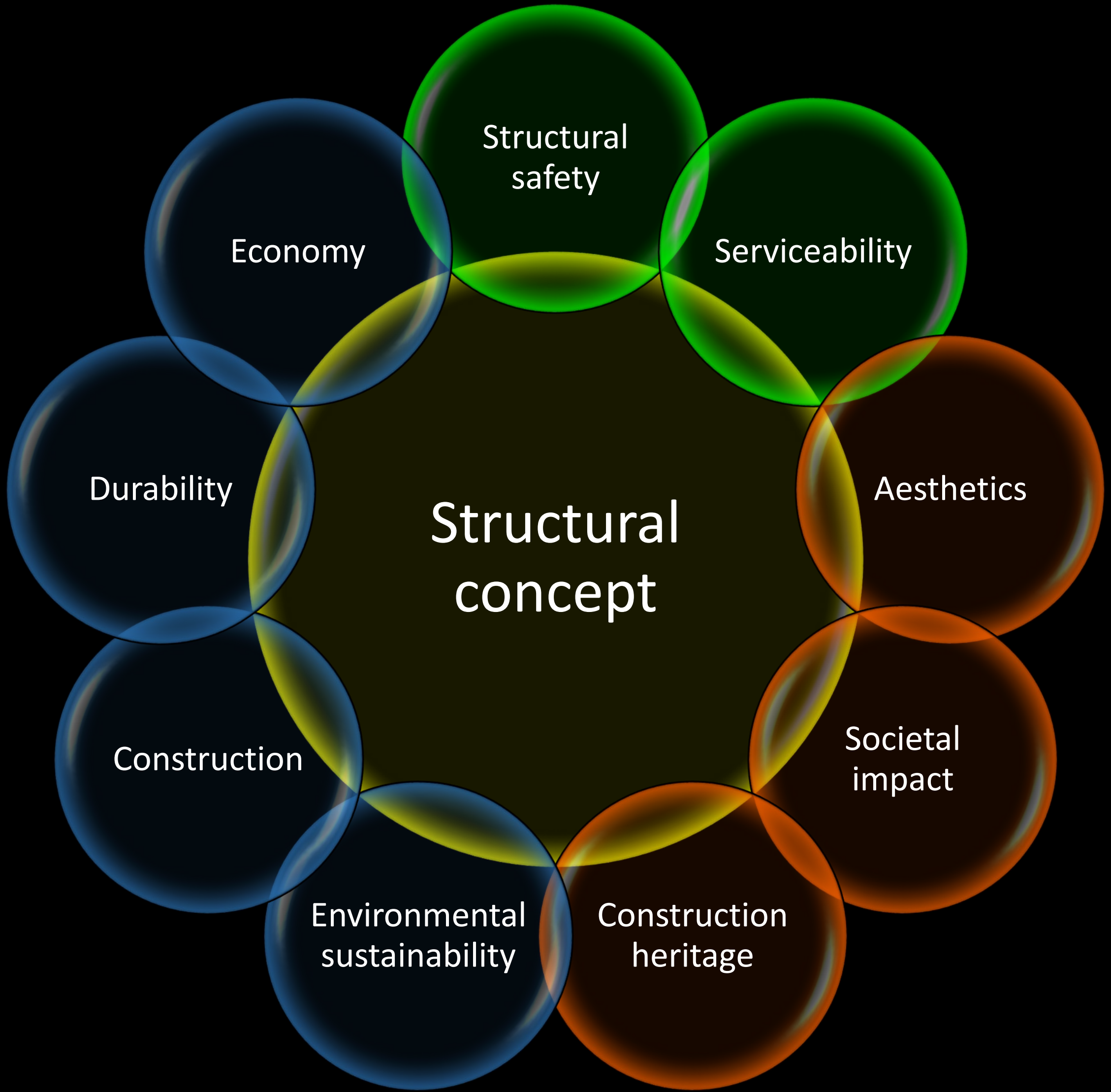
Design Criteria – Overview

- Designing a bridge means developing its Structural Concept, based on the given boundary conditions.
- Designing a bridge is a multi-faceted task, where many different topics are to be mastered by structural engineers, as illustrated schematically in the figure by colour:

  … “classical” structural engineering topics
  … topics closely related to structural engineering
  … topics beyond classic education of structural engineers

- Bridge designers therefore need to have broad interests, and at least a sufficient knowledge in all relevant fields to be able to communicate with experts.

(these design criteria are discussed in the following, except for societal impact which is left out due to limited time).



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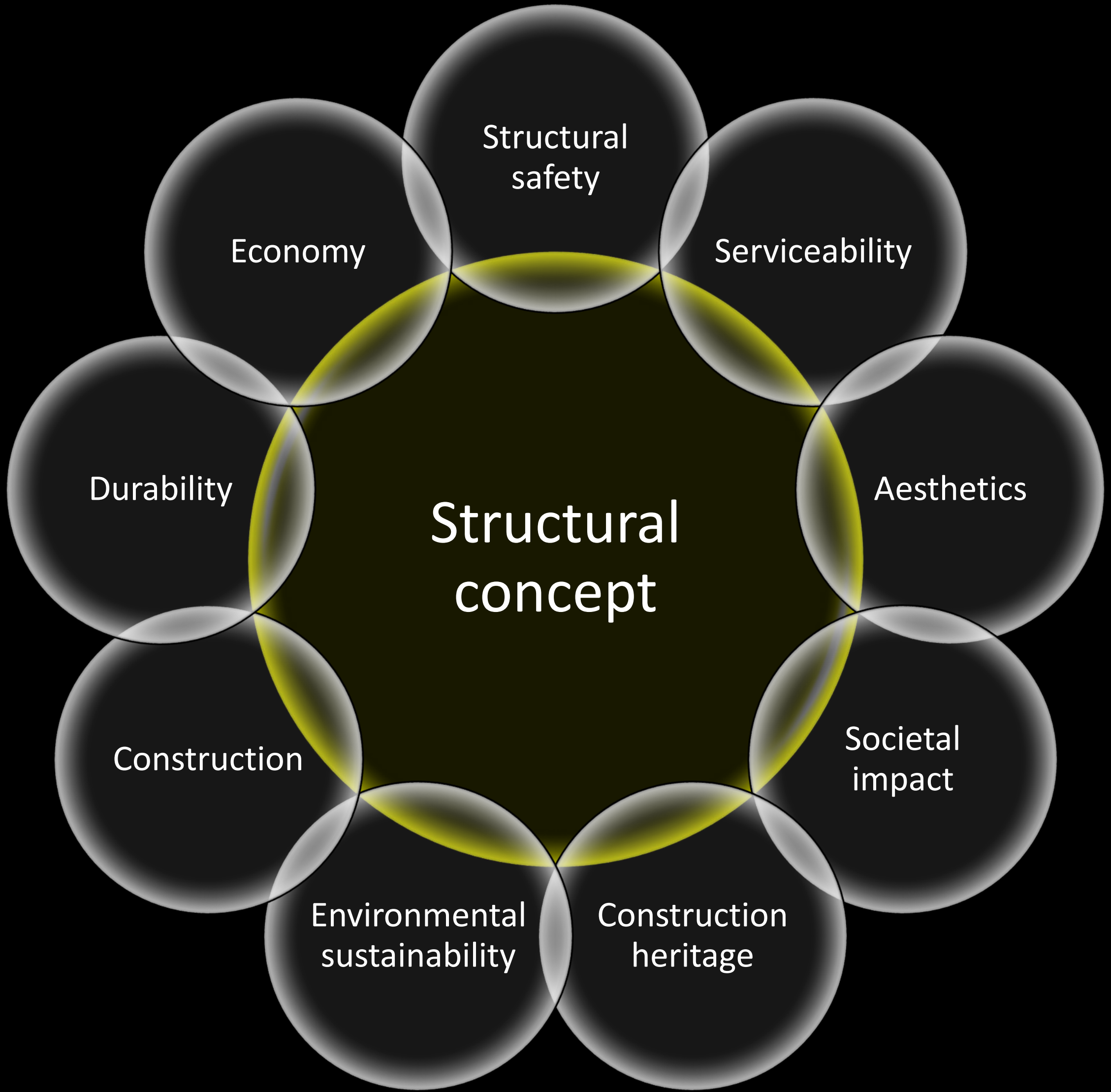
- These criteria are not independent, and many of them are conflicting, or even contradictory

→ Rather than maximising individual criteria, an overall optimum solution is sought



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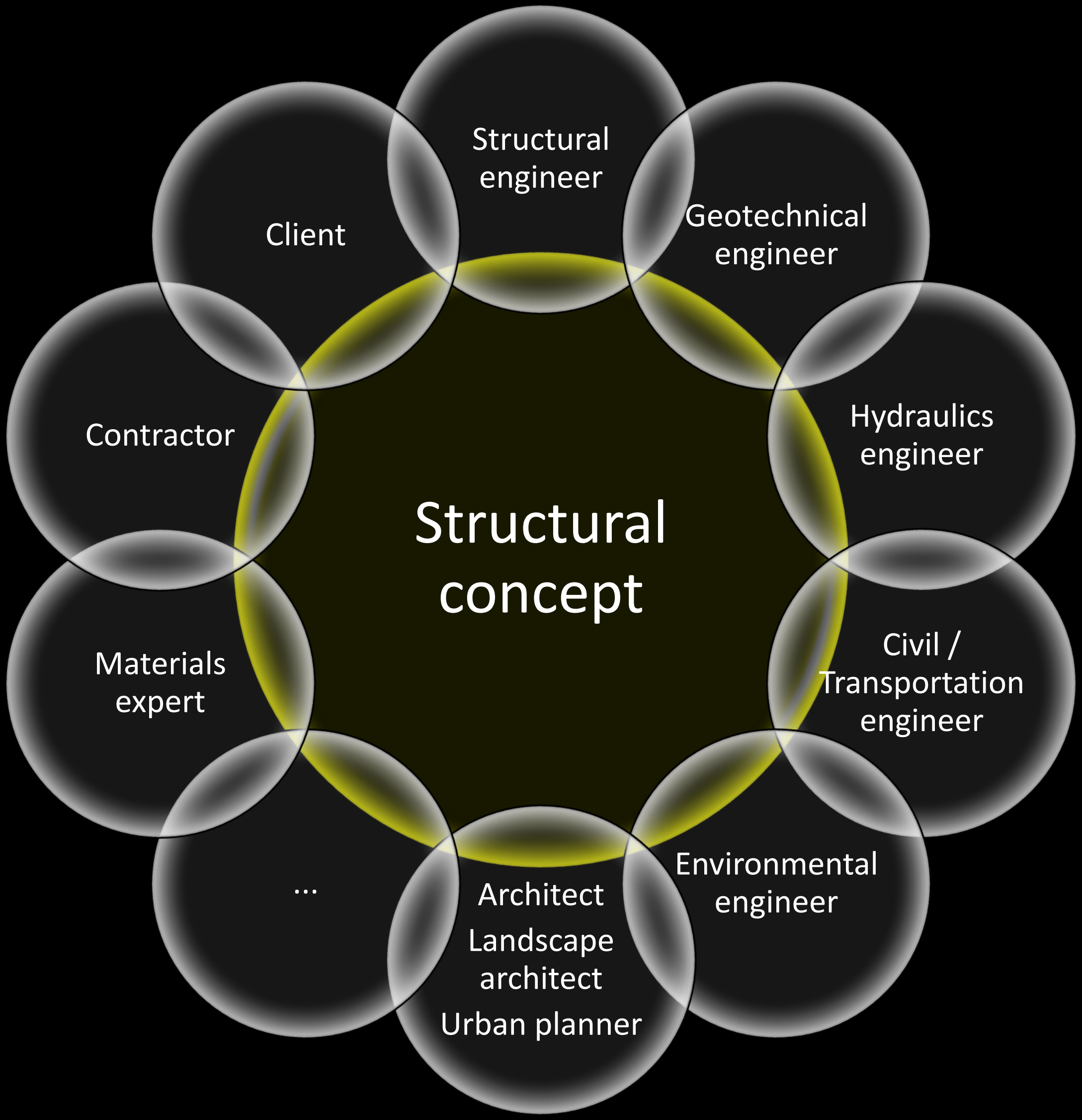
→ Most bridges are designed today in interdisciplinary design teams, covering the expertise relevant for a specific project, led by a structural engineer competent in all relevant topics (but supported by experts where required)



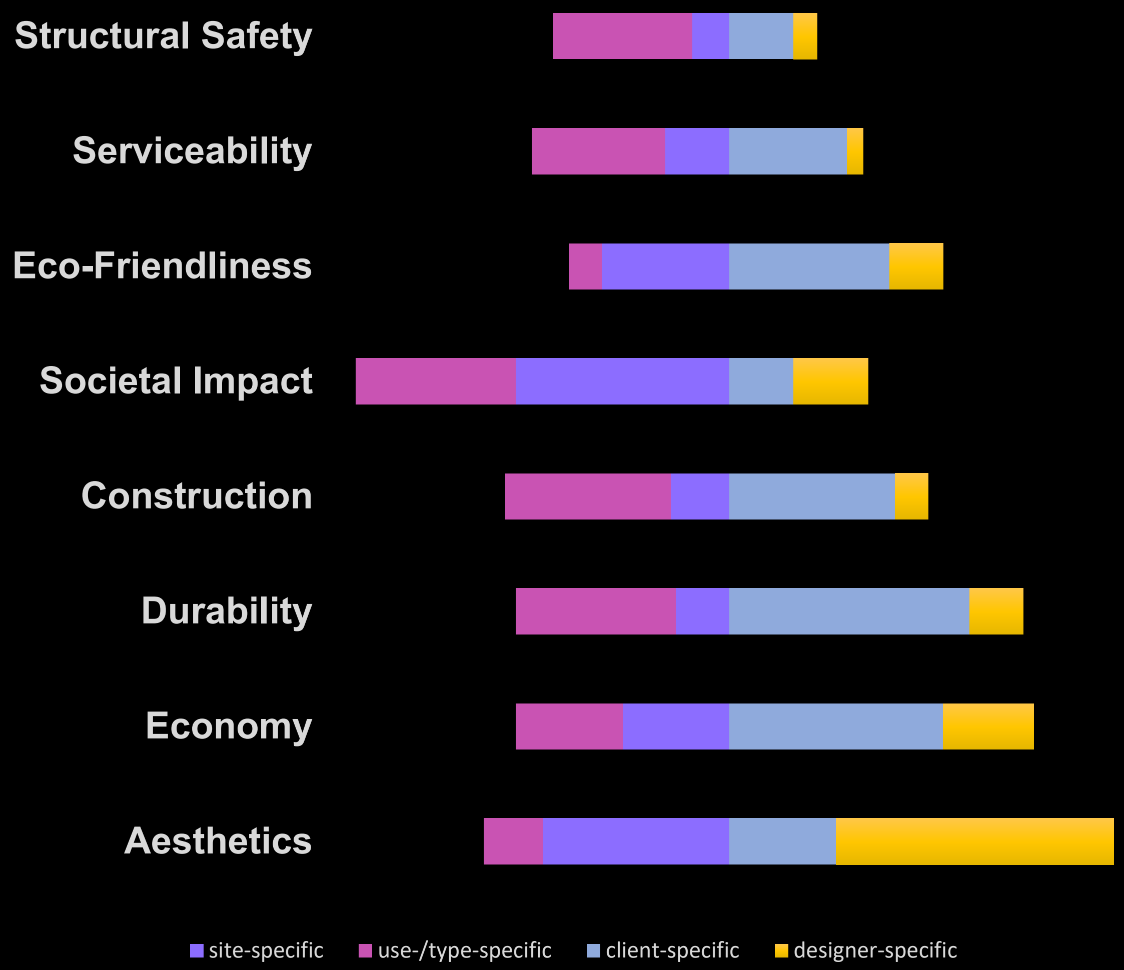
Design Criteria – Overview

- The design criteria depend to some degree on the specific project, in particular

  … the type and use of the bridge
  … the location of the bridge
  … the client's preferences
  … the designer's preferences

- If the bridge site and use are given, and the client is known, there remains much less variation in the design criteria

Note: The graphs to the right on this slide and the following are merely schematic



Design Criteria – Overview

- Most design criteria are project-specific, depending on
  … the type and use of the bridge
  … the location of the bridge
  … the client's preferences
  … the designer's preferences

- The project-specific design criteria should be agreed upon by the owner/client and the design engineers:

  → general aims for the use of the bridge
  → ambient conditions and third-party requirements
  → operational and maintenance requirements
  → special requirements of the owner
  → objectives of protection and special risks

  In Switzerland, these criteria are documented in the Service Criteria Agreement (Nutzungsvereinbarung), which is signed by owner and designer

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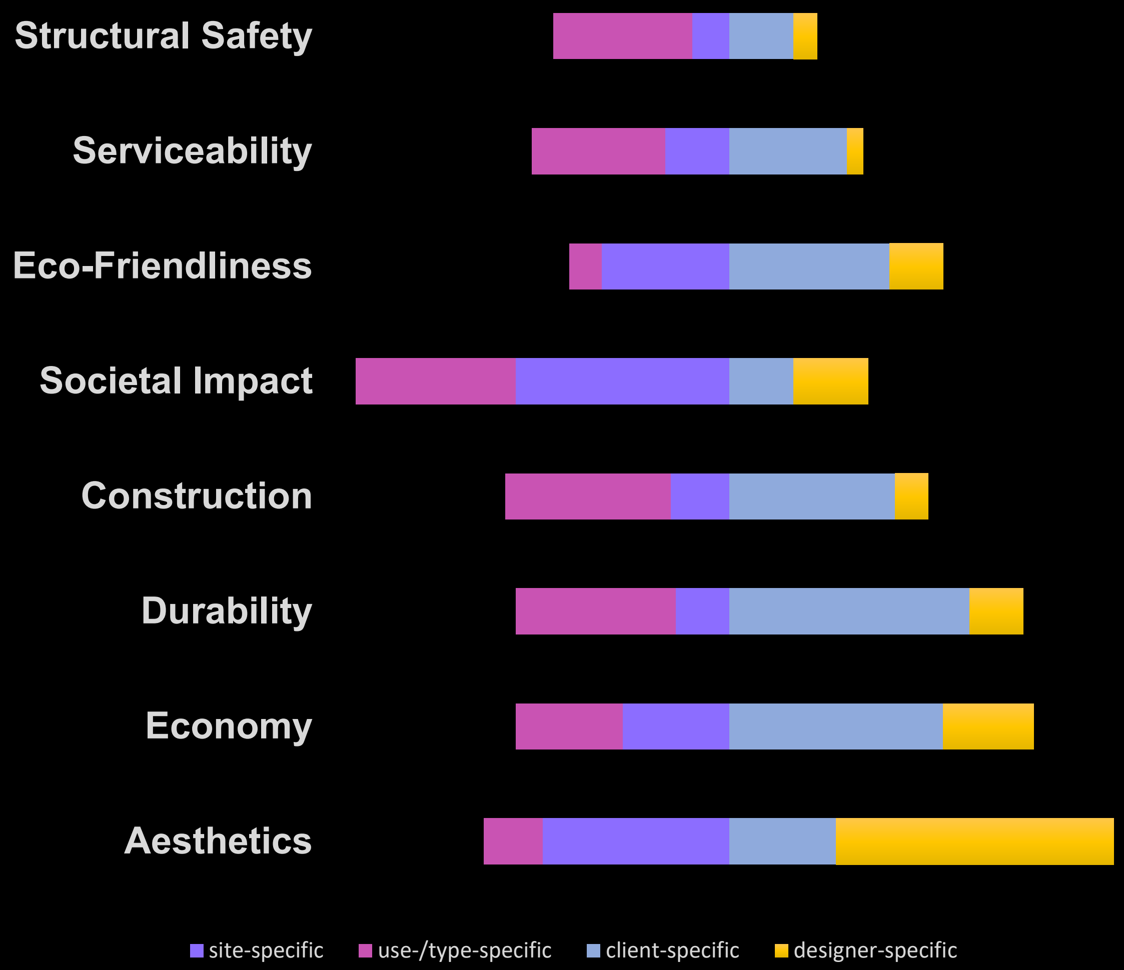
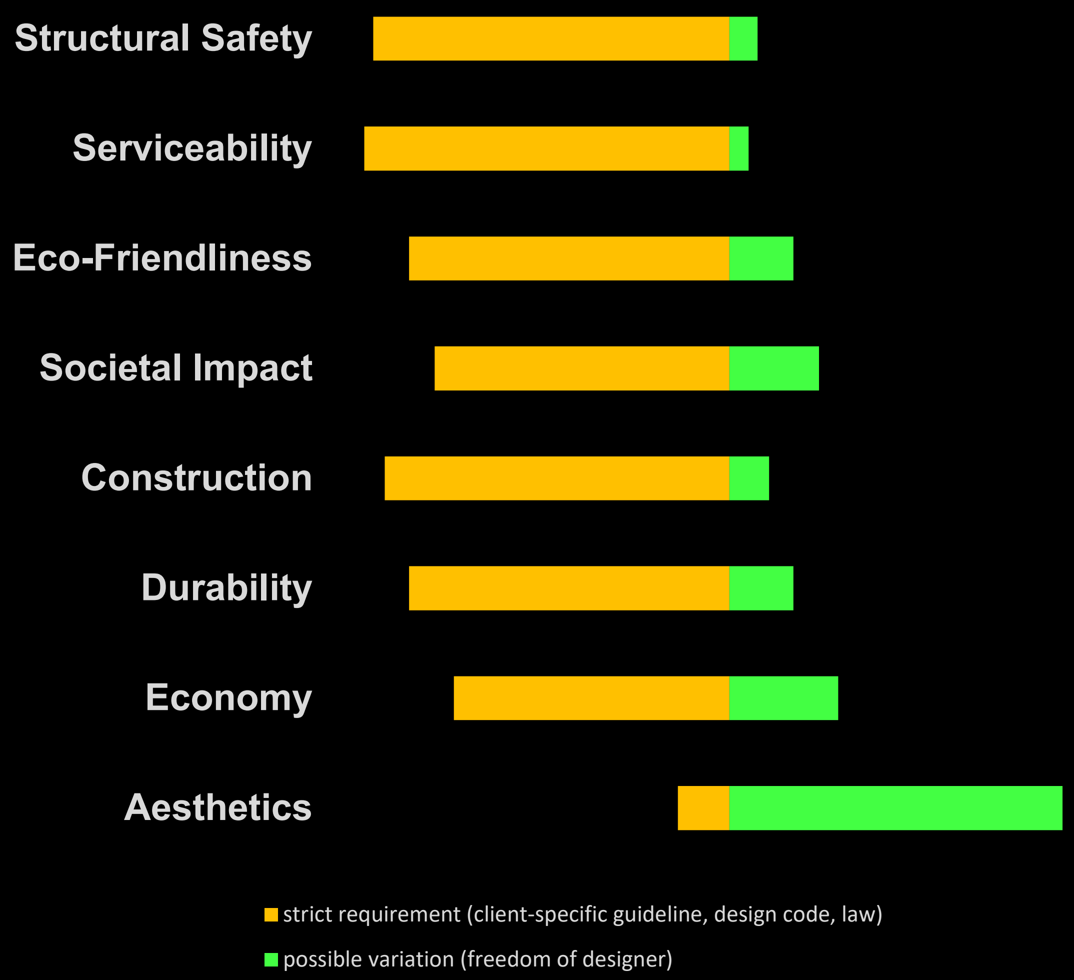


Design Criteria – Overview

- Many design criteria are based on strict requirements, such as guidelines imposed by the client, design codes, or even legal constraints

- Some design criteria are less restrictive and subjective, leaving room for the designer's creativity

- Many design criteria are subjective, and neither an overall design goal nor the relative importance of the individual criteria to achieve this goal can usually be objectively quantified
  - → No single "optimum" solution exists
  - → Finding a good solution is demanding
  - → Formalised decision making methods (weighted scoring method / "Nutzwertanalysen") are of limited use here, and may even be completely misleading



Conceptual Design

Design Criteria – Aesthetics

Entwurfskriterien – Gestaltung

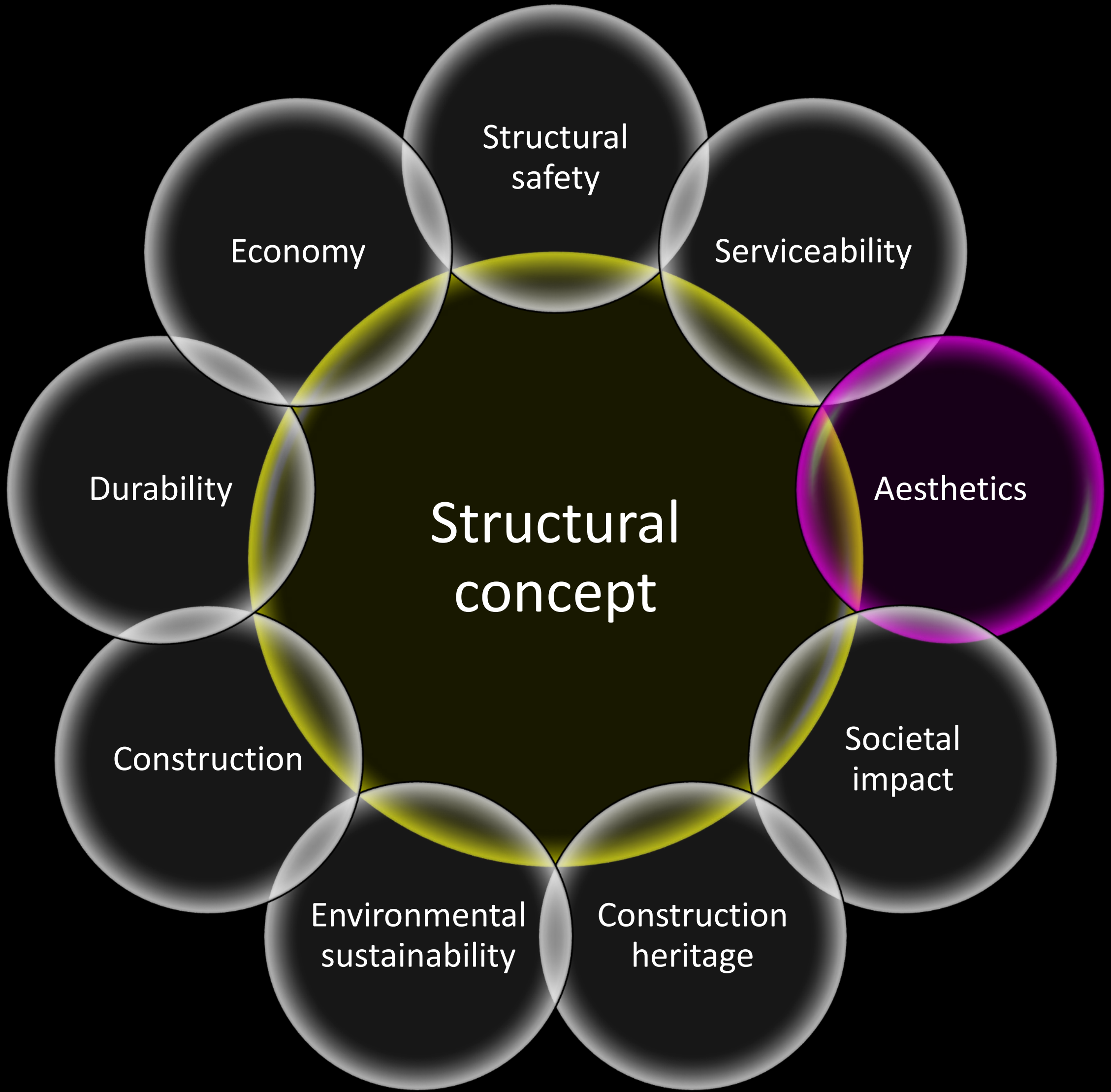
Design Criteria – Aesthetics

- Among all Design criteria, aesthetic quality is the most difficult one to measure
- Aesthetic quality is inherently subjective (individual perception, biased by the observer's socio-cultural background, education and personal preferences / taste)
- Aesthetic quality is hardly ever achieved by embellishment or ornamentation of an otherwise unsatisfactory design

→ Designing bridges of high aesthetic quality can hardly be taught in lectures

→ The course can merely
… insist on the high relevance of aesthetic quality and
… emphasise the responsibility of structural engineers for the built environment
… foster the awareness for aesthetics (open the eyes)

→ Aesthetics will be treated as "embedded topic" throughout the lecture (here, only some basic aspects are discussed)



Design Criteria – Aesthetics

- Bridges are prominent elements of public infrastructure
- Bridges are designed for a long lifespan (centuries)
- Bridges have a high impact on the quality of the built environment
- Bridges are perceived by many people, whether the designer cares about aesthetic quality or not

→ The aesthetic quality of bridges is highly relevant

Design Criteria – Aesthetics

- Bridge designers are responsible for the aesthetic quality of their bridges, as much as for structural safety and serviceability

- Bridges often have the potential to greatly increase the quality of exterior spaces if the opportunities are seized

→ Responsible bridge designers care about the quality of the built environment

Design Criteria – Aesthetics

Even though aesthetic quality is inherently subjective, there are some generally accepted principles to achieve an aesthetically satisfactory design:

- *Eduardo Torroja* postulated the “logic of form” (“Razón y ser de los tipos estructurales”), which is closely related to L. Sullivan’s maxim *form follows function* dating back to 1896
- *David Billington* suggested that an efficient bridge is not only economical, but also elegant: His axiom was “efficiency – economy – elegance”
- *Juan José Arenas* insisted in the importance of ethics, rather than economy (which is related, see next slide)
- *Fritz Leonhardt* established an entire set of aesthetic design principles
- Many authors postulated similar principles (e.g. *A.C. Liebenberg*, *Ch. Menn*, *M. Virlogeux*, …), whose common denominator can be summarised as:

  → Integration (in landscape, urban context, …)

  → Logic of form

  → Elegance (form, proportion, order, …)

Design Criteria – Aesthetics

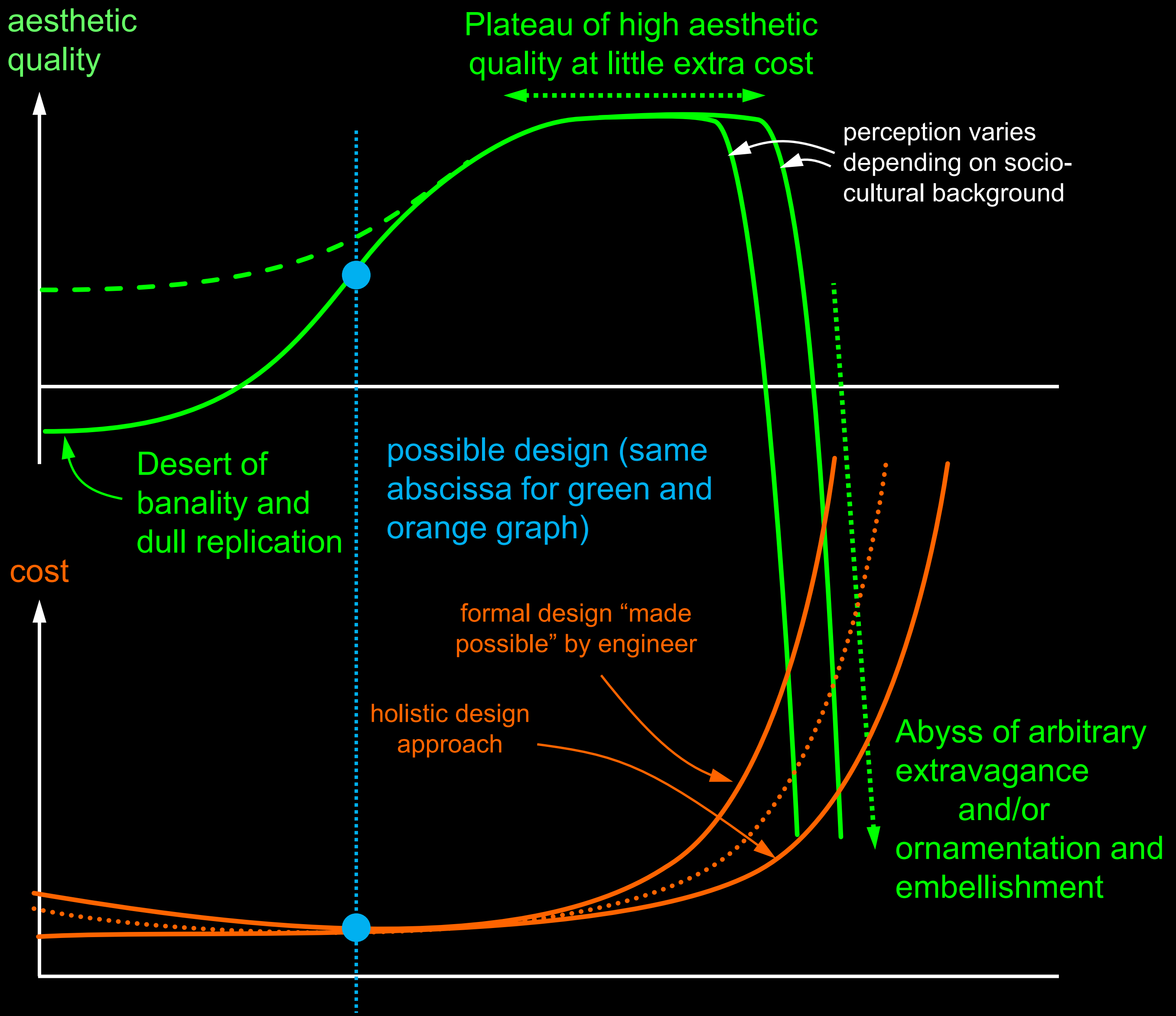
- High aesthetic quality usually causes some extra cost
- This extra cost may be high if an aesthetically bad design is “embellished” or “ornamented", and disproportionate if an arbitrarily extravagant design is “engineered” a posteriori, or unnecessarily long spans and/or complicated typologies are used for the sake of breaking world records

  Aesthetic quality often remains unsatisfactory in such cases, particularly if the form lacks logic – and designing such bridges is ethically questionable, at least if the bridges are paid for by taxpayers

- On the contrary, high aesthetic quality is achieved at very little extra cost by a holistic design approach:

  → consider aesthetics integrally in the design process, together with technical criteria

  → in particular, account for the construction process when designing long-span bridges



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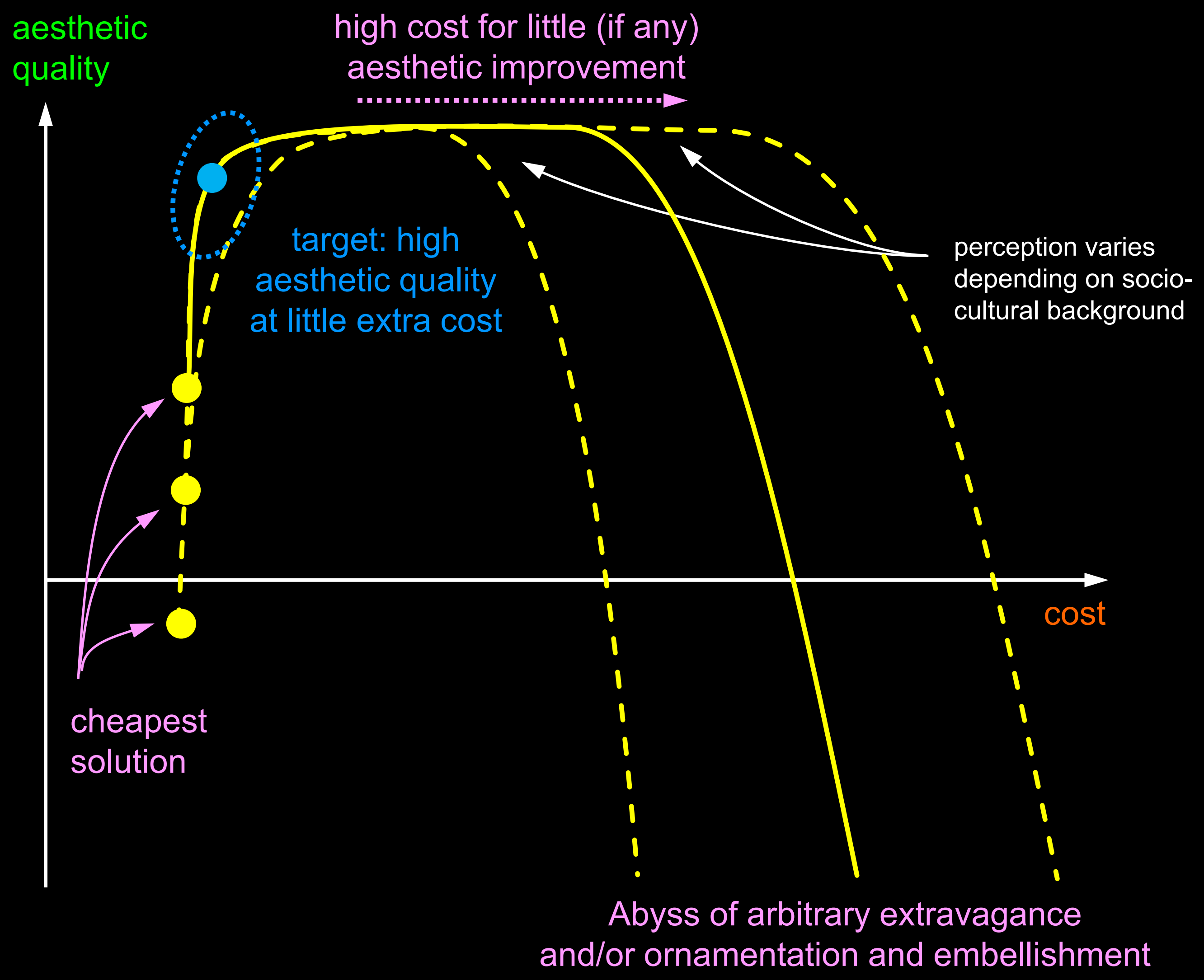

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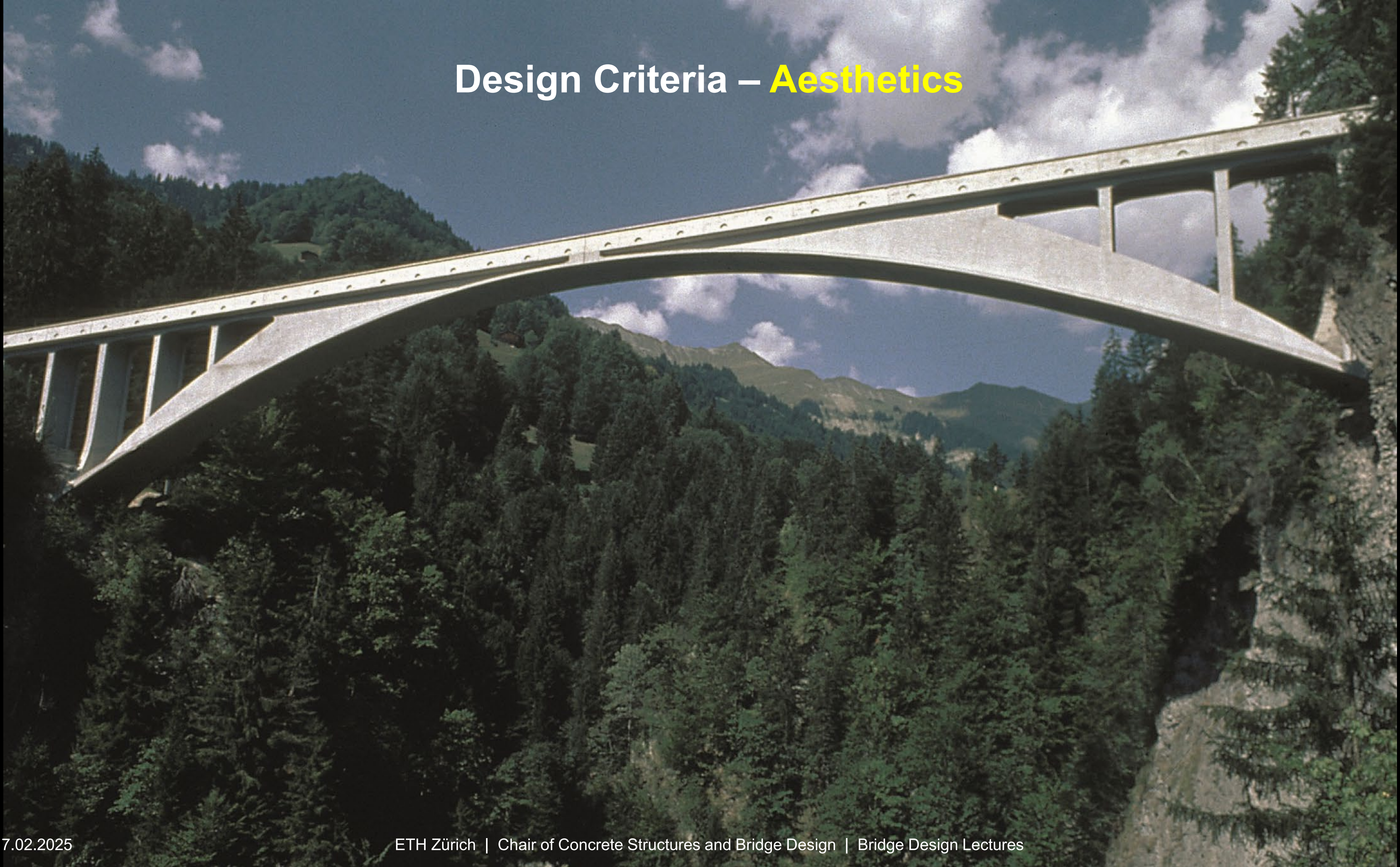


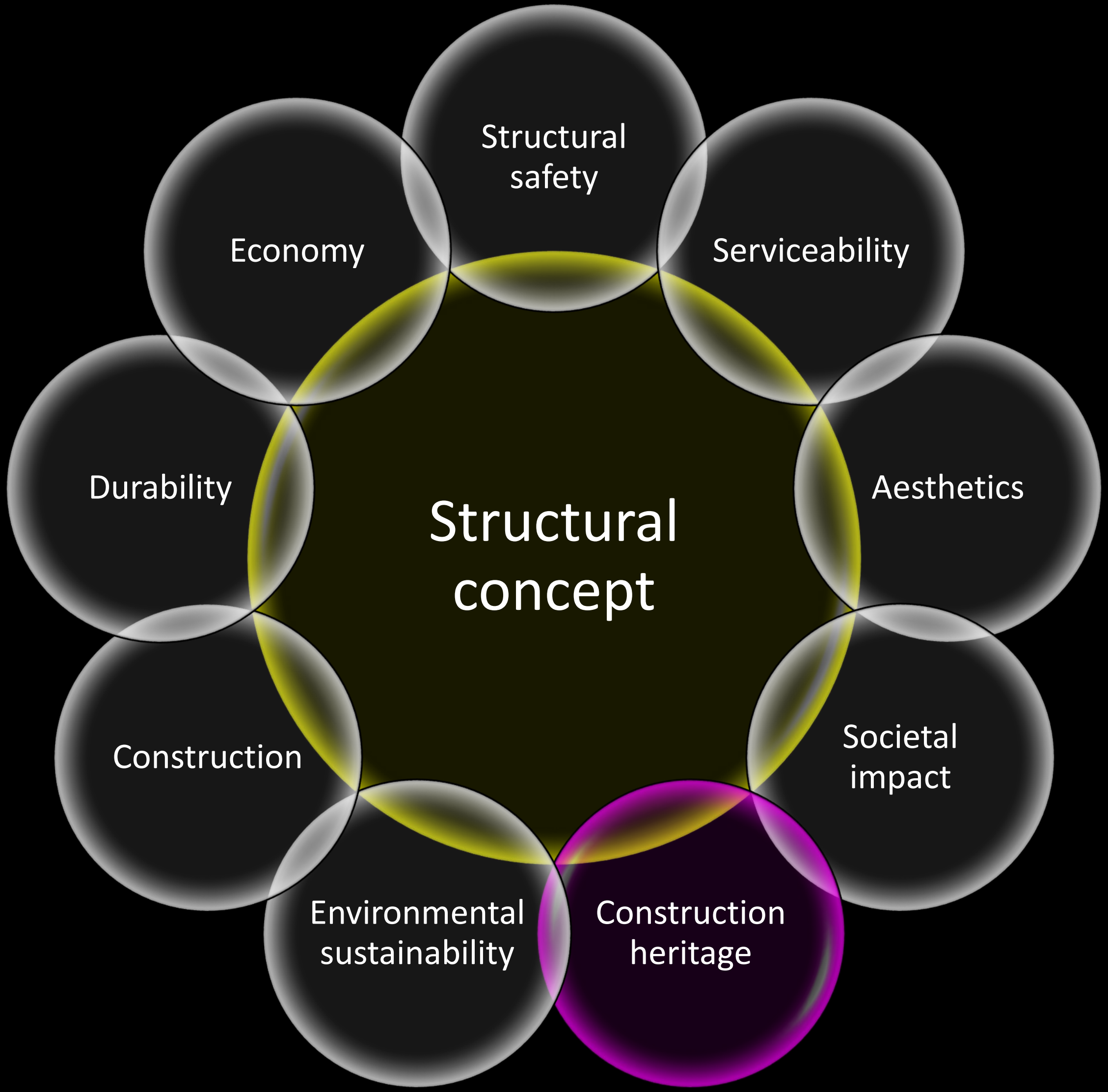
Conceptual Design

Design Criteria – Construction heritage

Entwurfskriterien – Konstruktionserbe / Denkmalpflege

Design Criteria – Construction heritage

- Another design criterion which is difficult to quantify is construction heritage. All bridges become part of it once built. However, only few will ever be worthy of protection.
- The design criterion construction heritage thus refers to situations where:
  - → an existing bridge worthy of protection needs to be replaced or adapted, e.g. due to a required widening
  - → a new bridge is built near a protected monument
- Typically, governmental commissions for monument preservation decide if a bridge is worthy of protection
  - → due to their visible value and character as monument
  - → as milestones of technological development (e.g. first prestressed bridges). This intangible construction heritage is not (yet) protected in CH
- Any interventions affecting protected bridges need to be coordinated with the responsible bodies.
- Even if a historic bridge is not protected, preserving it entirely or partly should be considered as an option in developing the structural concept.



Design Criteria – Construction heritage

- While interventions affecting construction heritage are highly site-specific and need to be coordinated with the responsible bodies, the following guidelines apply:
  - → preserve protected bridges e.g. by considering
    … alternative locations for a new bridge
    … alternative uses of the protected bridge (e.g. use as footbridge with reduced traffic loads)
  - → minimise interventions in protected bridges, preserving as much as possible of the original structure
  - → do not mimic historic construction when replacing or complementing a protected bridge (reconstructions may be viable in exceptional cases, see next slide)
  - → minimise impact of new structure on protected one (avoid spectacular designs, see next slide)
  - → develop a structural concept respecting and, if possible, reflecting the construction heritage (e.g. by adopting the span layout, see photo on this slide or referencing the protected structure – including intangible values – in modern design, see next slide)

Design Criteria – Construction heritage

Good example: BLS railway Viaduct over Saane river near Mauss/ Gümmenen (2021):

The new double track main span references the historic bolted single track Brown truss from 1901 with an innovative modern truss girder (Brown truss informed by shear forces).

The stone masonry viaducts (>400 m length) were adapted to accommodate the new double track line with minimum interventions.

Appropriate exception to the rule of not imitating: Mostar Bridge (Stari Most), reconstructed in 2004 after it had been destroyed in the Croat-Bosniak War

The Lusitania Bridge (1991), a spectacular design with uselessly long span, impairs one of the world's most important preserved Roman Bridges in Mérida (60 arches, over 700 m length)

Conceptual Design

Design Criteria – Structural Safety and Serviceability

Entwurfskriterien – Tragsicherheit und Gebrauchstauglichkeit

Design Criteria – Structural Safety and Serviceability

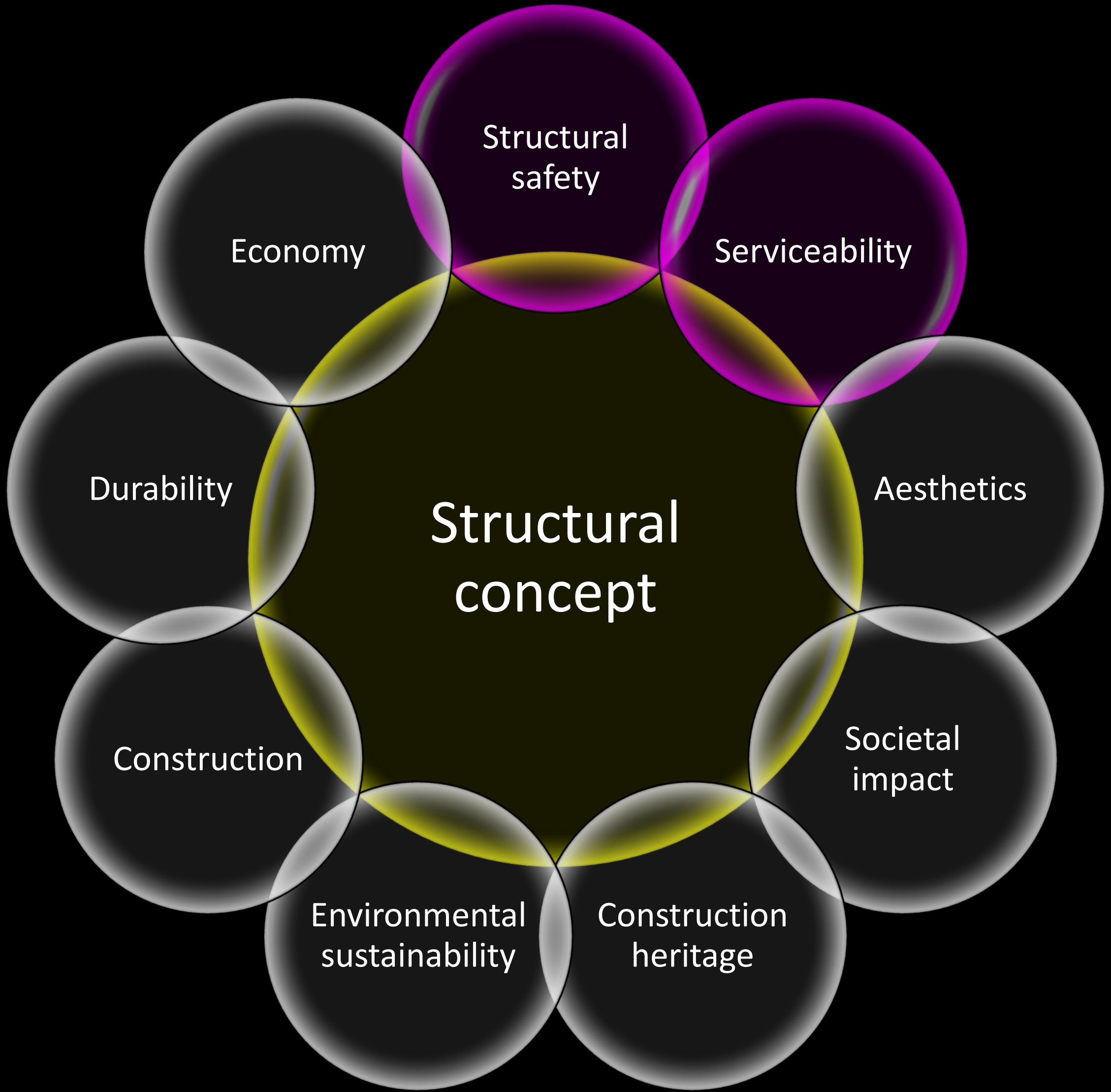
- Structural safety and serviceability have many points In common (loads, limit state design, etc.)
  → treated in same chapter of this the lecture

- The objectives of structural safety and serviceability are of paramount importance
  → specified in detail in design codes

- The project-specific service criteria should be agreed upon by the owner/client and the design engineers
  (→ Service Criteria Agreement / Nutzungsvereinbarung, see overview)

- The basic structural concept, i.e. the
  … structural system
  … relevant dimensions, material properties and details
  … methods of construction

  is developed based on these service criteria



Design Criteria – Structural Safety and Serviceability

- Depending on the concept chosen, specific requirements for the detailed design (dimensioning), execution, use and preservation are obtained:

  → hazard scenarios (Gefährdungsbilder) considered

  → requirements of structural safety, serviceability and durability and measures needed to guarantee them

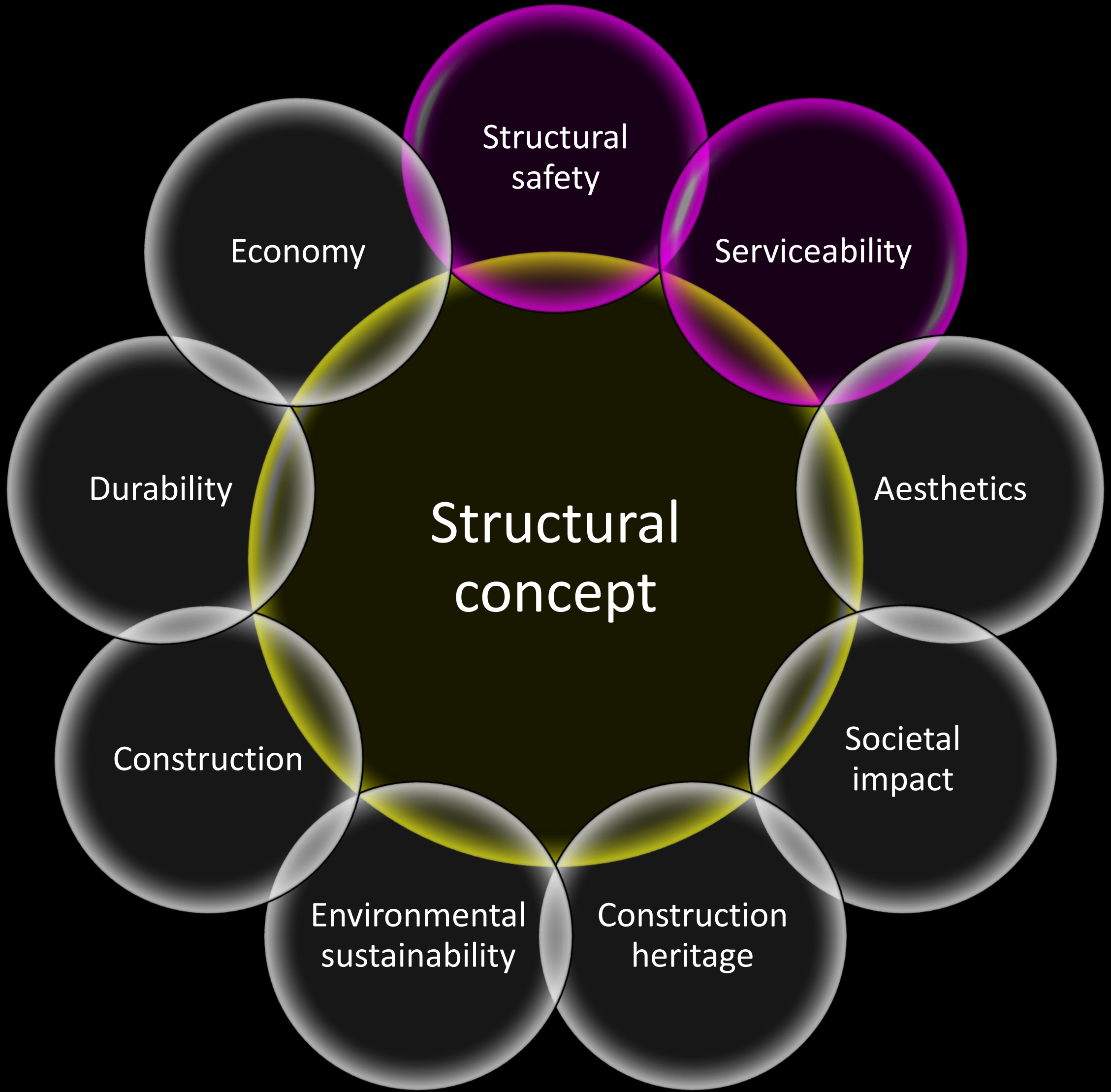
  → ground conditions

  → important assumptions in the structural models

  → accepted risks

  → other conditions relevant to the design

In Switzerland, these requirements are documented in the Basis of Design (Projektbasis), which is usually updated during the detailed design



Conceptual Design

Design Criteria – Structural Safety and Serviceability

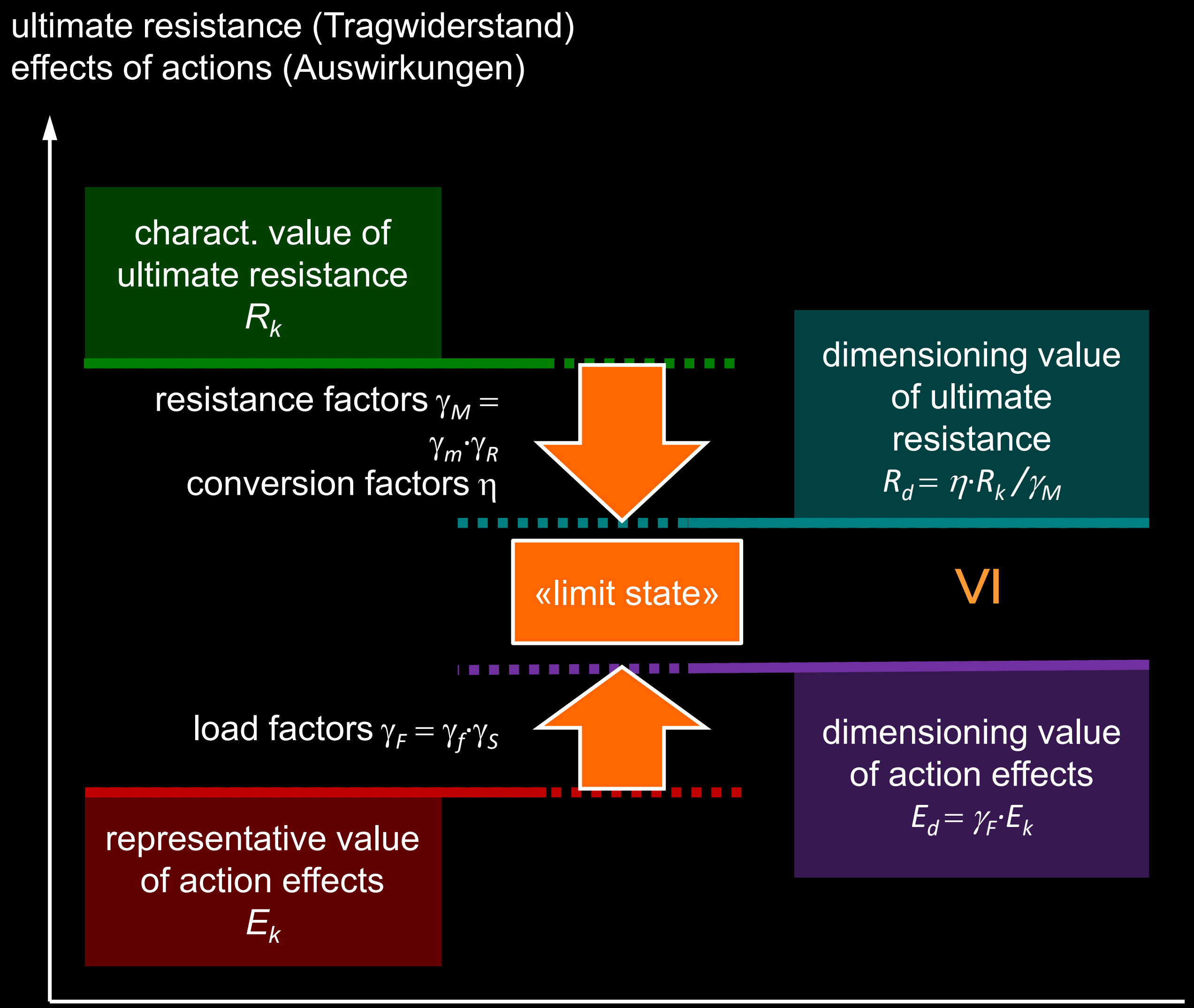
Limit State Design

Bemessung nach Grenzzuständen

Design Criteria – Structural Safety and Serviceability: Limit State Design

- Most modern design codes follow the Limit States approach, aka Load and Resistance Factor Design (LRFD)
- This approach is illustrated on the right for structural safety (often referred to as ultimate limits state = "ULS"), but also applicable to serviceability design (serviceability limit state = "SLS")
- Some codes still allow the use of Allowable Stress Design

- Students are assumed to be familiar with the concept of LRFD and its application to
  … the design of the basic construction materials
  (concrete, steel, timber)
  … and their interaction with soil
  (foundations, retaining structures)
- Thus, the lecture focuses on bridge-specific aspects of the design process



Design Criteria – Structural Safety and Serviceability: Limit State Design

Bridge Design Codes/Standards used around the world include publications by:

Europe

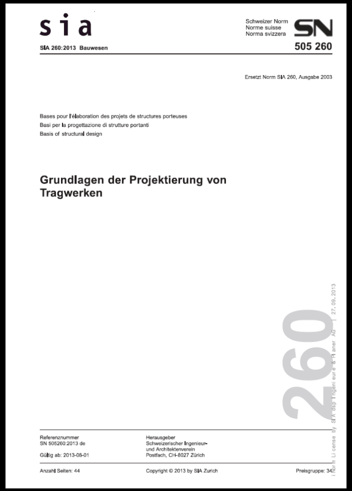
- SIA (Swiss Society of Engineers and Architects)
- EN (European Standards)
- SETRA (service d’études techniques des routes et autoroutes)

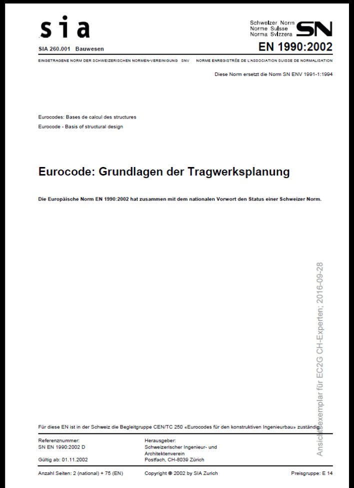
North America

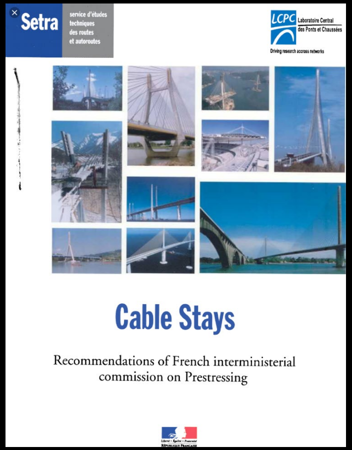
- AASHTO (American Association of State Highway and Transportation Officials)
- AREMA (American Railway Engineering and Maintenance-of-Way Association)
- CSA (Canadian Standards Association)

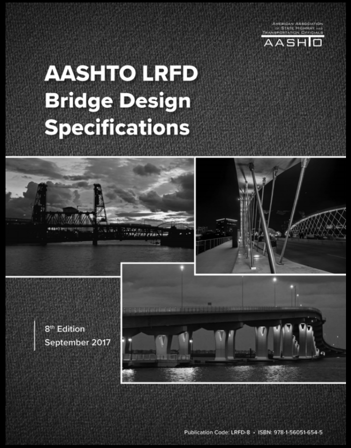
Asia

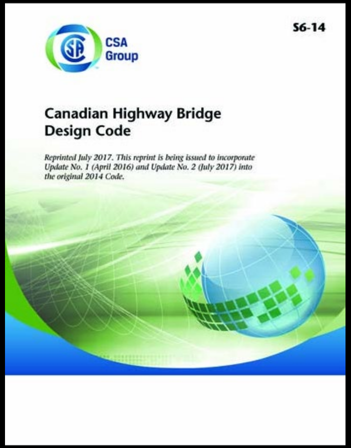
- China National Standards (GB)
- Japanese Association of Highways











Design Criteria – Structural Safety and Serviceability: Limit State Design

SIA 260 defines the following Limit States:

Ultimate Limit States “ULS”

- Concern safety of structure and persons
- Involve:
  - → Overall stability of structure
  - → Ultimate resistance of structure or one of its structural members (incl. supports & foundations)
  - → Fatigue resistance of structure or one of its structural members
- Consider:
  - → Permanent actions
  - → Variable actions
  - → Accidental actions

Always consider: construction phases, operation phase, future maintenance needs

Design Criteria – Structural Safety and Serviceability: Limit State Design

SIA 260 defines the following Limit States:

Serviceability Limit States “SLS”

- Concern functionality & appearance of structure, user comfort
- Criteria applied to:

→ Deformations (functionality, appearance, deterioration)

→ Vibrations (functionality, comfort)

→ Defective sealing (functionality, durability)

→ Cracking/Connection slipping (appearance, durability)

→ Effects on stream flow (environmental impacts)

Conceptual Design

Design Criteria – Structural Safety and Serviceability

Actions

Einwirkungen

Design Criteria – Structural Safety and Serviceability: Actions

Depending on the project, the following types of actions have to be considered:

Permanent Actions
- Dead loads: self-weight of the structure (Eigenlast)
- Superimposed dead loads: self-weight of non-structural components (Auflast) (attachments, utilities)
- Creep and Shrinkage
- Prestress forces including secondary effects
- Locked-in forces resulting from the construction process

Actions imposed by the ground (permanent or transient)
- Earth pressures, downdrag forces
- Soil surcharge
- Water pressure
- Stream flow pressure (see notes)

Variable Actions
- Live Loads (Nutzlasten) – including:
  - Vertical vehicular live load (incl. dynamic allowance)
  - Horizontal vehicular live load (braking, centrifugal and nosing = Schlingerkraft)
  - Vertical and horizontal pedestrian live load
- Friction loads at sliding surfaces (e.g. bearings)
- Wind Loads – on structure and on live load
- Temperature effects – uniform and gradient
- Snow load (see notes)

Accidental (Extreme) loads
- Seismic (earthquake) loads
- Ship impact / Vehicular collision / Train derailment
- Avalanche load
- Ice load
- Blast loading

Design Criteria – Structural Safety and Serviceability: Actions

Live Loads

- The following slides illustrate the traffic load models and provisions of SIA 261 (which is similar to EN1991-2, see notes). Other codes have similar provisions.
- The live loads are introduced following the categories of SIA 261, i.e.
  - non-motorised traffic (→ footbridges, sidewalks)
  - road traffic (→ road bridges)
  - rail traffic (→ railway bridges)
- Project-specific criteria may need to be developed for live loads not explicitly covered, such as:
  - special vehicles, military loads, tramway loads
  - bridges with combined road and rail traffic
  - bridges with spans longer than 200 m

Design Criteria – Structural Safety and Serviceability: Actions

Live Loads – Non-motorised traffic

- Covered in SIA 261, Chapter 9
- Structures covered include:
    1. Pedestrian and cycle path bridges
    2. Bridges at train stations across rail lines
    3. Piers
    4. Walkways on road bridges
    5. Service gangways


1


2

3


4

5

Design Criteria – Structural Safety and Serviceability: Actions

Live Loads – Non-motorised traffic

- Two, independent, non-simultaneously acting load models are considered
- Load Model 1 (crowd of people)
  - Uniformly distributed load q_k = 4.0 kN/m^2
  - Placed in most unfavourable position
- Load Model 2 (*lightweight* maintenance vehicle)
  - Concentrated load Q_k = 10 kN
  - Acting in most unfavourable position, on quadratic / circular bearing area:

- Horizontal Load for footbridges:
  - Acts in longitudinal axis of bridge at surfacing level (together with vertical live load)
  - Max. { 10% $\sum q_k$ or 60% Q_k }

Maximum Credible Loading

2.4 kN/m^2
(50 psf)

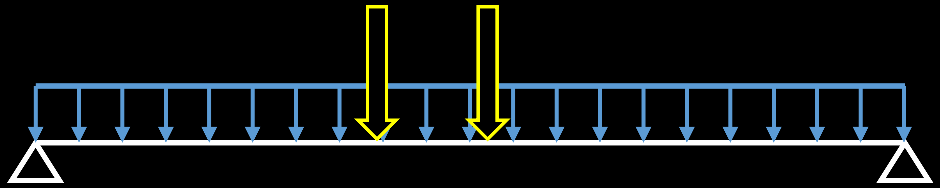
4.8 kN/m^2
(100 psf)

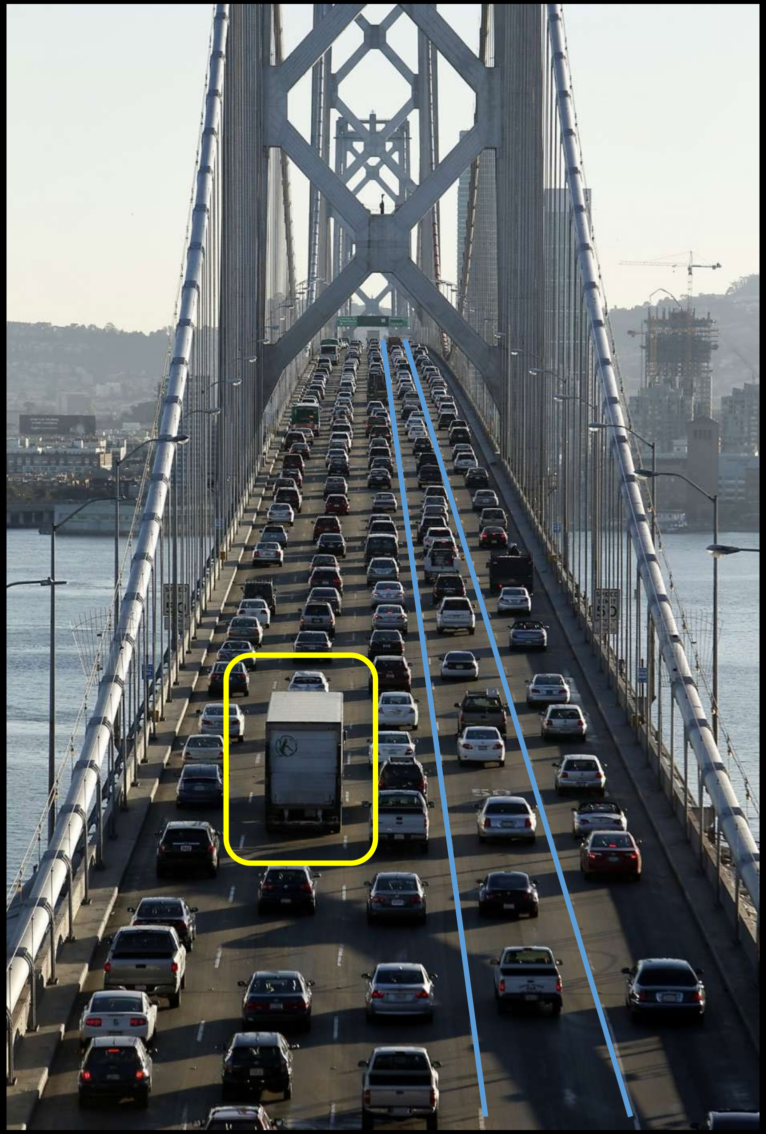
7.2 kN/m^2
(150 psf)

Design Criteria – Structural Safety and Serviceability: Actions

Live Loads – Road traffic

- Covered in SIA 261, Chapter 10
- Only normal use by road traffic is covered
- Special vehicles not covered
- For L > 200 m, special investigations may be warranted
- Traffic loads typically idealised as:
  1. Concentrated axle loads representing heavy vehicles (trucks / lorries)
  2. Uniformly distributed loads representing heavy traffic (trucks) on one lane and light vehicles (cars) and the remaining lanes



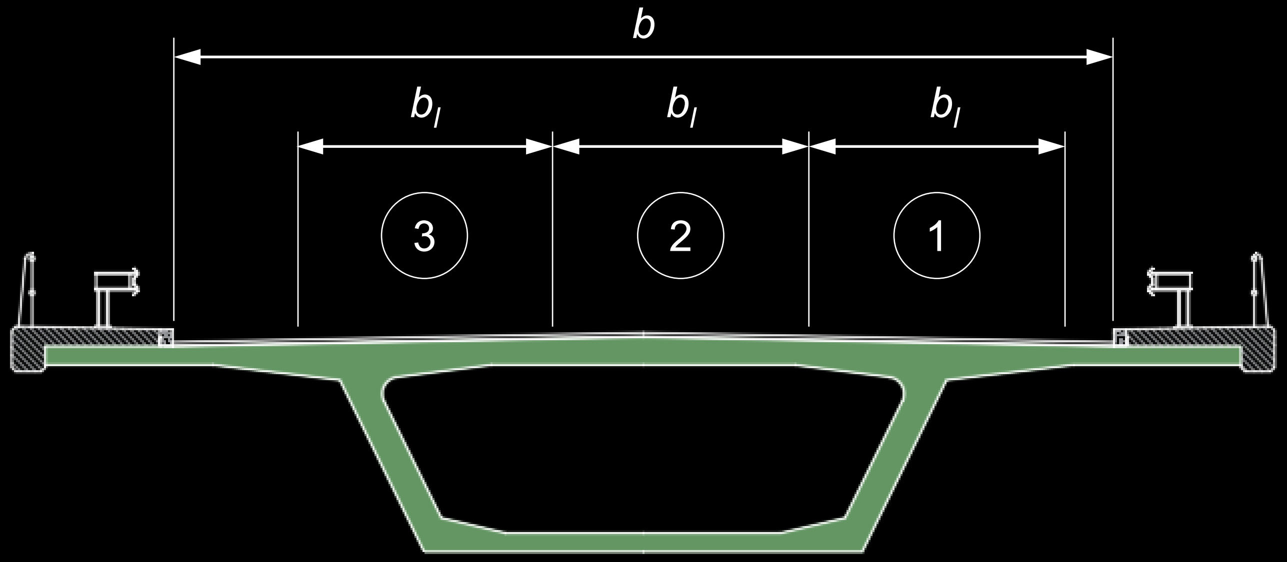


Design Criteria – Structural Safety and Serviceability: Actions

Live Loads – Road traffic

Division of roadway:

1. Define roadway width, *b*
2. Divide the roadway width into notional (fictitious) lanes according to table
3. Locate & number the notional lanes:
   - Depends on type of verification
   - Maximise effects of loading
   - Most unfavourable effect → Lane Number 1, second most unfavourable effect → Lane Number 2, etc.



Roadway width b	Number of notional lanes	Width of a notional lane b_l	Width of the remaining area
$b < 5.4$ m	$n_l = 1$	3 m	b – 3 m
5.4 m ≤ b < 6 m	$n_l = 2$	b / 2	0
6 m ≤ b	n_l = Int [b / (3 m)]	3 m	b – (3 m) x n_l

Note: Influence lines help identifying the governing load positions

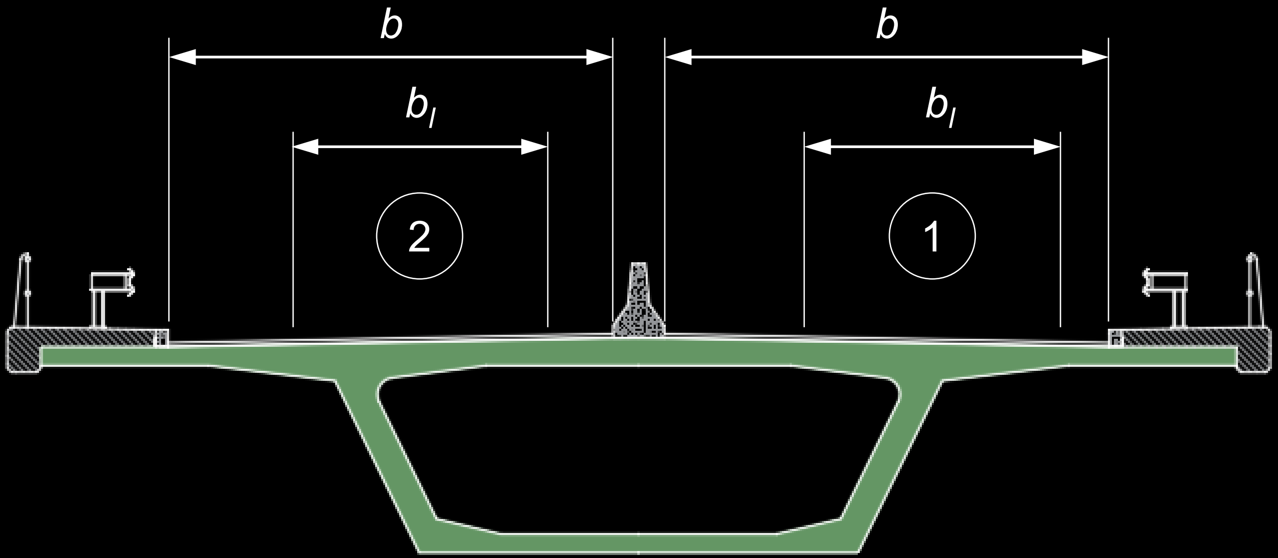
Design Criteria – Structural Safety and Serviceability: Actions

Live Loads – Road traffic

Division of roadway – Special Cases:

Separated roadways on common superstructure:

- If separation is permanent, each part of the roadway may be considered separately (for division into notional lanes), but numbering of notional lanes is continuous, i.e. there is only one Lane Number 1
- However, to account for future modifications, it is common to ignore the median barrier when defining notional lanes → conservative



Design Criteria – Structural Safety and Serviceability: Actions

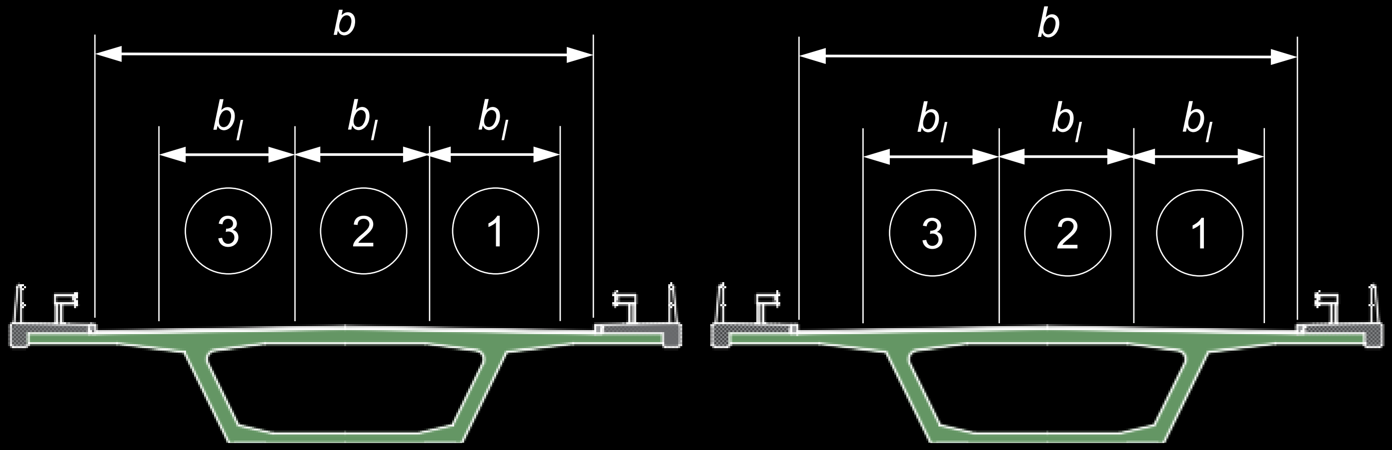
Live Loads – Road traffic

Division of roadway – Special Cases:

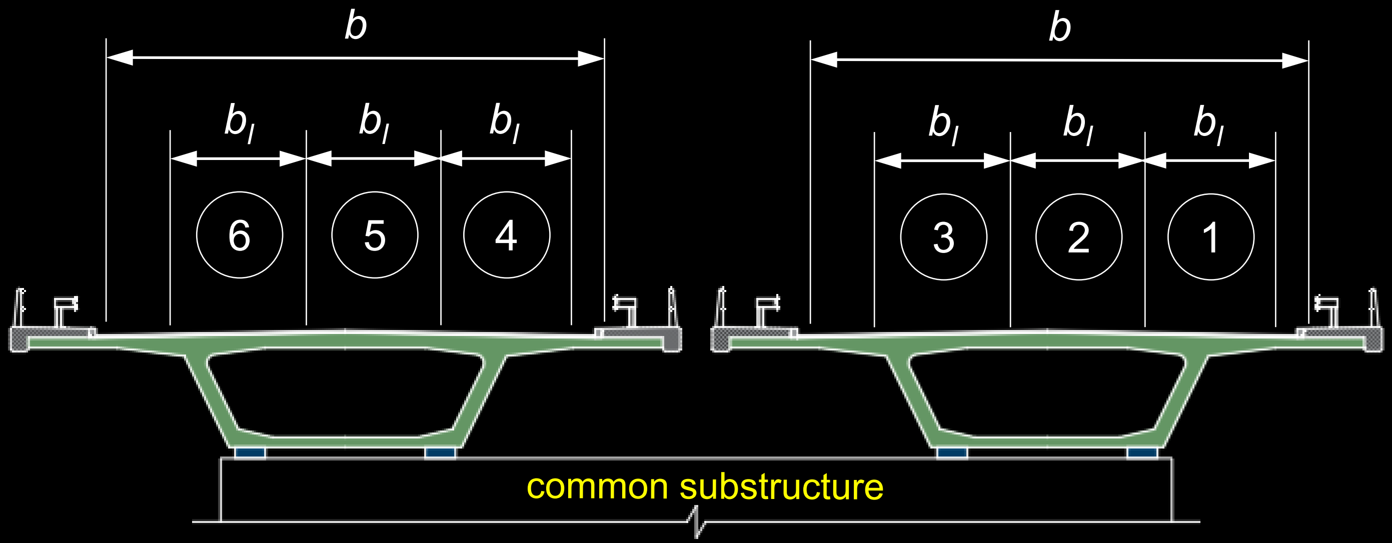
Separated roadways on independent superstructures:

- Each superstructure is considered separately, i.e. lane numbering is not continuous (two lanes Number 1).
- If substructure is common for both superstructures, numbering of notional lanes is continuous, i.e. there is only one Lane Number 1 for the design of the substructure elements.

Notional lanes for superstructure design:



Notional lanes for substructure design:



Design Criteria – Structural Safety and Serviceability: Actions

Live Loads – Road traffic

Application of Traffic Loads:

Load Model 1 (LM1):

- Axle Loads

  Lane 1: Q_{k1} = 300 kN

  Lane 2: Q_{k2} = 200 kN

- Uniformly distributed load

  Lane 1: q_{k1} = 9.0 kN/m^2

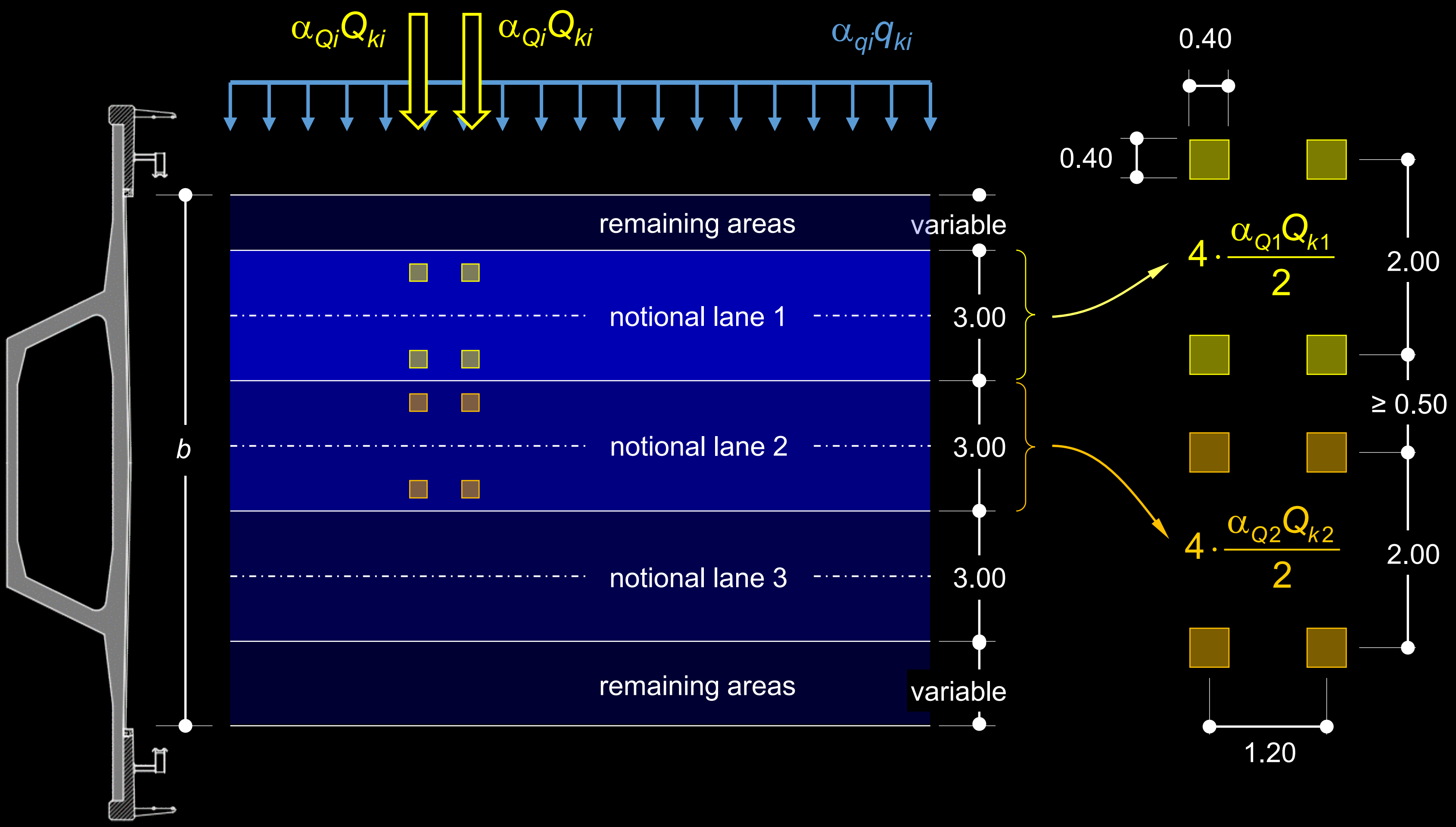
  Elsewhere: q_k = 2.5 kN/m^2

  (including remaining areas)

- α factors:

  Account for composition & density of traffic

  Normally: $\alpha_Q = \alpha_q = 0.9$



[Dimensions in m]

Design Criteria – Structural Safety and Serviceability: Actions

Live Loads – Road traffic

'Horizontal' Forces (only in combination with LM1):

Acceleration (QA) and braking (QB) forces:

- Modelled by 'horizontal' forces acting at the height of the roadway surface
- Correspond to the vertical loads of LM1 on Lane 1:

  $QA_k = QB_k = 1.2\ \alpha_{Q1}\ Q_{k1} + 0.1\ \alpha_{q1}\ q_{k1}\ b_1\ L$

  $QA_k = QB_k \leq 900$ kN

  where L = distance between expansion joints
- Act in the axis of Lane 1

  (For simplicity the line of action may be taken as the axis of the roadway, unless the eccentricity has a significant influence on the internal forces of the structure)

Centrifugal (QZ) and transverse forces:

- Generally of secondary importance in road bridges
- Centrifugal forces assumed to act in a radial direction at the height of the roadway surface:

Radius of curvature r	QZ_k
r < 200 m	$0.2\ Q_v$
200 m ≤ r ≤ 1500 m	$Q_v\ (40\text{ m} / r)$
r > 1500 m	0

where $Q_v = \sum \alpha_{Qi}\ (2Q_{ki})$ *[from LM1]*

- With the braking force QB_k acting in the longitudinal direction, a simultaneous transverse force of $0.25QB_k$ shall be assumed.

Design Criteria – Structural Safety and Serviceability: Actions

Live Loads – Road traffic

Fatigue:

- Structural members subjected to load cycles shall be investigated for fatigue effects.
- Number of load cycles depends on:
  - Service (working) life of bridge

    Typically 70…75 years for new bridges (often, design is carried out for infinite fatigue life = Dauerfestigkeit)
  - Volume of traffic

    Indicative values below:

Road category	Example	Number of vehicles over 3.5 t per year and direction of traffic
1	national highways	2 000 000
2	main roads	500 000
3	collecting roads	125 000
4	access roads	50 000

- Only axle loads of Load Model 1, acting on notional Lane 1 shall be considered
- Transverse placement of the axle loads corresponds to the effective (driving) lane, not notional lanes.
- Longitudinally, axle loads are arranged in the most unfavourable positions to determine the maximum and minimum stresses for the considered member

Design Criteria – Structural Safety and Serviceability: Actions

Live Loads – Rail traffic

- Covered in SIA 261, Chapter 11 (and 12 for narrow gauge)
- Focus on Normal Gauge (1435 mm) rail, design speed ≤ 200 km/h (high speed and narrow gauge rail loads are similar in principle)
- Design based on planned number and position of tracks
- Account for:
  - Track deviations from planned position
  - Uneven distribution of axle loads on rails
- Service criteria agreement and basis of design shall specify (where applicable):
  - Alternative track positions (e.g. in railway station underpasses, consider tracks in any transverse position)
  - Loads models for trains not covered by code
  - Need for load tests
  - Load models and aerodynamic forces for V > 200 km/h

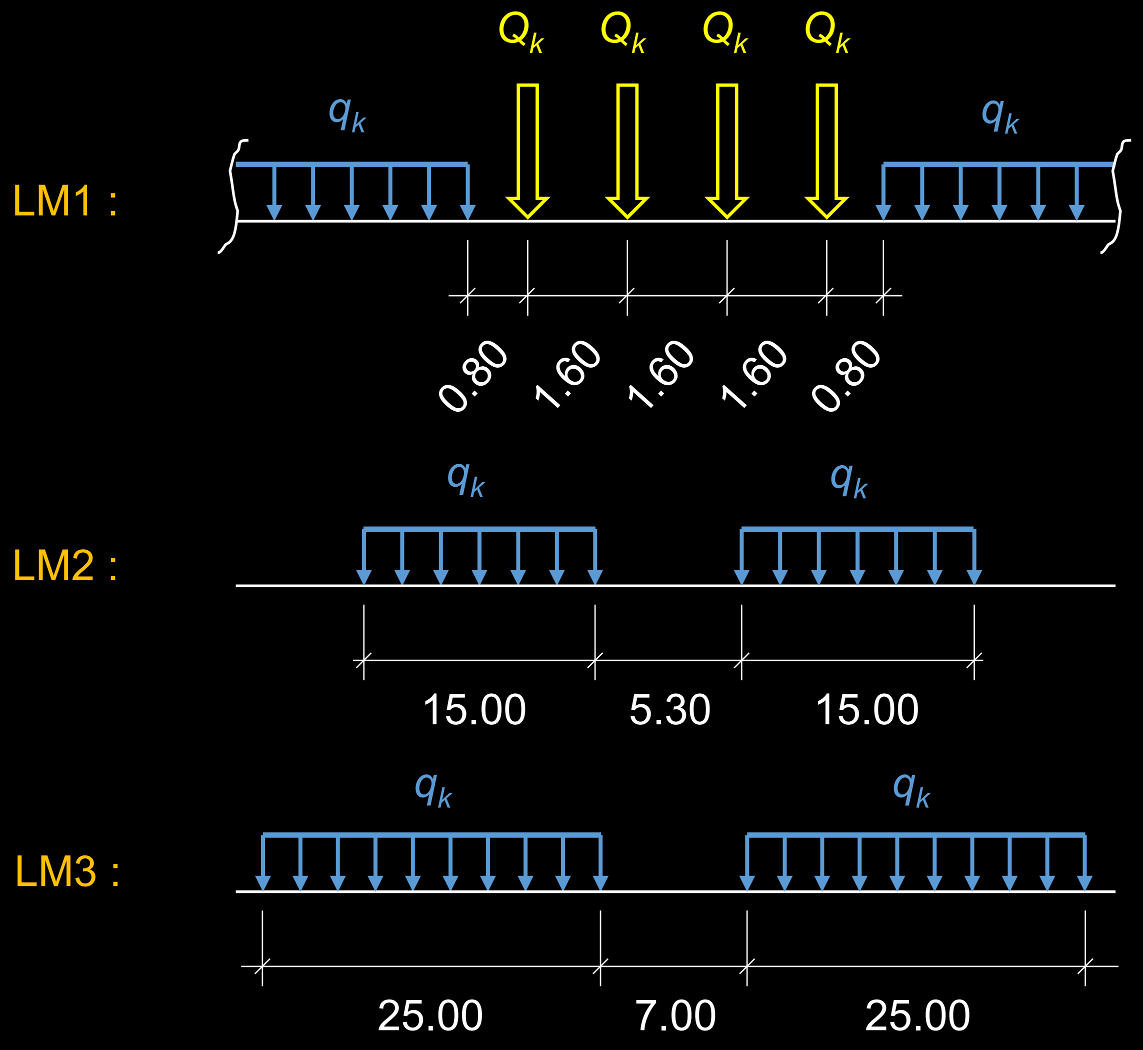
Design Criteria – Structural Safety and Serviceability: Actions

Live Loads – Rail traffic

Load Models (static effect)

- LM1 – normal rail traffic
- LM2 – normal rail traffic on continuous girders (to be applied only once per track)
- LM3 – heavy rail traffic (to be applied only once per structure, and only where applicable, to be decided by supervisory authority)

Load Model	Q_k [kN]	q_k [kN/m]
1	250	80
2	-	133
3	-	150



Design Criteria – Structural Safety and Serviceability: Actions

- **Live Loads – Rail traffic:**

Acceleration (QA) and braking (QB) forces:

- Modelled by 'horizontal' forces acting in the axis of the track at the top of the rails
- Assumed uniformly distributed over length l [m] on which vertical rail traffic loads act:

Load Model	QA_k [kN]	QB_k [kN]
1	$33\ l \leq 1000$	$20\ l \leq 6000$
2	$33\ l \leq 1000$	$20\ l$
3	$33\ l \leq 1000$	$35\ l$

- For special construction (sliding platforms, moveable bridges) values shall be increased by 25%
- For structures with l > 300 m, QA_k & QB_k shall be specified through consultation with the supervisory authority

Nosing force (Schlingerkraft QS):

- Accounts for effect of lateral impacts caused by nosing of the vehicle
- Modelled by 'horizontal' concentrated force acting in the most unfavourable position, at the top of the rails, perpendicular to the axis of the track:
- QS_k = 100 kN

Design Criteria – Structural Safety and Serviceability: Actions

- **Live Loads – Rail traffic:**

  Centrifugal forces (QZ, qZ):

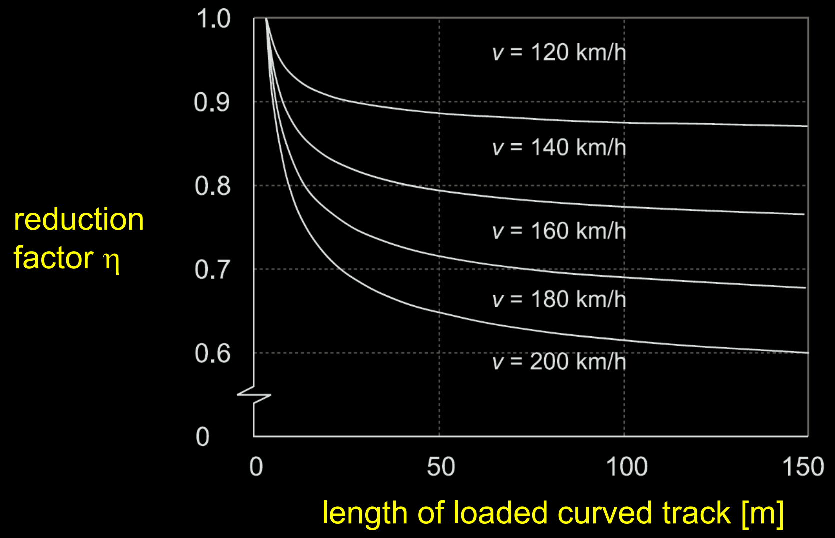
  - Considered in the case of curved track sections
  - Assumed to act in a radial direction, 1.8 m above the top of the rails
  - Characteristic values are a function of the vertical rail traffic loads (for all load models):

$$QZ_k = \frac{\eta v^2 Q_k}{rg} \qquad qZ_k = \frac{\eta v^2 q_k}{rg}$$

  where:

  - g = acceleration of gravity (9.81 m/s^2)
  - r = radius of curvature (m)
  - v = design speed (m/s)
  - η = reduction factor if v > 120 km/h

- Design speed specified by supervisory authority
- For LM3, $v \leq 80$ km/h (= 22.2 m/s)
- For $v > 120$ km/h, check for:
  - Full loads LM1 or LM2 with QZ & qZ for v = 120 km/h
  - LM1 or LM2 multiplied by η together with corresp. QZ & qZ forces for specified $v > 120$ km/h



Design Criteria – Structural Safety and Serviceability: Actions

Live Loads – Rail traffic

Dynamic Factor

Accounts for track/vehicle imperfections

$$\Phi = \frac{1.44}{\sqrt{l_\Phi} - 0.2} + 0.82 \qquad 1 \leq \Phi \leq 1.67$$

where l_Φ (m), the decisive length (table 15 of SIA 261)

For arch and concrete bridges with cover > 1 m, Φ can be reduced:

$$\Phi_{\text{red}} = \Phi - \frac{h-1}{10} \geq 1$$

where h (m), denotes the cover including the ballast.

For columns with a slenderness ratio < 30, abutments, foundations, retaining walls and ground pressures:

$\Phi = 1$

Case	Structural member	Decisive length l_Φ
	Longitudinal direction	
1	simply supported beams and single span slabs	span in principal structural direction
2	continuous girders and slabs over n spans	$l_\Phi = \sum l_i\, k/n$ ($k = 1 + 0.1n \leq 1.5$)
3	arch girders, stiffened girders of bowstring	half span
4	single span frames	$l_\Phi = 1.3\,(l_{s1} + l_r + l_{s2})/3$
5	multiple-span frames	as in case 2, lengths of end legs as extra spans
	Transverse direction	
	Steel deck with longitudinal and transverse ribs (orthotropic plates with ballast bed)	
6	deck in both directions	three times cross girder spacing
7	longitudinal ribs with cantilevers up to 0.5 m	three times cross girder spacing
8	cross girders	twice length of cross girder
	Steel deck without longitudinal ribs (orthotropic plates with ballast bed)	
9	deck in both directions	twice cross girder spacing plus 3 m
10	cross girders	twice cross girder spacing plus 3 m
	Concrete deck (with ballast bed)	
11	deck as part of box girder	three times spacing between webs
12	cantilever part of the deck	three times spacing between webs
13	trough bridge with deck spanning in transverse direction	twice span of deck plus 3 m
14	trough bridge with deck spanning in longitudinal direction	twice span of deck or span of longitudinal girder (the smaller value applies)
	Vertical direction	
15	suspension bars of deck-stiffened arches	four times longitudinal spacing of suspension bars
16	columns, bearings, tension anchors, joints	analogous to Cases 1 to 5

Design Criteria – Structural Safety and Serviceability: Actions

Live Loads – Rail traffic

Factor for the classification of standard load models

Accounts for composition of rail traffic

Normal case α = 1.33

Existing bridges α = 1.00

Applies to:

- LM1 & LM2 loads
- Acceleration forces
- Braking forces
- Centrifugal forces
- Nosing forces
- Earth pressures due to rail traffic

- **Live Loads – Rail traffic**

  Groups of actions

  All actions shall be considered in groups as follows:

  - For bridges with 2 tracks, consider:
    - LM1 or LM2 on both tracks
    - LM1 on one track & LM2 on the other track
    - LM3 on one track & LM1/LM2 on the other track
  - For bridges with ≥ 3 tracks, actions shall be specified in consultation with the supervisory authority.
  - Consider most unfavourable effect of:
    - 100% (QA or QB) + 50% (QS, QZ, qZ)
    - 50% (QA or QB) + 100% (QS, QZ, qZ)

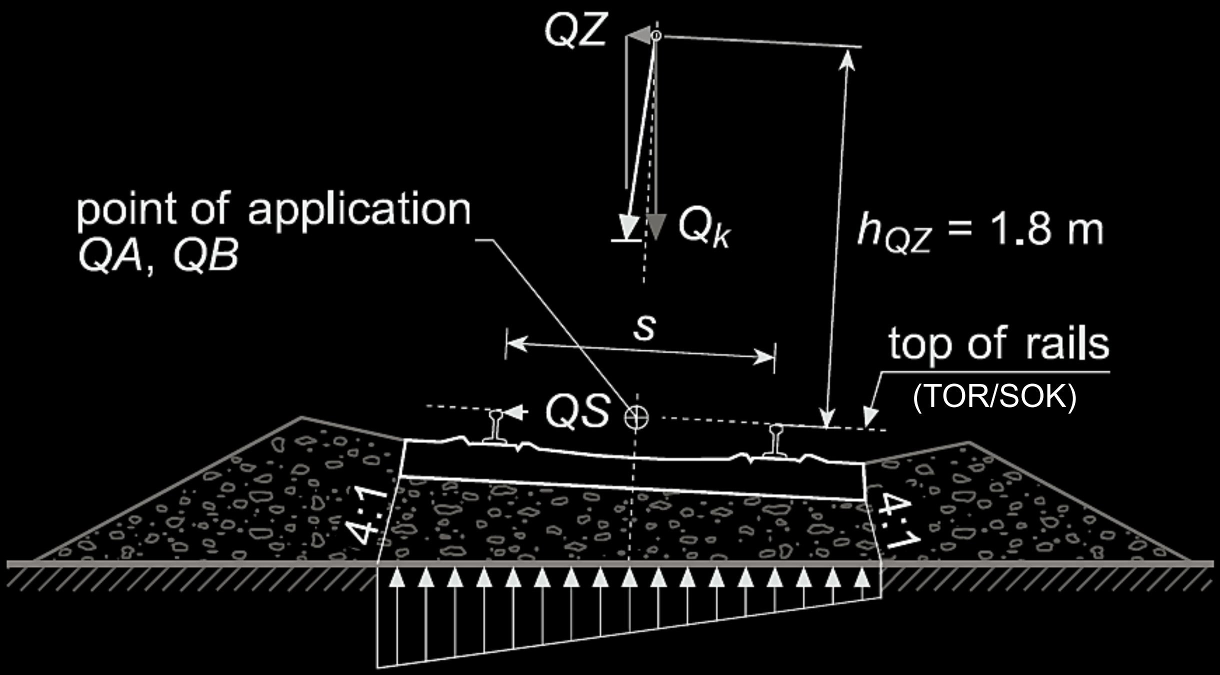
Design Criteria – Structural Safety and Serviceability: Actions

Live Loads – Rail traffic

Load eccentricity

The following accidental eccentricities shall be considered:

- For bridges with ballast, consider deviation of track axis from planned position of ± 100 mm.
- For LM1 & LM2, consider eccentricity of axle load of 1/18 of track width (80 mm) to account for non-uniform loading of rail vehicles.
- Consider eccentricities due to track cant according to the following sketch:



Point of application and actions

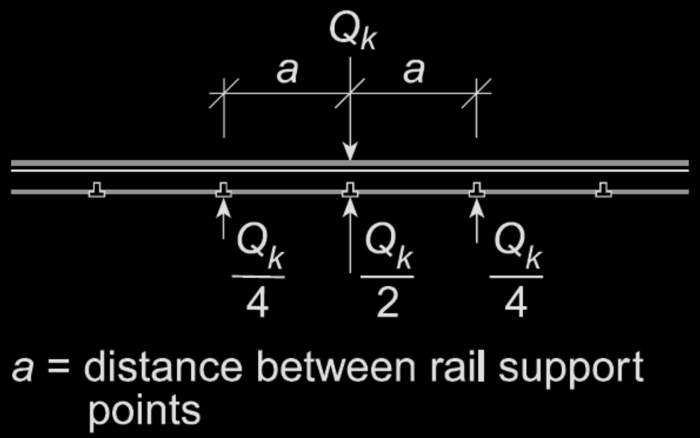
Top of rails (TOR) = Schienenoberkante (SOK)

Design Criteria – Structural Safety and Serviceability: Actions

Live Loads – Rail traffic

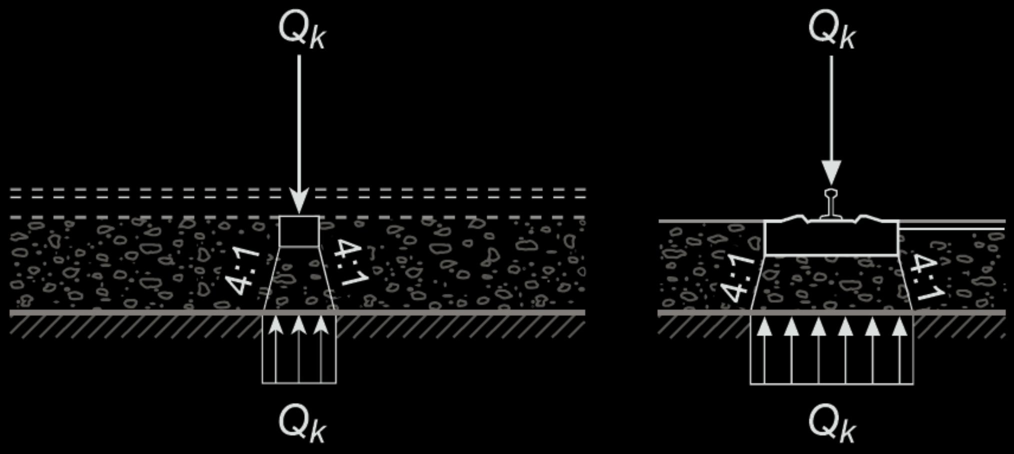
Load distribution

May be considered according to the following sketches:



Rail supported on sleepers

Grooved rail embedded in concrete



Sleepers supported on ballast bed

Design Criteria – Structural Safety and Serviceability: Actions

Live Loads – Rail traffic

Fatigue

- Structural members of railway bridges subjected to alternating loads shall be investigated for fatigue
- Number of loaded cycles depends on:
  - Service (working) life of bridge

    Typically 100 years for new bridges (often, design is carried out for infinite fatigue life = Dauerfestigkeit)
  - Traffic volume

    Indicative values below:

Traffic composition	Number of trains per day and per track	Annual tonnage per track
regional traffic	≤ 120	≤ 25 000 000
standard traffic	≤ 120	≤ 25 000 000
heavy traffic with 25 t axle loads	> 120	> 25 000 000

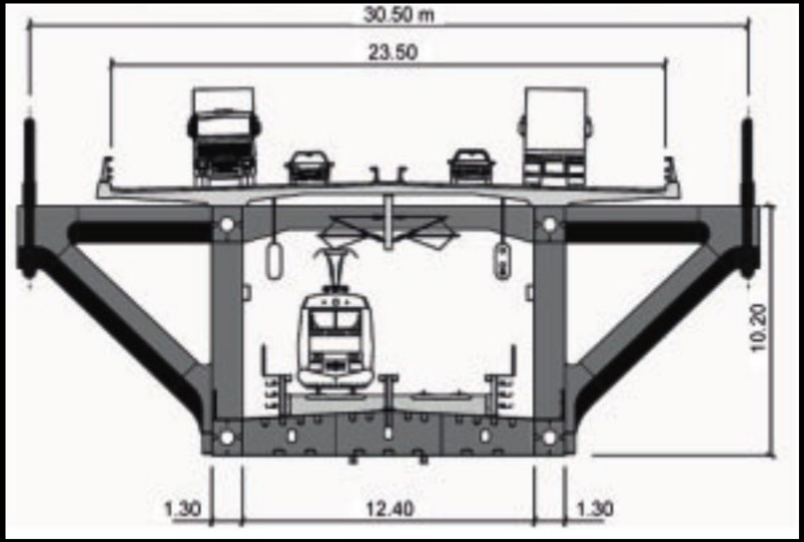
- Fatigue load model
  - LM1 shall be used
  - Q_k & q_k values multiplied with Φ and α factors
  - QZ & qZ shall be considered with $\alpha = 1$
  - For > 3 tracks, fatigue LM shall be applied to 2 tracks max.
  - In special cases, fatigue may be verified using special load models subject to the approval of the supervisory authority.

Design Criteria – Structural Safety and Serviceability: Actions

Live Loads – Combined Road & Rail traffic

- Bridges simultaneously subjected to road and rail traffic loads shall be dimensioned for the more unfavourable of the following situations:
  - whole traffic surface subjected to road vehicle loading
  - rail traffic loads on track areas, road vehicle loading on remaining traffic areas

- For longer spans / major links, it is common to use double deck solutions to separate road from rail traffic
  $\rightarrow$ full combination possible
  $\rightarrow$ load combinations to be agreed with owner
  (service criteria agreement)



Design Criteria – Structural Safety and Serviceability: Actions

- **Wind Loads:**
  - Covered in SIA 261, Chapter 6. These provisions
    … apply to bridges with negligible dynamic response, i.e. generally road and rail bridges of spans up to 40 m (see also notes).
    … can be adapted to cover longer span and cable-supported bridges with input from wind specialists
  - Wind tunnel tests are typically required for long span bridges
  - Wind forces are generally assumed to act normal to the surface under consideration
  - Effects to be considered:
    … increase of exposed area due to simultaneous actions such as traffic load, snow or ice accretion
    … interaction with adjacent structures
    … influence of wind-induced vibrations on fatigue life

Wind tunnel testing on a new cable-stayed bridge; the presence of an existing truss bridge is accounted for, in order to capture potential interaction between the bridges.

Design Criteria – Structural Safety and Serviceability: Actions

- **Wind Loads:**
  - Dynamic Pressure, q_p

$$q_p = q_{p0} \cdot c_h$$

$$c_h = 1.6\left[\left(\frac{z}{z_g}\right)^{\alpha_r} + 0.375\right]^2$$

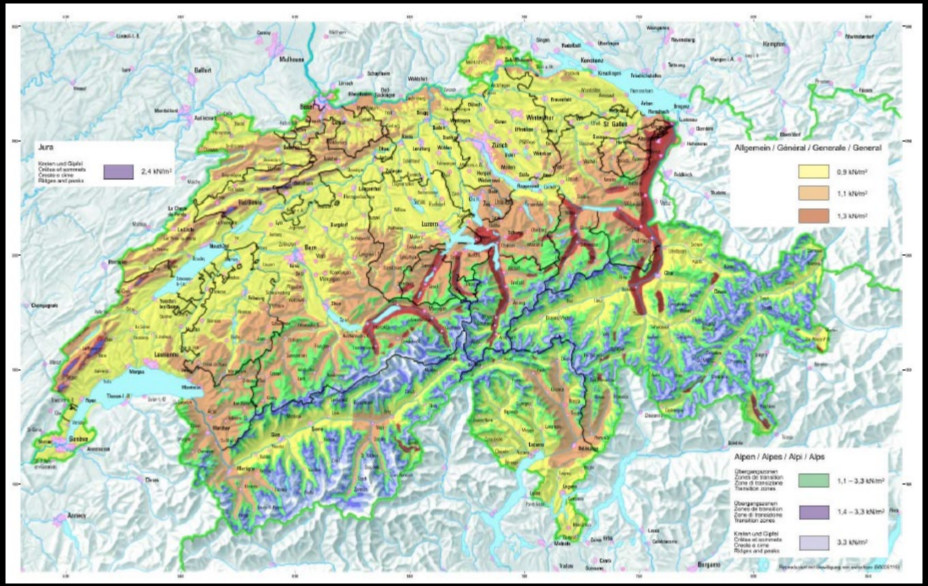
height

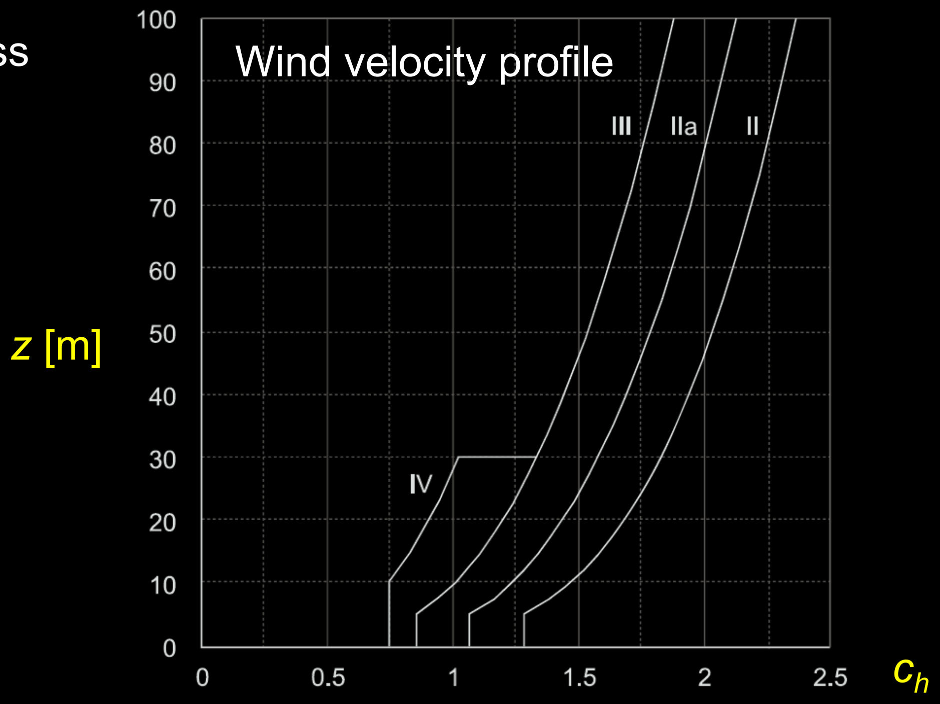
terrain roughness

gradient height

reference value – taken from map:

(General: 0.9…1.3 kPa / Alps: 1.1…3.3 kPa)





Terrain category	Examples	z_g [m]	α_r
II	lakeside	300	0.16
IIa	large plain	380	0.19
III	villages, free field	450	0.23
IV	large urban area	526	0.30

Design Criteria – Structural Safety and Serviceability: Actions

- **Wind Loads:**
  - Wind forces, Q_1 (horizontal) & Q_3 (vertical)

Reduction factor = 1.0 for superstructure; for substructure:

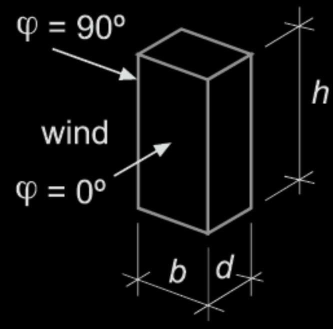
$$Q_{k,1/3} = c_{red}\, c_d\, c_{f,1/3}\, q_p\, A_{ref}$$

dynamic factor (1.0 for short to moderate span bridges, see notes)

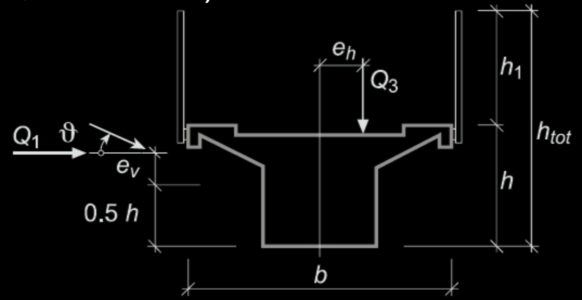
force factors:

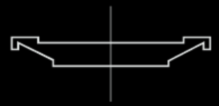
dynamic pressure

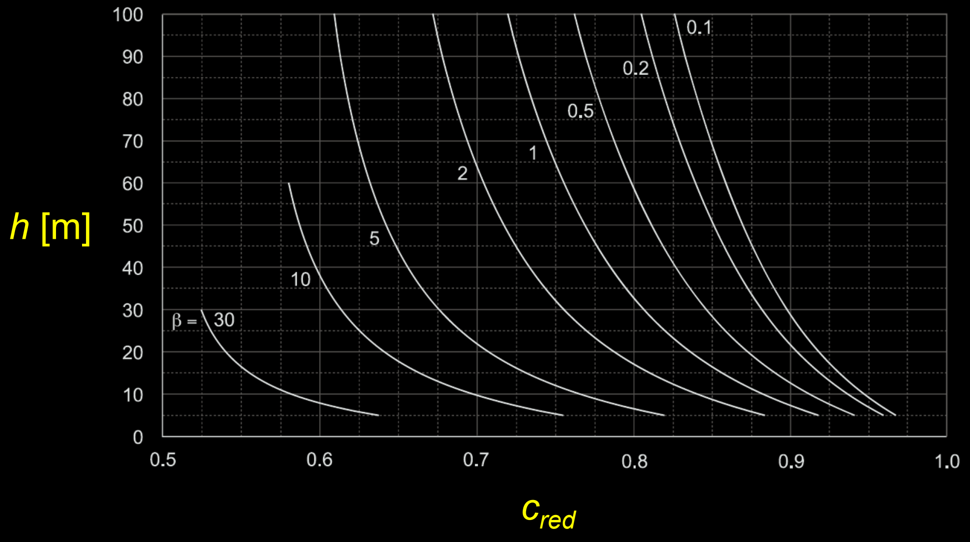
reference area for considered surface



$$\beta = \frac{b}{h} \quad \text{or} \quad \frac{d}{h}$$



	ϑ	$\frac{c_{f1}}{l \cdot h_{tot}}$	$\frac{c_{f3}}{l \cdot b}$	$\frac{e_v/h}{h}$	$\frac{e_h/b}{b}$
$h : b = 0.110$ 	0°	1.45	0.32	−0.27	−0.09
	−6°	1.45	−0.34	1.41	−0.26
	−10°	1.55	−0.79	0.59	−0.20



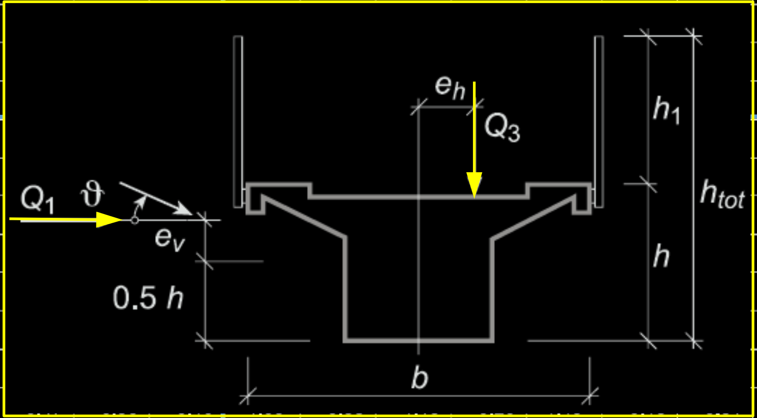
Design Criteria – Structural Safety and Serviceability: Actions

- **Wind Loads:**
  - Wind forces, Q_1 (horizontal) & Q_3 (vertical) – Force Factors and Eccentricities (Appendix C)

barrier height

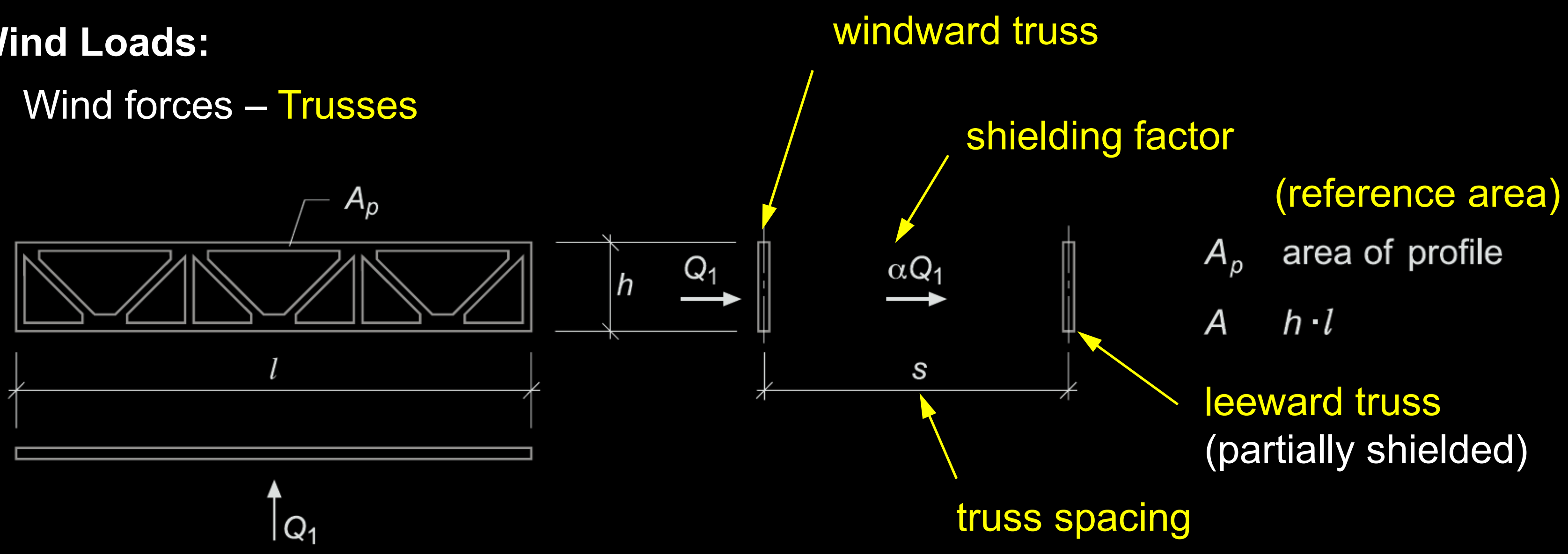
section type / aspect ratio

		$h_1 : b = 0$				$h_1 : b = 0.15$				$h_1 : b = 0.35$				$h_1 : b = 0.15$				$h_1 : b = 0.35$			
		c_{f1}	c_{f3}	e_v/h	e_h/b	c_{f1}	c_{f3}	e_v/h	e_h/b	c_{f1}	c_{f3}	e_v/h	e_h/b	c_{f1}	c_{f3}	e_v/h	e_h/b	c_{f1}	c_{f3}	e_v/h	e_h/b
	ϑ	$l \cdot h_{tot}$	$l \cdot b$	h	b	$l \cdot h_{tot}$	$l \cdot b$	h	b	$l \cdot h_{tot}$	$l \cdot b$	h	b	$l \cdot h_{tot}$	$l \cdot b$	h	b	$l \cdot h_{tot}$	$l \cdot b$	h	b
$h : b = 0.110$	0°	1.45	0.32	−0.27	−0.09	0.92	0.02	0.09	0.00	0.91	−0.01	−0.50	0.00	0.77	0.49	−0.64	−0.20	1.10	1.06	−0.59	−0.16
	−6°	1.45	−0.34	1.41	−0.26	0.92	−0.45	0.73	−0.10	1.07	−0.27	0.41	−0.01	0.85	−0.10	1.41	−0.06	1.11	0.63	−0.59	−0.09
	−10°	1.55	−0.79	0.59	−0.20	1.12	−0.54	0.73	−0.10	1.23	−0.37	0.86	−0.05	0.54	−0.63	0.59	−0.20	1.04	0.28	0.00	−0.01
$h : b = 0.282$	0°	1.65	−0.41	1.13	−0.19	1.00	−0.48	0.95	−0.18	1.14	−0.38	0.94	−0.08	1.16	0.00	1.19	0.00	1.12	0.39	0.50	0.02
	−6°	1.42	−0.61	0.92	−0.22	1.13	−0.38	1.00	−0.13	1.27	−0.26	0.97	−0.06	0.87	−0.23	1.40	−0.17	0.98	0.29	0.68	0.04
	−10°	1.38	−0.61	0.84	−0.20	1.24	−0.30	1.05	−0.10	1.36	−0.19	1.02	−0.04	0.72	−0.52	0.89	−0.24	0.87	0.14	0.86	0.04
$h : b = 0.510$	0°	1.72	−0.87	0.56	−0.04	1.32	−0.79	0.57	0.04	1.67											0.00
	−6°	1.73	−0.78	0.52	−0.01	1.42	−0.62	0.55	−0.02	1.81											0.01
	−10°	1.74	−0.59	0.47	0.00	1.52	−0.45	0.55	−0.01	1.81											0.01
$h : b = 0.110$	0°	1.55	0.14	−0.48	−0.09	1.19	−0.14	−0.01	0.02	1.07											−0.16
	−6°	1.55	−0.46	1.28	−0.22	1.12	−0.44	0.73	−0.10	1.26											−0.10
	−10°	1.55	−0.84	0.56	−0.18	1.31	−0.52	0.73	−0.10	1.37											−0.05
$h : b = 0.305$	0°	1.71	−0.61	0.93	−0.19	1.21	−0.62	0.85	−0.16	1.26											0.02
	−6°	1.51	−0.70	0.82	−0.20	1.28	−0.42	0.97	−0.13	1.42											0.02
or	−10°	1.54	−0.67	0.81	−0.18	1.36	−0.29	1.05	−0.09	1.44											0.01
$h : b = 0.250$	0°	2.16	−0.72	0.87	−0.19	1.20	−0.66	0.82	−0.18	1.28											0.02
	−6°	1.88	−0.76	0.81	−0.21	1.28	−0.53	0.90	−0.16	1.41											0.03
	−10°	1.72	−0.70	0.81	−0.21	1.35	−0.37	1.04	−0.14	1.57	−0.34	1.03	−0.07	0.88	−0.52	0.96	−0.26	1.22	0.13	0.97	0.02



Design Criteria – Structural Safety and Serviceability: Actions

- **Wind Loads:**
  - Wind forces – Trusses



Force factor, c_{f1}	
A_p / A	c_{f1}
0.01	2.0
0.1	1.9
0.15	1.8
0.2	1.7
0.3…0.8	1.6
0.95	1.8
1.0	2.0

Reduction factor, c_{red}

A_p / A	0.25	0.5	0.9	0.95	1.0
$l / h = 5$	0.96	0.91	0.87	0.77	0.6
$l / h = 20$	0.98	0.97	0.94	0.89	0.75
$l / h = 50$	0.99	0.98	0.97	0.95	0.9
$l / h = \infty$	1.0	1.0	1.0	1.0	1.0

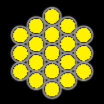
Shielding factor, α

A_p / A	0.1	0.2	0.3	0.4	0.5	0.6…1.0
$s / h = 0.5$	0.93	0.75	0.56	0.38	0.19	0
$s / h = 1$	0.99	0.81	0.65	0.48	0.32	0.15
$s / h = 2$	1.0	0.87	0.73	0.59	0.44	0.3
$s / h = 4$	1.0	0.9	0.78	0.65	0.52	0.4
$s / h = 6$	1.0	0.93	0.83	0.72	0.61	0.5

Design Criteria – Structural Safety and Serviceability: Actions

- **Wind Loads:**
  - Wind forces – Cables

    Force factors for wires, bars, tubes and cables with l / d ≥ 100

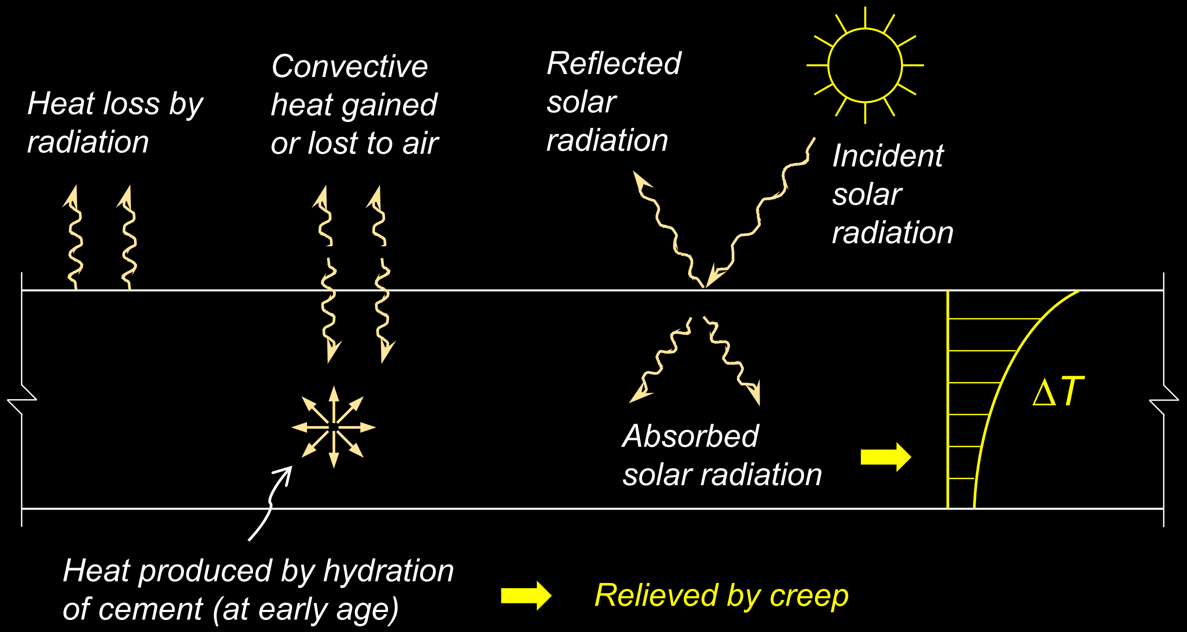
$d\sqrt{q_p}$ kPa	Global force factors c_f			
	reference area = $d \cdot l$ (d = diameter, l = length, both in m)			
≤ 0.3	1.2	1.2	1.2	1.3
> 0.3	0.5	0.7	0.9	1.1
	 smooth wires, bars and tubes	 medium rough wires and bars	 fine-stranded power and suspension cables	 coarse-stranded power and suspension cables

Design Criteria – Structural Safety and Serviceability: Actions

- **Temperature Effects:**
  - Covered in SIA 261, Chapter 7
  - Only climatic effects are addressed
  - Temperature variations lead to deformations
  - Restrained deformations lead to stresses

→ Basically, the designer may choose to
… accomodate deformations or
… design for restraint stresses

→ see Support and Articulation chapter (jointed bridges vs. integral and semi-integral bridges)



Heat transfer processes for a bridge deck in daytime in summer [after Ghali et al, 2002]

temperature variation

$$\varepsilon_T = \alpha_T \, \Delta T$$

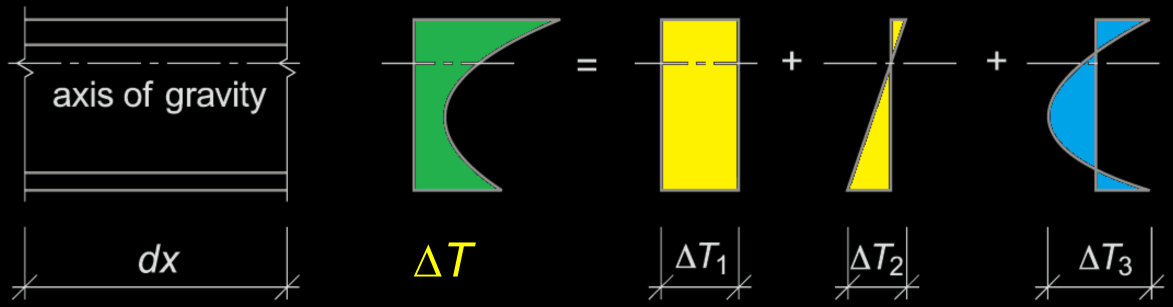
strain due to temperature variation

coefficient of thermal expansion

= 10^{-5} / °C for concrete & steel

Design Criteria – Structural Safety and Serviceability: Actions

- **Temperature Effects:**
  - Components of temperature variation:
    → Uniform (ΔT_1) – variation from mean
    → Linear (ΔT_2) – one-sided warming/cooling
    → Non-linear (ΔT_3) (usually ignored – see next slide)



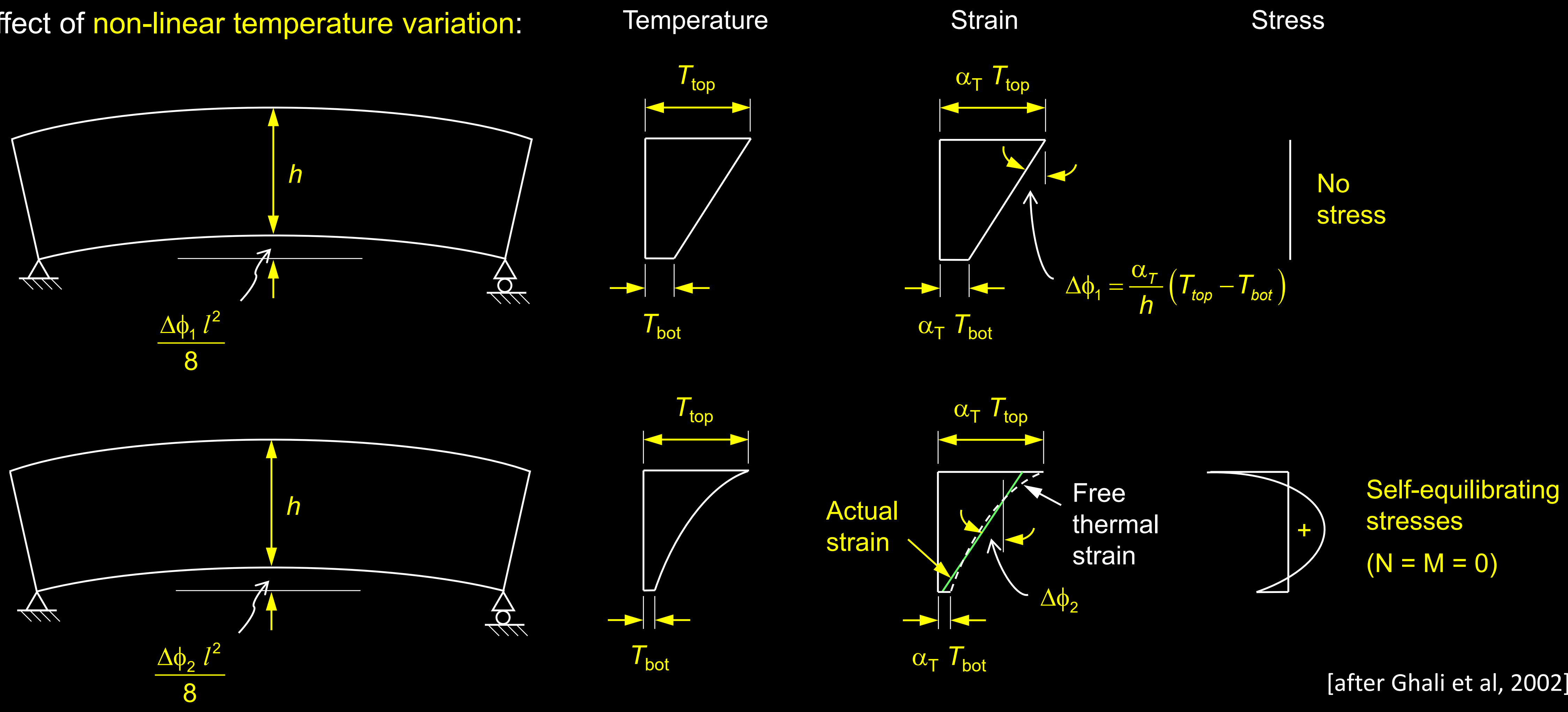
Type of construction	ΔT_{1k} [°C]
plain concrete	± 15
reinforced and prestressed concrete	± 20
steel	± 30
composite steel-concrete	± 25

Type of bridge	Warm upper surface ΔT_{2k} [°C]	Cold upper surface ΔT_{2k} [°C]
steel bridges	+ 10	- 6
concrete bridges		
h ≤ 1.0 m	+12	- 4
h ≥ 3.0 m	+8	- 3
composite bridges		
concrete slab	+12	- 4
steel girder	0	0

h = height of cross-section

Design Criteria – Structural Safety and Serviceability: Actions

- **Temperature Effects:**
  - Effect of non-linear temperature variation:



[after Ghali et al, 2002]

Design Criteria – Structural Safety and Serviceability: Actions

- **Accidental (Extreme) Actions:**

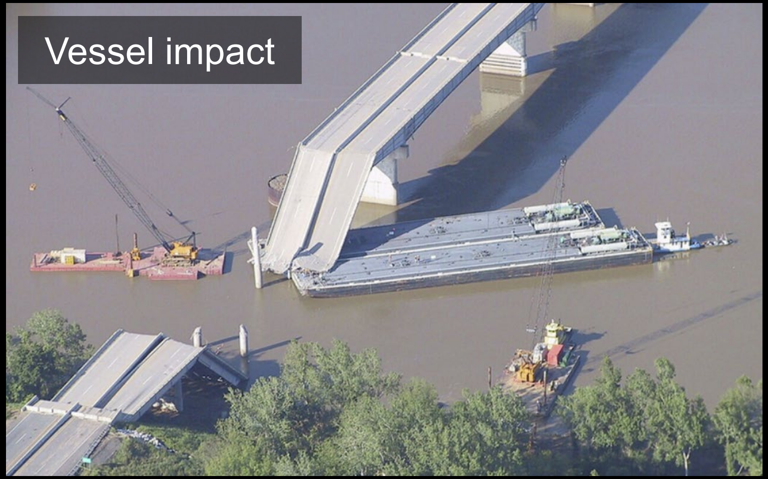
  Covered in SIA 261 – see below for chapters

  Caused by human activity/error:

  - Vehicular impact (Ch. 14), Train derailment (Ch. 11 & 12)
  - Vessel impact
  - Explosion (Ch. 17), Fire (Ch. 15)

  Caused by nature:

  - Seismic (earthquake) loads (Ch. 16)
  - Avalanche load
  - Ice load

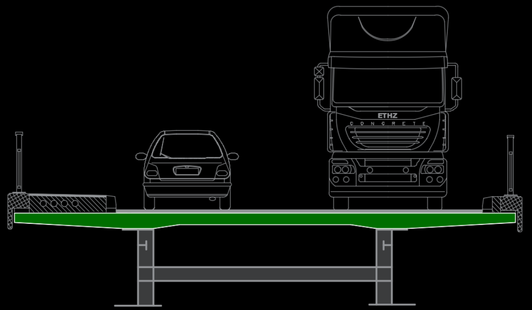


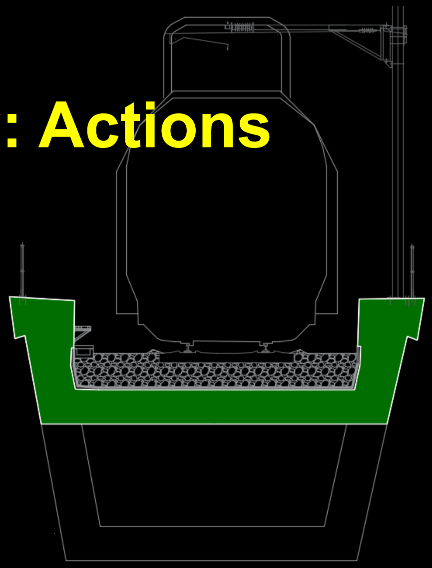
Design Criteria – Structural Safety and Serviceability: Actions

The loads depend heavily on the use of the bridge

→ design of "footbridges" differs significantly from "bridges"

→ focus of lecture: road and railway bridges





Bridge use	Pedestrian / Bicycle	Road ($\alpha_Q=\alpha_q=0.9$)	Railway ($\alpha=1.33$, $\Phi_{dyn}=1.67$ for typ. deck)
Concentrated loads "Q"	low (service vehicles only) [CH: 10 kN]	high / var. position of vehicle axis [CH LM1: $4\cdot\alpha_Q\cdot(150+100)$ kN = 900 kN]	very high / distributed by ballast [CH LM1: $4\cdot\alpha\cdot\Phi_{dyn}\cdot 250$ kN = 2220 kN, per track]
Distributed loads "q"	moderate [CH: 4 kPa, full width]	moderate-high (on limited width) [CH LM1: $\alpha_q\cdot 9$ kPa = 8.1 kPa, 3 m width]	high [CH LM1: $\alpha\cdot\Phi_{dyn}\cdot 80$ = 178 kN/m, per 3.80 m]
Longitudinal horizontal loads	low	moderate (braking / traction)	high (braking / traction)
Transverse horizontal loads	low	low-moderate (centrifugal)	moderate-high (centrifugal / nosing)
Fatigue	usually irrelevant	moderate (local elements)	highly relevant
Dynamic effects	slender bridges often sensitive to vibrations	included in traffic loads (most codes)	dynamic factor depending on structural element / dynamic analysis for high speed rail
Deflections (vertical)	moderate $w \le l / 600$ (LM1)	moderate $w \le l / 500$ (LM1)	highly relevant $w \le l / 2000$, v = 160 km/h (LM1-2)
Durability issues	moderate (de-icing)	high (de-icing, heavy load on joints)	low (no de-icing, joints not directly loaded)

Conceptual Design

Design Criteria – Structural Safety and Serviceability

Deformations

Verformungen

Design Criteria – Structural Safety and Serviceability: Deformations

- **Deflection limit criteria for Roadway bridges:**

  Covered in SIA 260 – Appendix B

  - Deflection calculation in accordance with corresponding material codes (SIA 262 to 266)
  - Project specific deflection limits may be agreed upon with the supervisory authority.

    → Limits can be relaxed for secondary members

    → Long span bridges (l > 200 m) require special attention

Limit State	**Consequences of effects of actions**		
	irreversible	reversible	reversible
	Load case		
	occasional	frequent	quasi-permanent
Functionality - vertical relative displacement at expansion joints		$\delta_v \leq 5$ mm 1) 2) 3)	
Comfort		$w \leq l / 500$ 4)	
Appearance			$w \leq l / 700$ 1) 2)

Notes:
1) After deduction of camber. Consider long-term effects: CR + SH.
2) After installation of equipment.
3) Observe supplier guidelines.
4) Due to LM1.

Design Criteria – Structural Safety and Serviceability: Deformations

- **Deflection limit criteria for Pedestrian and cycle-path bridges:**

  Covered in SIA 260 – Appendix C

  - Deflection calculation in accordance with corresponding material codes (SIA 262 to 266)
  - Project specific deflection limits may be agreed upon with the supervisory authority.

    → Limits can be relaxed for secondary members

    → Long span bridges (l > 200 m) and flexible cable-supported or stress-ribbon bridges require special attention

Limit State	Consequences of effects of actions		
	irreversible	reversible	reversible
	Load case		
	occasional	frequent	quasi-permanent
Functionality - deflection within span - vertical relative displacement at expansion joints		$\delta_v \leq 5$ mm [1) 2) 3)]	$w \leq l / 700$ [1) 2) 3)]
Comfort		$w \leq l / 600$ [4)]	
Appearance			$w \leq l / 700$ [1) 2)]

Notes:
1) After deduction of camber. Consider long-term effects: CR + SH.
2) After installation of equipment.
3) Observe supplier guidelines.
4) Due to LM1.

Design Criteria – Structural Safety and Serviceability: Deformations

- **Deflection limit criteria for** **Normal gauge railway bridges**:

  Covered in SIA 260 – Appendix D
  - Deflection calculation in accordance with corresponding material codes (SIA 262 to 266)
  - Project specific deflection limits may be agreed upon with the supervisory authority.

    → Limits can be relaxed for secondary members and special sections (feeder tracks, multiple track lines)

    → Long span bridges (l > 200 m) require special attention

Limit State	**Consequences of effects of actions**		
	irreversible	reversible	reversible
	Load case		
	occasional	frequent [1]	quasi-permanent
Functionality [2]			
• deflections [3]			
- $v \le 80$ km/h		$w \le l / 800$	
- 80 km/h $\le v \le$ 200 km/h		$w \le l / (15v - 400)$	
• track twist			
- $v \le 120$ km/h		$\alpha_t \le 1.0$ mrad/m	
- 120 km/h $< v \le$ 200 km/h		$\alpha_t \le 0.7$ mrad/m	
- $v > 200$ km/h		$\alpha_t \le 0.3$ mrad/m	
• relative vertical displacement of deck ends behind abutments [5]			
- $v \le 160$ km/h		$\delta_v \le 3$ mm	
- $v > 160$ km/h		$\delta_v \le 2$ mm	
Appearance			$w \le l / 700$ [6] [7]

See notes below

Conceptual Design

Design Criteria – Structural Safety and Serviceability

Vibrations

Schwingungen

Design Criteria – Structural Safety and Serviceability: Vibrations

- **Vibration limit criteria for**
  Pedestrian and cycle-path bridges:

Covered in SIA 260 – Appendix C and 261 Chapter 9

- Control of vibrations to ensure pedestrian comfort is a critical aspect of the design
- Codes provide guidelines in terms of limits on eigenfrequencies.
- Deviations from these limits require explicit modelling of pedestrian movements and dynamic structural response

Limit state	**Eigenfrequency [Hz]**
Comfort	
• vertical vibrations	$f > 4.5$ or $f < 1.6$
• horizontal vibrations (transverse)	$f > 1.3$
• horizontal vibrations (longitudinal)	$f > 2.5$

For comparison:
- Pace frequency for walking ≈ 2.0 Hz
- Pace frequency for running ≈ 2.4…3.5 Hz

Design Criteria – Structural Safety and Serviceability: Vibrations

- **Vibration limit criteria for (High-speed) railway bridges:**

  Covered in EN 1990 A1 & 1991-2:

  - EN 1991-2 §6.4.4 outlines procedure to determine whether a dynamic analysis is required depending on design speed and eigenfrequencies

  Traffic Safety:

  - If a dynamic analysis is required, EN 1990 A1 §A2.4.4.2.1 specifies limits on peak vertical accelerations along the track:
    - 3.5 m/s^2 for ballasted track
    - 5 m/s^2 for direct fastened tracks

    Above limits ensure traffic safety → prevention of track instability (e.g. “Schotterflug”)
  - It is recommended that the first eigenfrequency of lateral vibration of a span is not less than 1.2 Hz

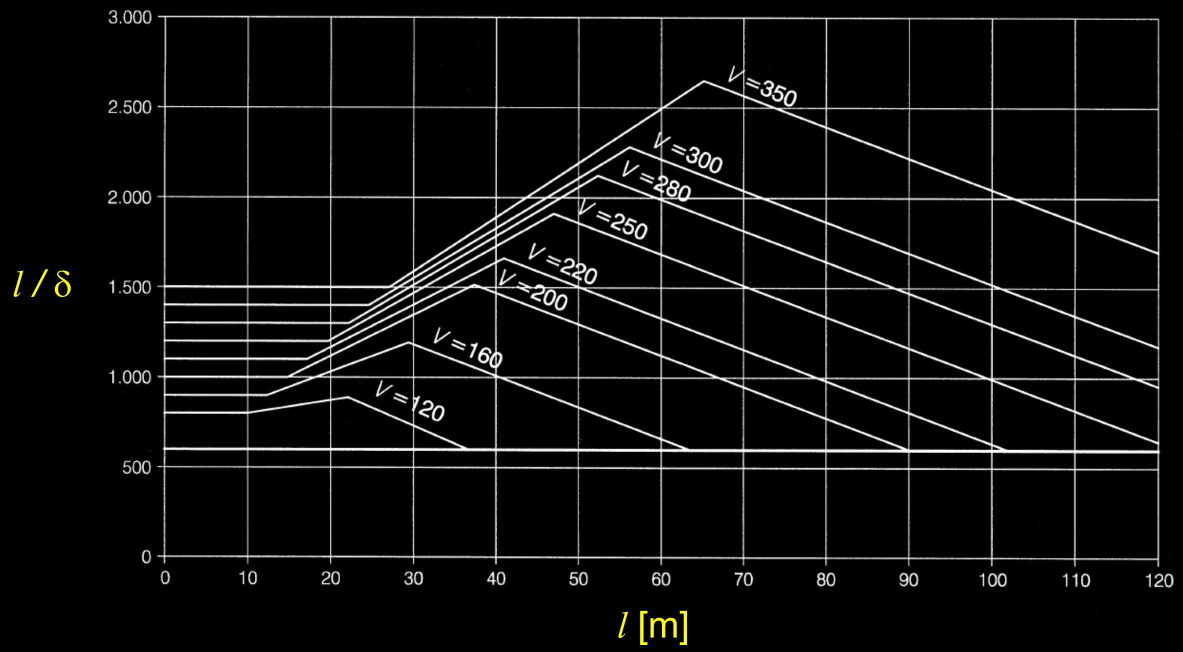
Design Criteria – Structural Safety and Serviceability: Vibrations

- **Vibration limit criteria for (High-speed) railway bridges:**

  Covered in EN 1990 A1 & 1991-2:

  Passenger Comfort:

  - Depends on vertical acceleration inside the coach.
  - Recommended levels of comfort (EN 1990 A1, Table A2.9):
    - Very good → 1.0 m/s^2
    - Good → 1.3 m/s^2
    - Acceptable → 2.0 m/s^2
  - EN 1990 A1, Figure A2.3 provides deflection limits to implicitly ensure very good level of comfort.
  - Alternatively, a dynamic vehicle/bridge interaction analysis may be used to explicitly determine vertical accelerations. This analysis is based on real trains, i.e. not load models.



EN 1990 A1, Figure A2.3

Conceptual Design

Design Criteria – Structural Safety and Serviceability

Clearances

Lichtraumprofile

Design Criteria – Structural Safety and Serviceability: Clearances

Clearances

From the definition of a bridge:

- A bridge provides a passage for vehicles, people, water, materials, utilities, …
- A bridge crosses a natural or manmade obstacle

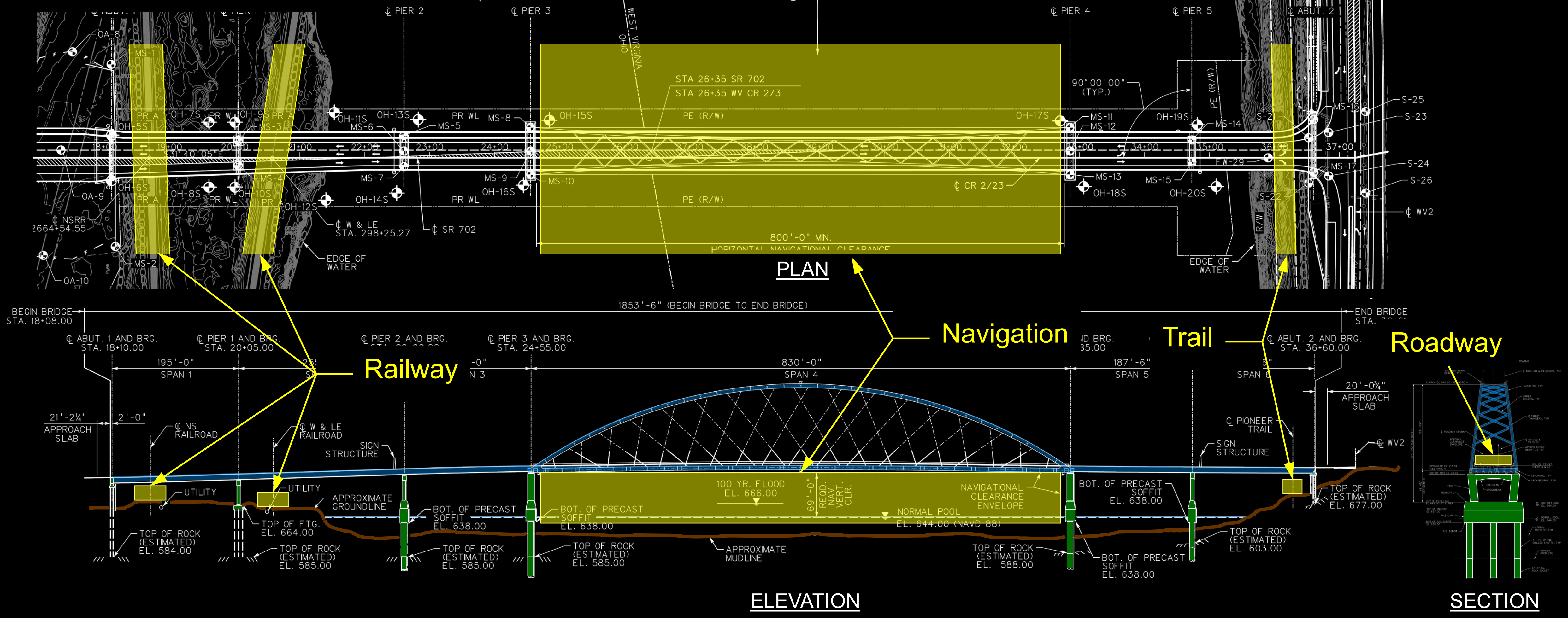
Hence, the geometry of the bridge is determined from the geometry of the objects that it provides passage to and the objects that it crosses.

Example: Ohio River Bridge Crossing near Wellsburg, WV, USA (expected opening 2021)

- Bridge typology, span arrangement and erection schemes were dictated by the clearance requirements
- Various types of clearances had to be provided and at different stages:
  - Navigational, Rail, Vehicular, Pedestrian & Cyclist, Trail
  - During construction, service and future change of usage

Design Criteria – Structural Safety and Serviceability: Clearances

Clearances - Example



Design Criteria – Structural Safety and Serviceability: Clearances

Clearances

During the planning phase:

- Define the use of the bridge
  … road, railway, etc
  … clearance requirements of vehicles on bridge
- Identify obstacles that thee bridge needs to cross
  … over
  … under
- Proactively, reach out to all affected entities (some may not be aware of the bridge project):
  … road authorities, railway companies, coast guard, airports, utility companies, etc.
  … establish present and future requirements
- Clearance restrictions of nearby structures may dictate the bridge type and/or erection methods. Consider
  … how the bridge will be constructed
  … how material, equipment and prefabricated elements will be transported to the site

Design Criteria – Structural Safety and Serviceability: Clearances

Clearances

During the planning phase:

- Define the use of the bridge
  … road, railway, etc
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  airports, utility companies, etc.
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  the bridge type and/or erection methods. Consider
  … how the bridge will be constructed
  … how material, equipment and prefabricated elements
  will be transported to the site

Design Criteria – Structural Safety and Serviceability: Clearances

Clearances - Swiss Standards

Clearance Profiles are specified in Guidelines published by:

- BAV – Bundesamt für Verkehr

  [Federal Office of Transport]

  Ausführungsbestimmungen zur Eisenbahnverordnung (AB-EBV)

  [Implementing provisions for the Railway Ordinance]

- VSS – Schweizerischer Verband der Strassen- und Verkehrsfachleute

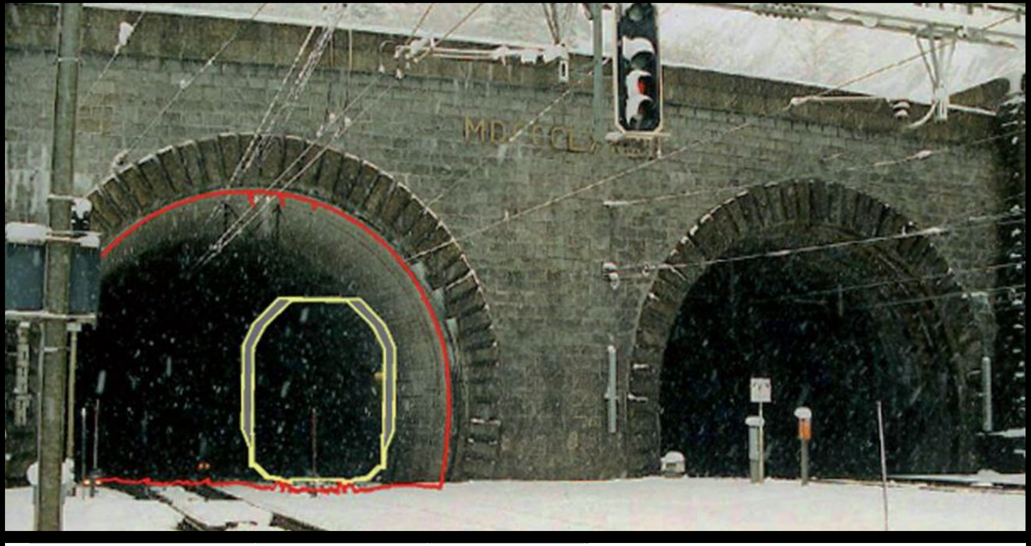
  [Swiss Association of Road and Transportation Professionals]

  Standards 40 201 & 40 202 – Typical Geometric Profiles

- ASTRA - Bundesamt für Strassen

  [Federal Roads Office (FEDRO)]

  Guidelines – 11001 – Typical Profiles – 1st and 2nd Class National Roads with direction separation



Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Bundesamt für Verkehr BAV

VSS

Forschung und Normierung im Strassen- und Verkehrswesen
Recherche et normalisation en matière de route et de transports
Ricerca e normalizzazione in materia di strade e trasporti
Research and standardization in the field of road and transportation

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Bundesamt für Strassen ASTRA

Design Criteria – Structural Safety and Serviceability: Clearances

Clearances - Swiss Standards

- BAV – Bundesamt für Verkehr

  A-EBV

  [Clearance Profile – Standard Gauge]

  Clearance Profile EBV 4 (Normalspur):

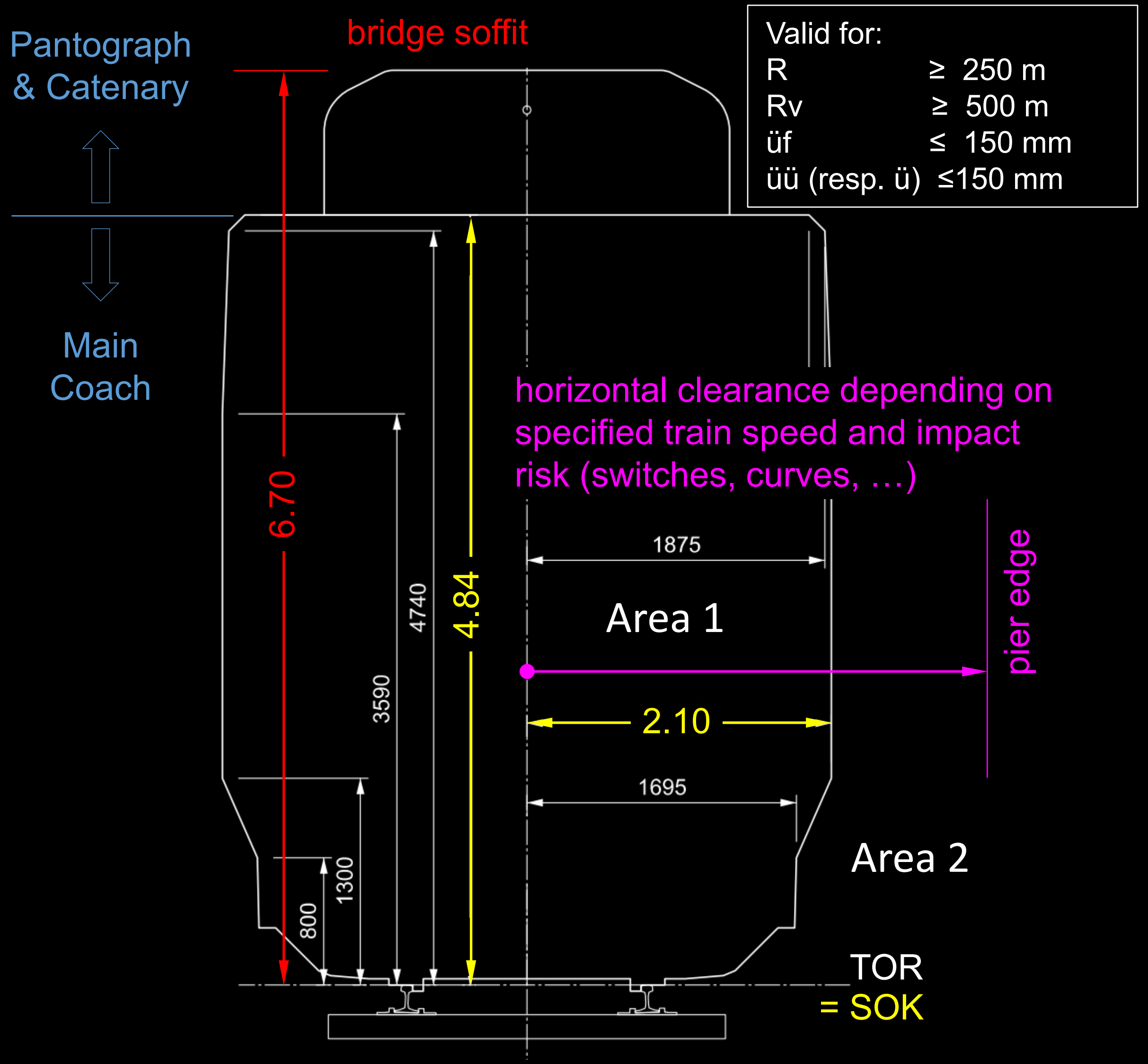
  Applicable for:

  - New lines for the North-South routes Basel-Chiasso and Basel-Iselle
  - New and extension lines with V > 160 km/h

  Note basic dimensions:

Area 1 height	= 4.84 m
Area 1 width	= 4.20 m

  By default, SBB requires a vertical clearance of 6.70 m for new bridges. Lower clearances can often be agreed with SBB (extra cost for catenary adjustments)



Design Criteria – Structural Safety and Serviceability: Clearances

Clearances - Swiss Standards

- BAV – Bundesamt für Verkehr

  A-EBV

  [Clearance Profile – Standard Gauge]

  Clearance Profile EBV 4 (Normalspur):

  Applicable for:

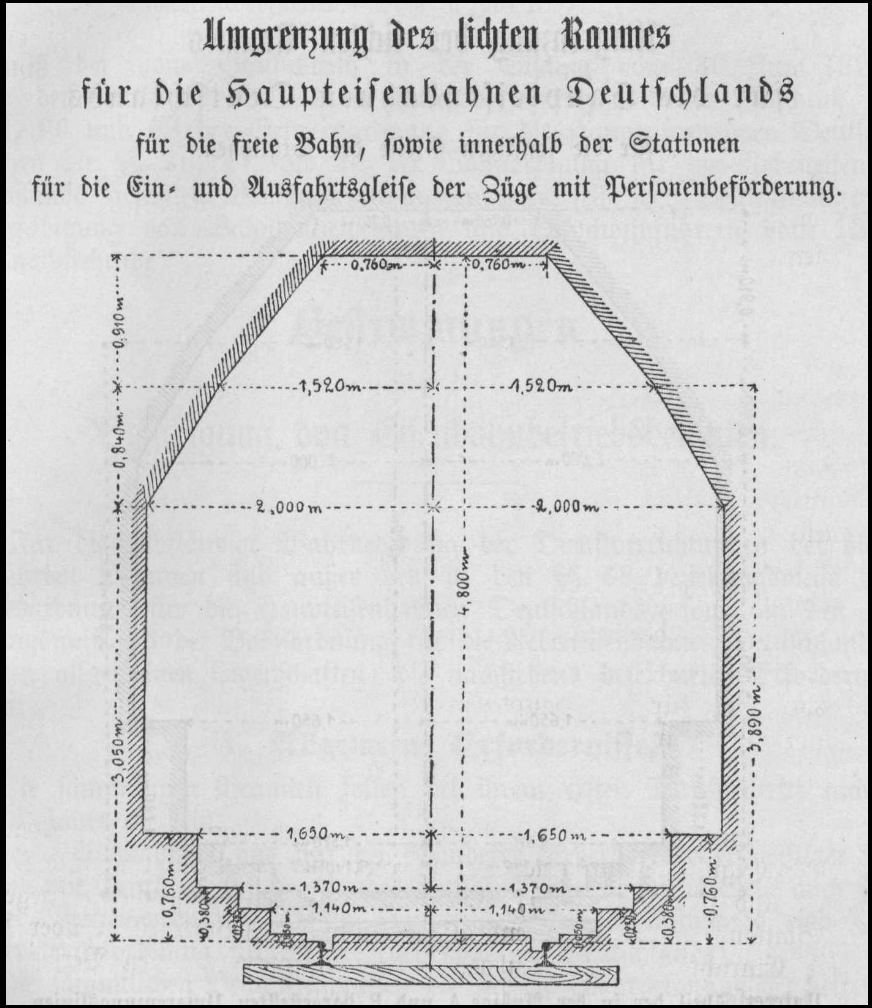
  - New lines for the North-South routes Basel-Chiasso and Basel-Iselle
  - New and extension lines with V > 160 km/h

  Note basic dimensions:

Area 1 height	= 4.84 m	Dynamic approach
Area 1 width	= 4.20 m	

  Compare to German Regulations (1892 – 1991):

Envelope height	= 4.8 m	Static approach
Envelope width	= 4.0 m	



Design Criteria – Structural Safety and Serviceability: Clearances

Clearances - Swiss Standards

- BAV – Bundesamt für Verkehr

  A-EBV

  [Clearance Profile – Standard Gauge]

  Clearance Profile EBV A (Meterspur):

  Applicable for:

  - Adhesion railways and funiculars without transporter wagons or trailers

  Note basic dimensions:

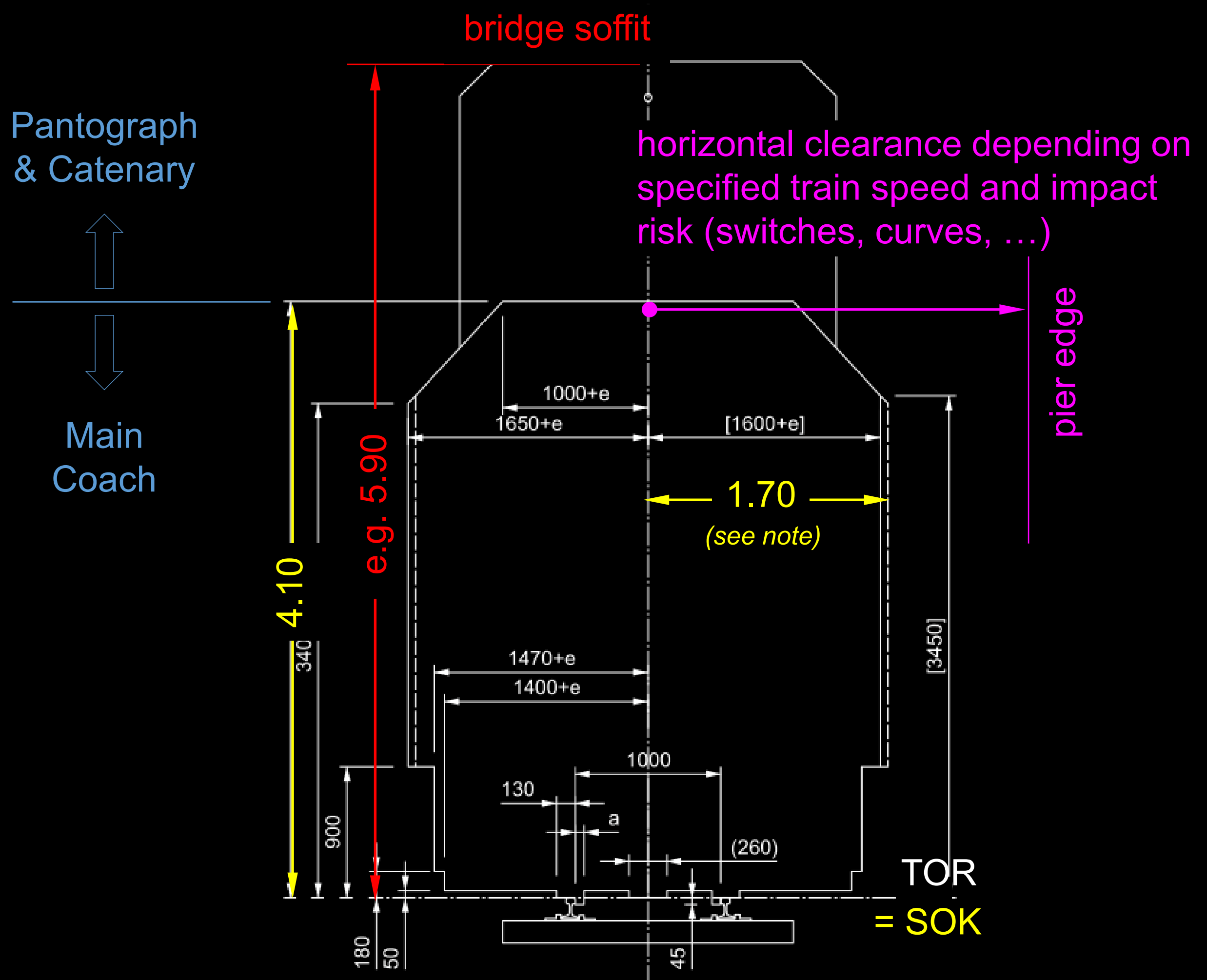
  Envelope height = 4.1 m

  Envelope width = 3.3 m + 2*e*

  where *e* accounts for radius of curvature, *R*

  $$e = (25\ m^2) / R$$

  Larger vertical clearances (e.g. 5.90 m RhB) are requested for new bridges. Lower clearances can often be agreed (extra cost for catenary adjustments)



Design Criteria – Structural Safety and Serviceability: Clearances

Clearances - Swiss Standards

- VSS – Standards 40 201 & 40 202

  Typical Geometric Profiles

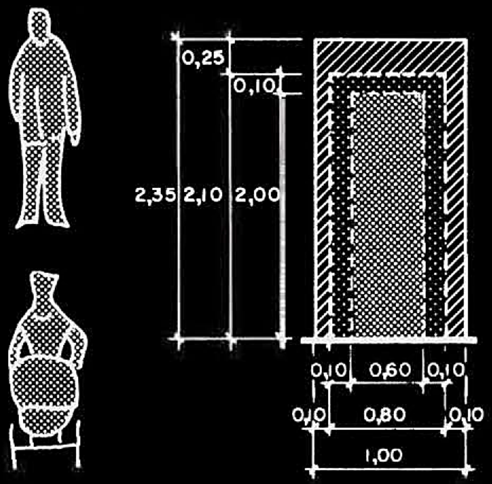
  Clearance Profile for Pedestrians

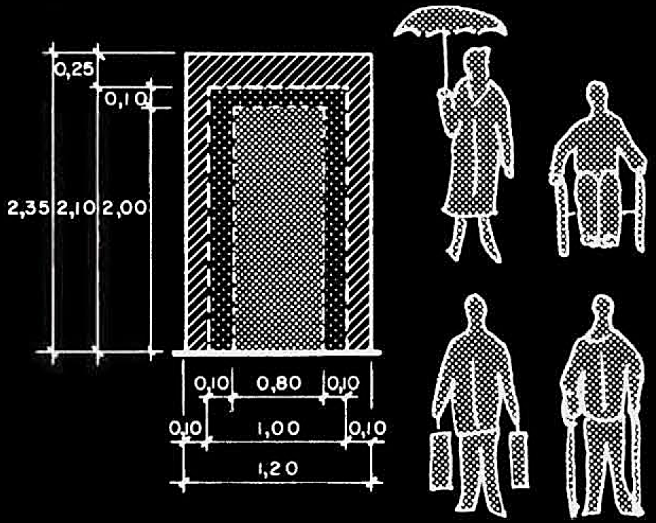
  - Varies based on the expected amount of pedestrians and the desired comfort level
  - Normal range of motion:

    Horizontal / Vertical = 10 cm
  - Safety margin:

    Horizontal = 10 cm

    Vertical = 25 cm
  - Next to walls, buildings, etc. an additional clear width of 25 cm is required (50 cm for lanes with heavy traffic)





Basic dimensions of users	Width (m)	Height (m)
Pedestrians with or without strollers	0.60	2.00
Pedestrians with luggage, umbrella; wheelchair	0.80	2.00

Design Criteria – Structural Safety and Serviceability: Clearances

Clearances - Swiss Standards

- VSS – Standards 40 201 & 40 202

  Typical Geometric Profiles

  Clearance Profile for Light Two-Wheelers

  - Generally assuming:

    Radius of curvature > 80 m (i.e. straight)

    Grade < 4%

  - Normal range of motion:

    Horizontal = 10 cm (20 – 40 cm if Grade ≥ 4%)

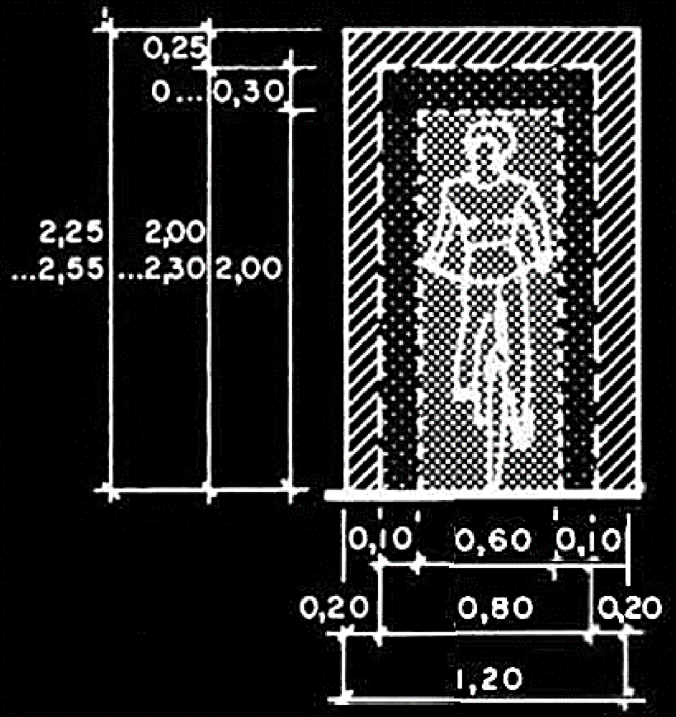
    Vertical = 0 – 30 cm

  - Safety margin:

    Horizontal = 20 cm

    Vertical = 25 cm

  - Next to walls, buildings, etc. an additional clear width of 25 cm is required



Basic dimensions of users	Width (m)	Height (m)
Light two-wheeler	0.60	2.00

For R > 80 m: When cornering, because of their inclined position, light two-wheelers require a greatly increased range of motion.

Design Criteria – Structural Safety and Serviceability: Clearances

Clearances - Swiss Standards

- VSS – Standards 40 201 & 40 202

  Typical Geometric Profiles

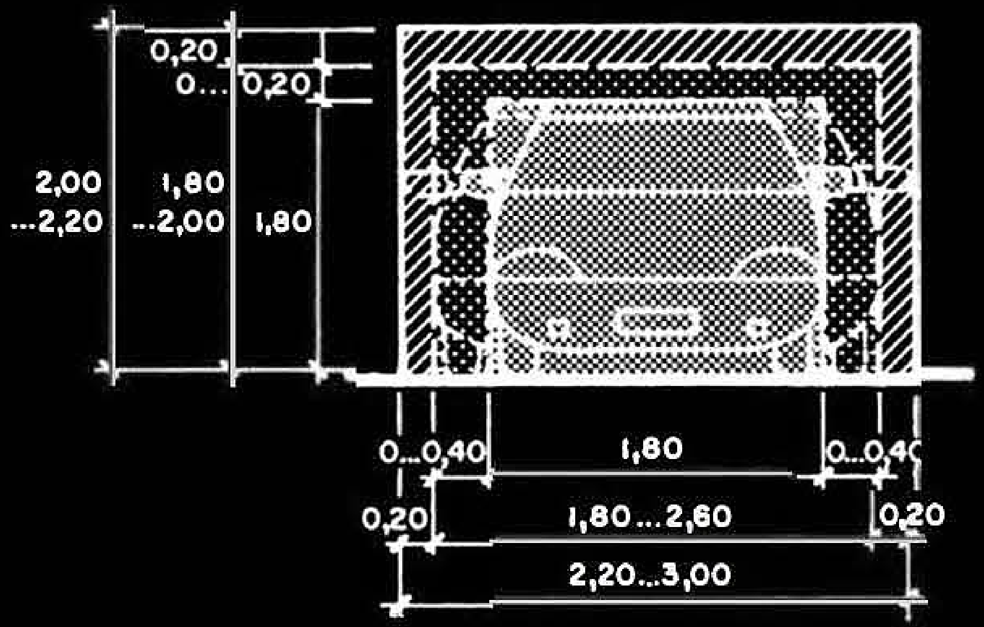
  Clearance Profile for Passenger Cars & Vans

  - The range of motion depends on speed
  - Normal range of motion:

    Horizontal = 0 – 40 cm

    Vertical = 0 – 20 cm
  - Safety margin:

    Horizontal / Vertical = 20 cm
  - Values apply to straight sections
  - In the case of tight curves, additional clearance for the heights is necessary for long vehicles



Basic dimensions of users	Width (m)	Height (m)
Passenger cars	1.80	1.80
Delivery vans, minibuses and mobile homes (< 3.5 t)	2.10 – 2.20	2.70 – 3.00

Design Criteria – Structural Safety and Serviceability: Clearances

Clearances - Swiss Standards

- VSS – Standards 40 201 & 40 202

  Typical Geometric Profiles

  Clearance Profile for Heavy Trucks & Buses

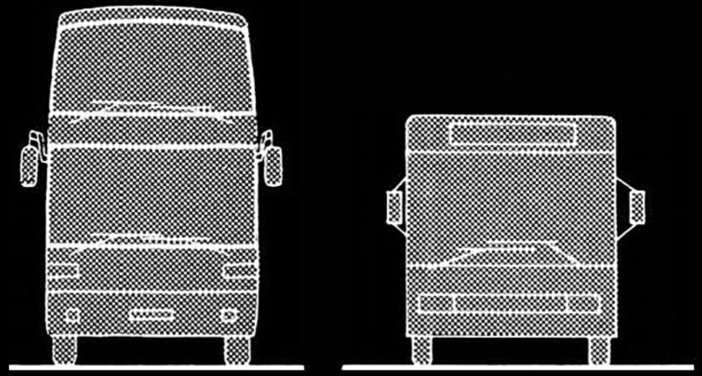
  - The range of motion depends on speed
  - Normal range of motion:

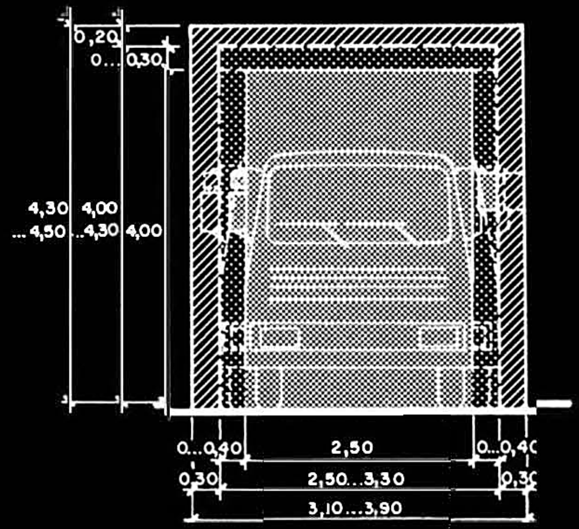
    Horizontal = 0 – 40 cm

    Vertical = 0 – 30 cm
  - Safety margin:

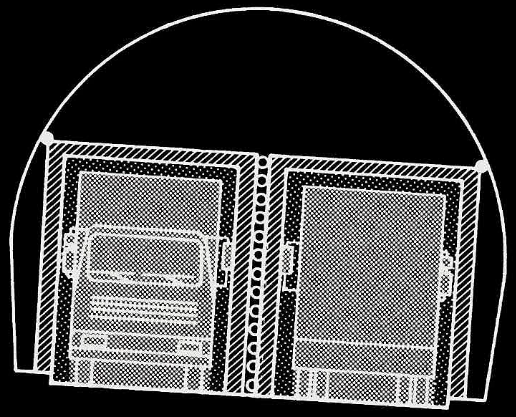
    Horizontal = 30 cm

    Vertical = 20 cm
  - These values apply to straight sections. In the case of tight curves, additional clearance for the heights is necessary for long vehicles.
  - The cross slope must also be taken into account





Basic dimensions of users	Width (m)	Height (m)
Heavy trucks & buses	2.50	4.00
Agricultural vehicles	2.50 – 3.50	3.00 – 4.00



Design Criteria – Structural Safety and Serviceability: Clearances

Clearances - Swiss Standards

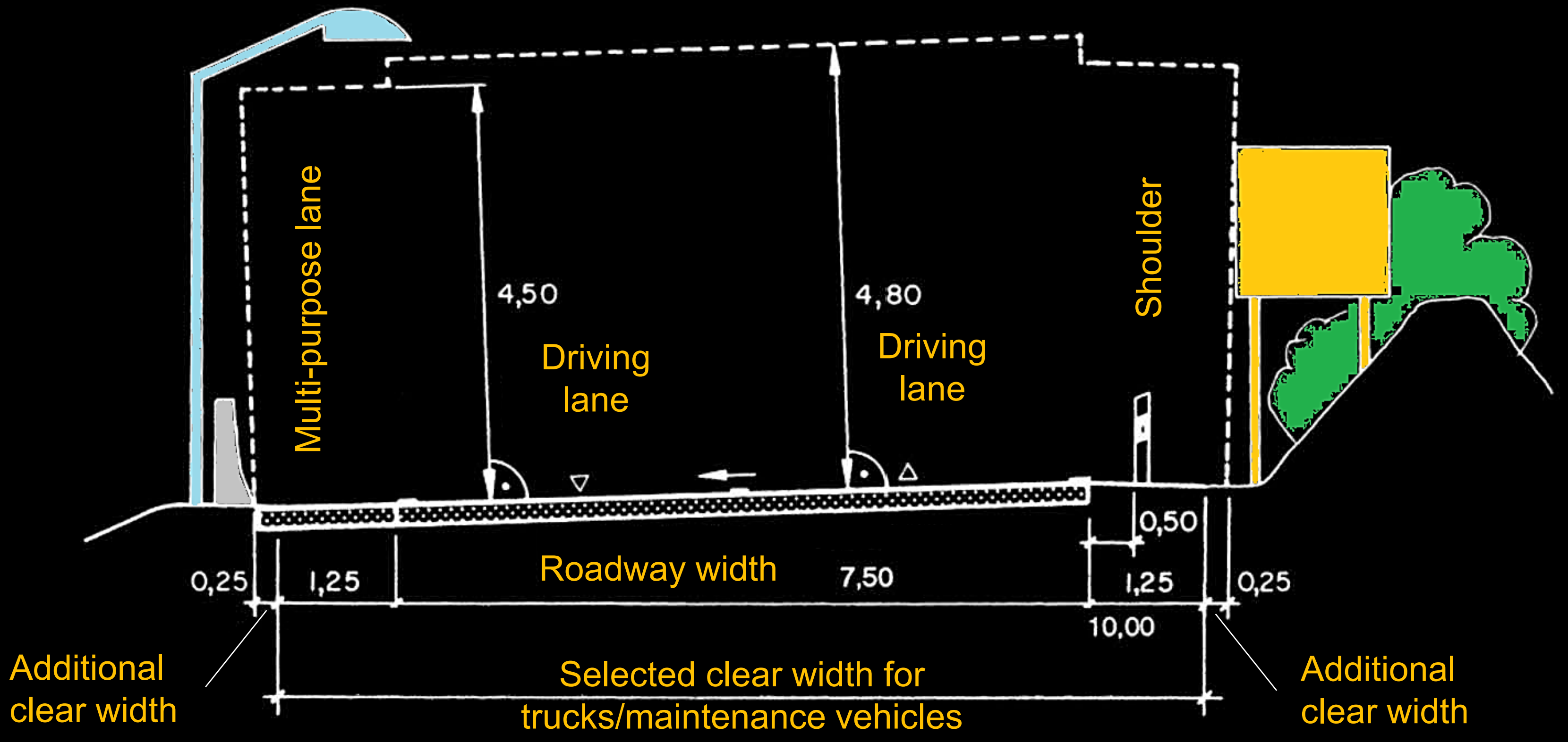
- VSS – Standards 40 201 & 40 202

  Typical Geometric Profiles

Typical geometric profile within water protection areas

Typical geometric profile outside water protection areas

Clearance Profile Example



Design Criteria – Structural Safety and Serviceability: Clearances

Clearances - Swiss Standards

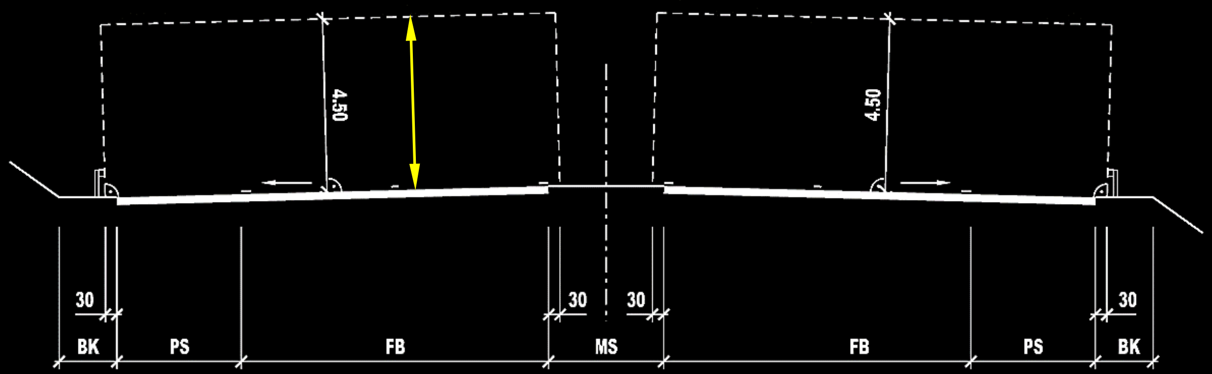
- ASTRA – Guidelines 11001

  Typical Profiles – 1st and 2nd Class National Roads with direction separation

  Clearance profile requirements (free routes, bridges):

  - width of clearance profile:
    … width required for the vehicles plus
    … movement, overtaking and safety margins
  - side safety margins (0.30 m) extend beyond the edge of the road into the median or the shoulder
  - vertical clearance of 4.50 m:
    … account for cross slope, i.e.
    … measured at right angles to the road surface
    … increase to 4.90 m under traffic sign structures
    … increase by ≥ 0.10 m (min. 4.60 m) under overpasses (deflections, reserve for future strengthening of superstructure / surfacing)

4.50 / 4.60 / 4.90



Design Criteria – Structural Safety and Serviceability: Clearances

Clearances - Swiss Standards

- ASTRA – Guidelines 11001

  Typical Profiles – 1st and 2nd Class National Roads with direction separation

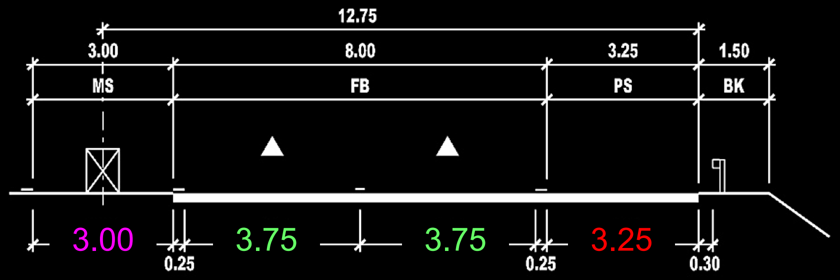
  Lane widths in new motorways (see figures at right):

  - 2 lanes: 3.75 m per lane
  - > 2 lanes: right lane 3.75 m, other lanes 3.50 m
  - emergency lane 3.25 m
  - directional separation 3.00 m

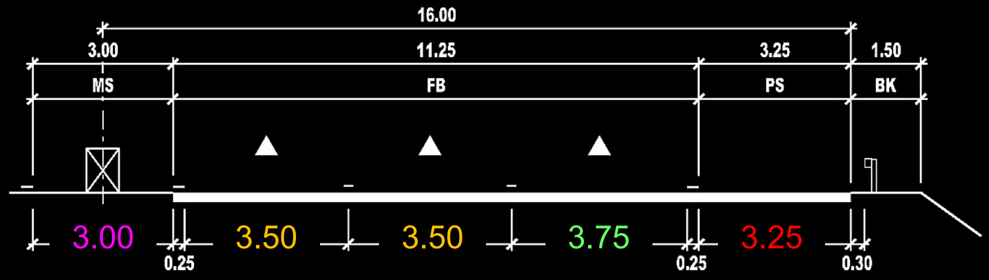
  Minimum lane widths in rehabilitation (not illustrated):

  - 2 lanes: 3.50 m per lane
  - >2 lanes: left lane 3.25 m, other lanes 3.50 m
  - Emergency lane 2.50 m

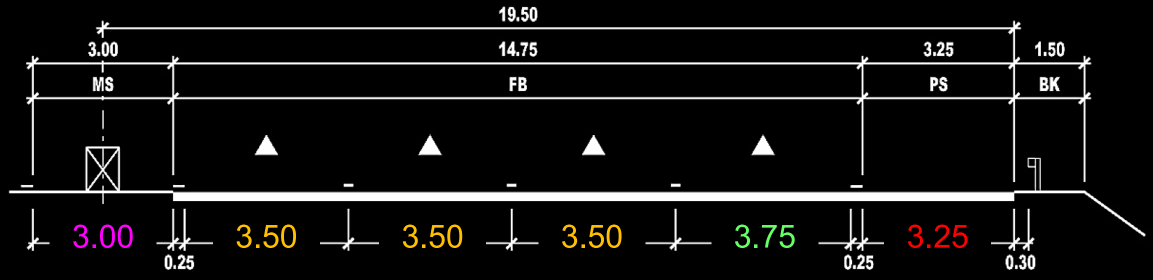
2 lanes / direction



3 lanes / direction



4 lanes / direction



Design Criteria – Structural Safety and Serviceability: Clearances

Clearances

- Reduced (Substandard) Clearances
  - in certain cases, bridge structures do not provide the required standard clearances due to
    … site constraints
    … change of use, and/or standard requirements
  - This should be avoided whenever possible. Even the most high-tech warning measures are typically ineffective in preventing accidents

Design Criteria – Structural Safety and Serviceability: Clearances

Clearances

- Reduced (Substandard) Clearances
  - Accidents due to inadequate clearances may result in
    … damage to the structure and/or vehicle
    … personal injury/death
    … bridge/highway closures and traffic discruptions
  - In extreme cases, inadequate clearances may result in collapse of the bridge

Example: I-5 Skagit River Bridge, WA, USA (1955)

- On May 23, 2013, a span of the bridge carrying Interstate 5 over the Skagit River in the U.S. state of Washington collapsed
- The cause of the catastrophic failure was determined to be an oversize truck striking several of the bridge's overhead sway frames, leading to an immediate collapse of the northernmost span

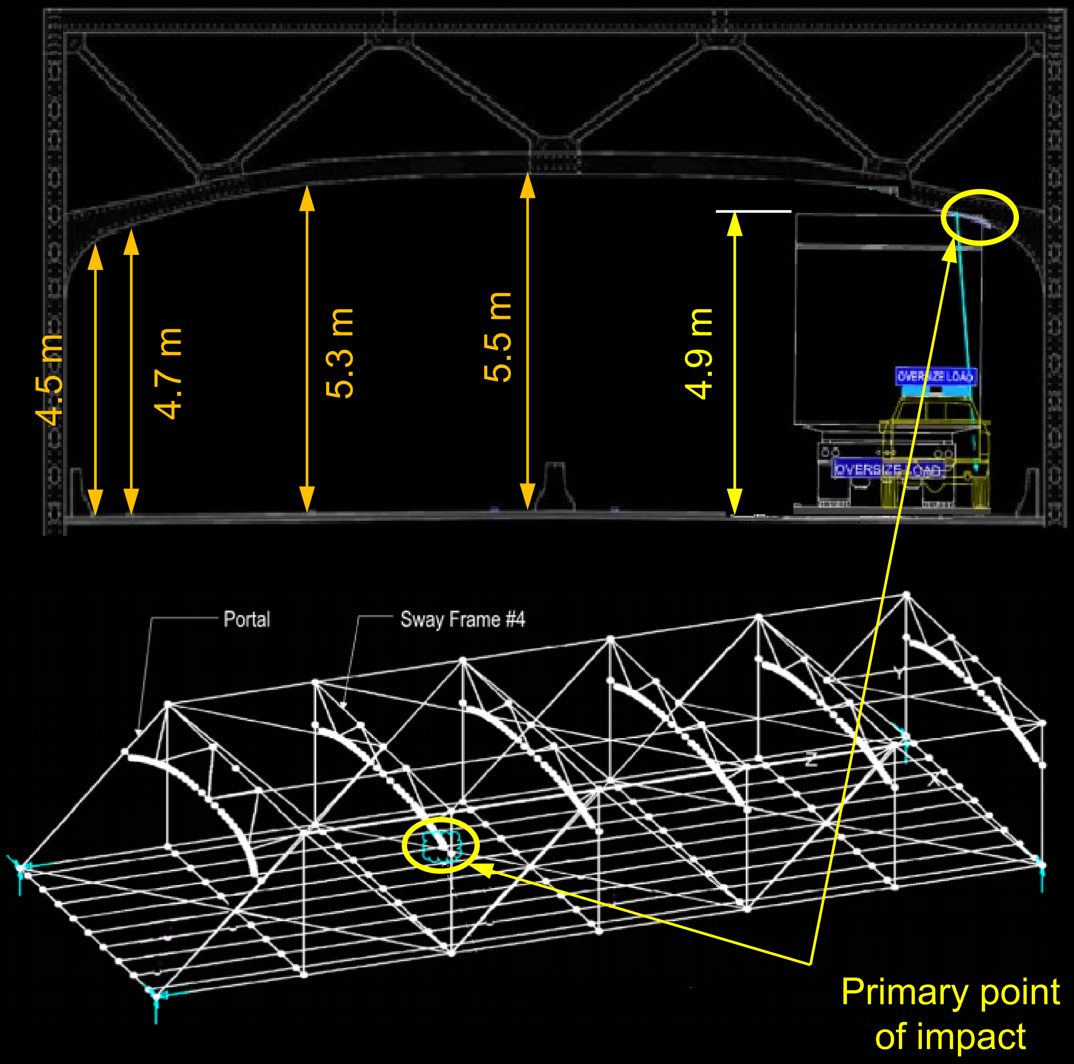
Design Criteria – Structural Safety and Serviceability: Clearances

Clearances

- Reduced (Substandard) Clearances

  Example: I-5 Skagit River Bridge, WA, USA (1955)

  - Variable clearance to sway frames across width.
  - Oversize truck with height of 4.9 m.
  - Pilot car failed to identify clearance issue.
  - Bridge span collapse was initiated when the oversize truck hit Sway Frame 4, causing horizontal deformation of the adjacent vertical member. This deformation pulled the attached upper chord member downward, causing instability in the upper chord.
  - Due to the non-redundant structural system, failure of the upper chord led to collapse of the truss span.

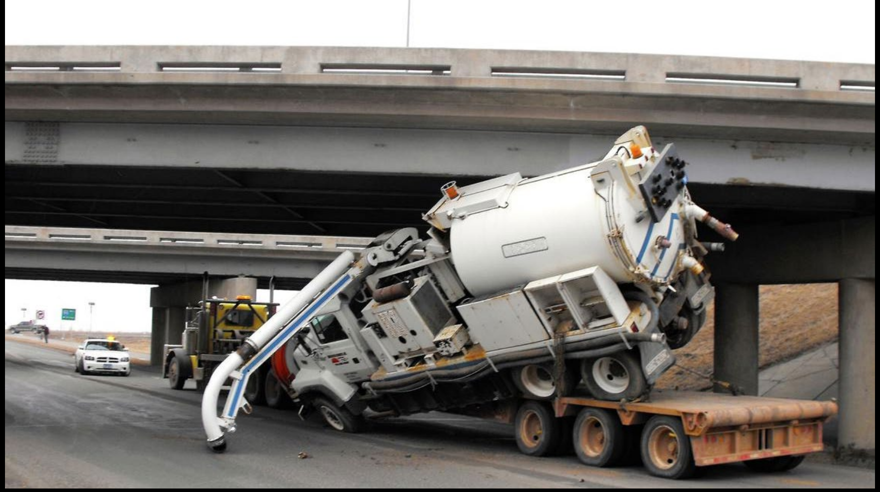


Design Criteria – Structural Safety and Serviceability: Clearances

Clearances

- Reduced (Substandard) Clearances

  Other Examples of Oversize Combination Vehicles:



Design Criteria – Structural Safety and Serviceability: Clearances

Clearances

- Reduced (Substandard) Clearances

  Local Examples of Oversize Combination Vehicles:

Design Criteria – Structural Safety and Serviceability: Clearances

Clearances

- Change in clearance requirements

  Over the service life of a bridge the clearance requirements may change (usually increase).

  Example: Bayonne Bridge, NY & NJ, USA (1931)

Roadway was raised by 20 m to accommodate post-Panamax ships (2013-2019).

Conceptual Design

Design Criteria – Durability

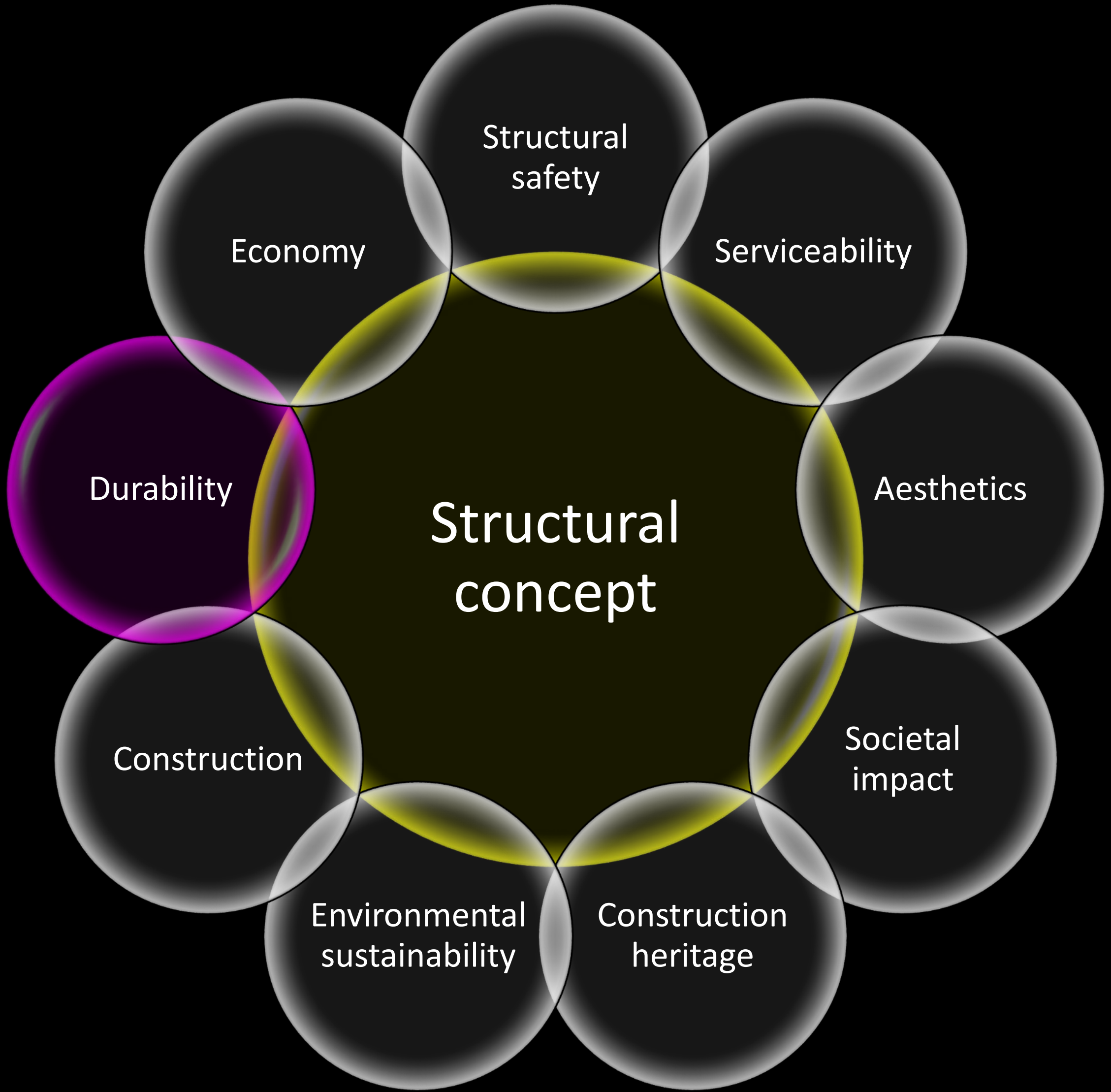
Entwurfskriterien – Dauerhaftigkeit

Design Criteria – Durability

General aspects

Durability is essential and needs to be accounted for from the conceptual design stage to the end of construction.
Specific aspects (relevant for all construction materials):

- Avoid joints (→ support and articulation)
- Protect structure from chloride attack
  … reliable waterproofing and controlled drainage of decks
  … minimise exposed surfaces
- Use proper materials, for example
  … avoid weathering steel or timber in wet zones
  … use freeze-thaw resistant concrete
- Carefully detail the entire structure, for example
  ... avoid horizontal surfaces (puddles, “stehendes Wasser”)
  … provide gutters («Tropfkanten»)
- Facilitate access for inspection and maintenance e.g. to:
  … interior of box-girders (h ≥ 1.50 m)
  … expansion joints and bearings (maintenance chamber)
- Ensure quality during execution – the proper execution of a detail is at least as important as choosing the right detail



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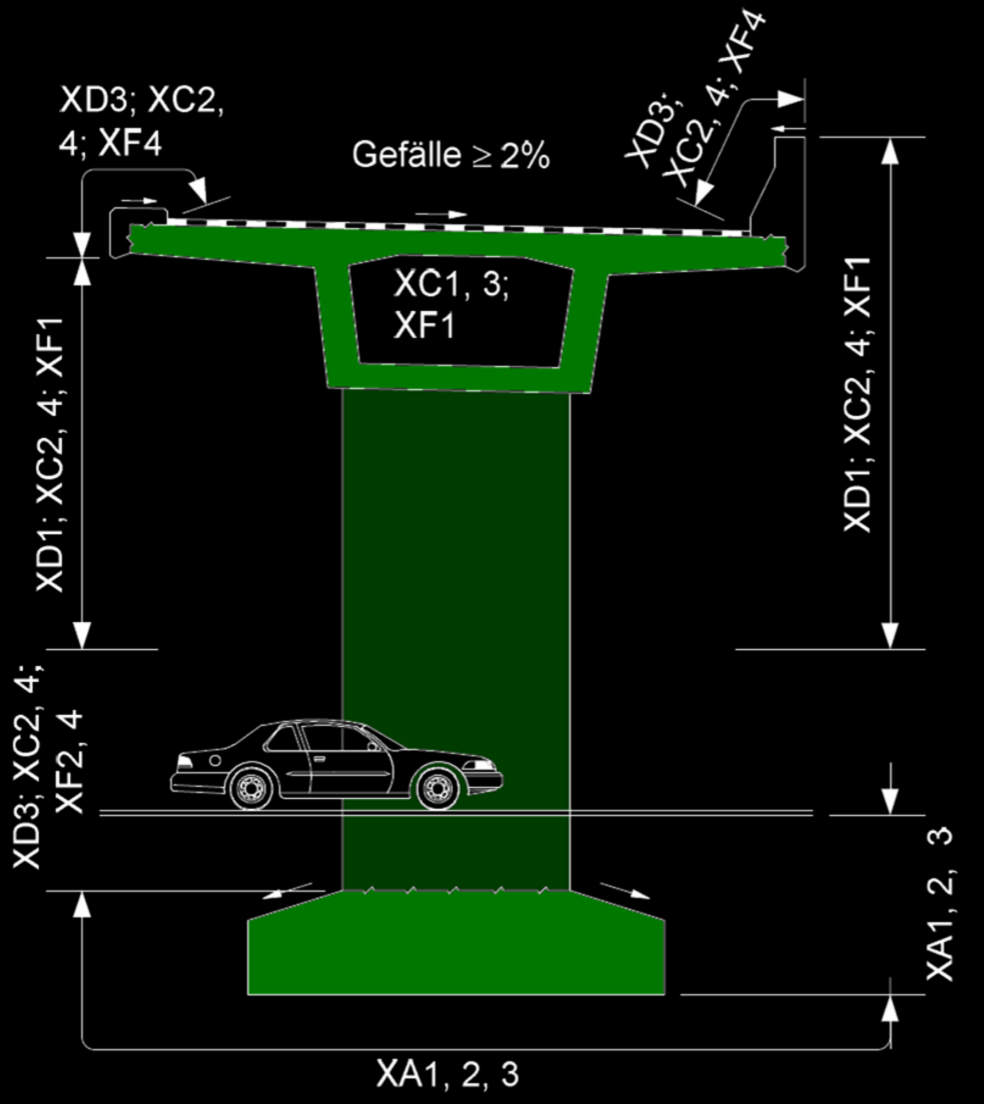
Design Criteria – Durability

Concrete

- Specify concrete with adequate freeze-thaw resistance depending on exposure classes XF (see figure)
- Ensure dense cover concrete (air permeability)
- Make sure that post-tensioning ducts are properly grouted
- Full prestressing (avoid cracks) at least for permanent load
- Specify adequate concrete cover, depending on exposure classes XC, XD and XA (see table and figure) for lifespan of 80… 100 years:

Exposure classes / clear cover (ASTRA RL 12001)		reinforcement cover [mm]	prestressing cover [mm]
XC: Carbonation	XC1-4	40	50
XD: Chloride attack	XD1	40	50
	XD2,3	55	65
XA: Chemical attack (Astra: incl. chlorides)	XA1,2	55	65
	XA3	70	80

(*) increase by 10 mm if concrete permeability is high for XC3,4 and XD



Design Criteria – Durability

Steel (conventional)

- Ensure proper surface preparation (Sa 2½ or Sa3, edges)
- Apply coating in workshop (quality control, climate)
- Ensure air-tightness of inaccessible elements (inside box girders and closed profiles) or provide dehumidification
- Protective coating with adequate protection (category of corrosiveness, usually C3/C4 for bridges)
  … conventional, see table
  … thermal spray zinc coating («Spritzverzinkung»)
  (instead of primer, intermediate + top coating as above)

Typical protective coating for CH steel bridges (SBB AQV 2007, category C4)		thickness [μm]
Primer (*) (base layer)	Two pack zinc epoxy / phosphate (2-K-Epoxidharz-Zinkstaub)	70
Intermediate coatings (2)	Two pack Epoxy MIO (**) (2-K-Epoxidharz-Eisenglimmer)	80
		80
Top coating	Two pack Polyurethane MIO (**) (2-K-Polyurethan-Eisenglimmer)	80

(**) micaceous iron oxide (Eisenglimmer)

Design Criteria – Durability

Steel (with improved corrosion resistance)

- Weathering steel («Cortenstahl») may be used without protective coating in many cases / exposures since a protective patina will form if wet/dry phases alternate
- Weathering steel should not be used:
  … in humid sites (< 3 m above river, < 0.5 m above ground)
  … in case of chloride exposure (e.g. crossing a road with de-icing salt deployment, or site close to sea)
- Careful detailing is important for durability and appearance (avoid rust stains)

- Stainless steel is only used in exceptional cases due to the high initial cost

Design Criteria – Durability

Timber

- Durability is problematic since bridges cannot be completely protected from weathering and humidity
- Improvement by impregnation with chromated copper arsenate (CCA) or oil-tar creosotes (“carbolineum”), but severe environmental issues (prohibited in many countries)
- Careful detailing is important for durability and appearance (protect from weathering, avoid mould, use durable wood where available, see lower example)

Design Criteria – Durability

Stay cables

- Require particular attention since they are usually
  … important load-bearing elements
  … subjected to severe exposure

- Stays of early cable stayed bridges had limited durability

- Modern stay cables are high-tech, durable components (see image on next slide):
  … individually encapsulated (sheathed) strands
  … galvanised or epoxy-coated strands
  … replaceable strands and cables (under traffic)
  … dehumidification of ducts
  (in harsh exposure, e.g. marine environment)

Design Criteria – Durability

Compatible with modern construction methods
Compact anchorages fully prefabricated in workshop, no anchorage component assembly on the deck, single strand installation with light equipment, easy force monitoring and adjustment.

Full encapsulation
Each strand separately protected inside the anchorage.

Increased corrosion protection
Factory-applied individual protection treatment, up to 100 years design life in the most aggressive environments.

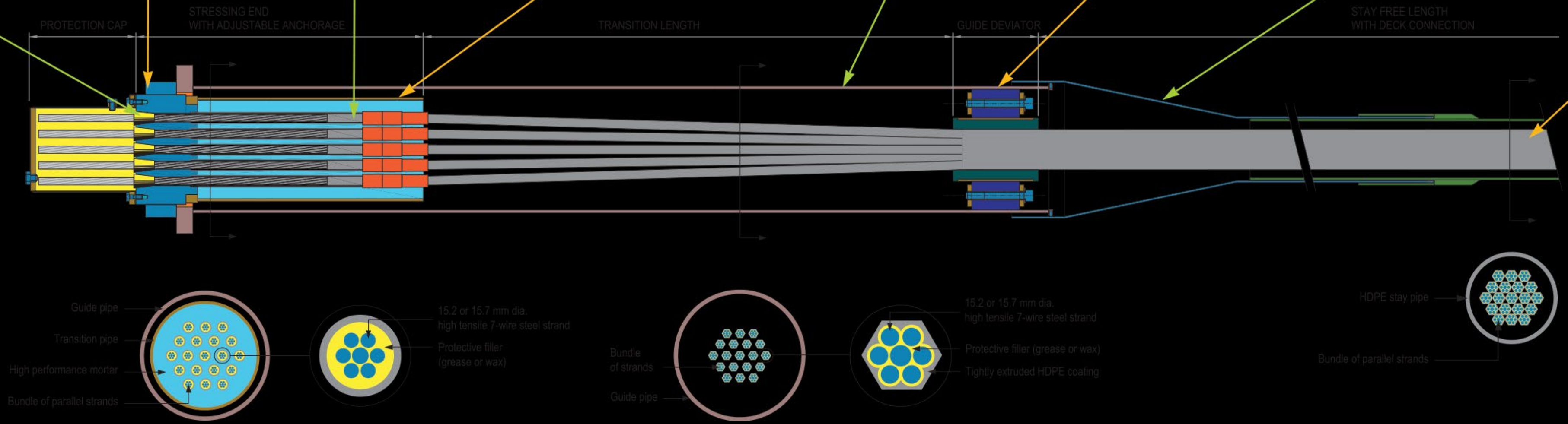
Economical
Faster installation and erection cycles. Reduced maintenance.

Increased stay anchorage protection
Deviator placed in the guide pipe povides an additional level of protection by filtering cable bending stresses before they reach the anchorage.

Versatile
Designed to receive in the future vibration damping systems (friction dampers) if necessary.

High fatigue resistance
200 MPa with an upper load of 45% of the stay capacity over $2x10^6$ load cycles; excellent ultimate resistance after fatigue testing (min. 95% of the specified stay capacity).

Replaceable strands
Ability to remove and to replace individual strands on demand.



Conceptual Design

Design Criteria –Environmental sustainability

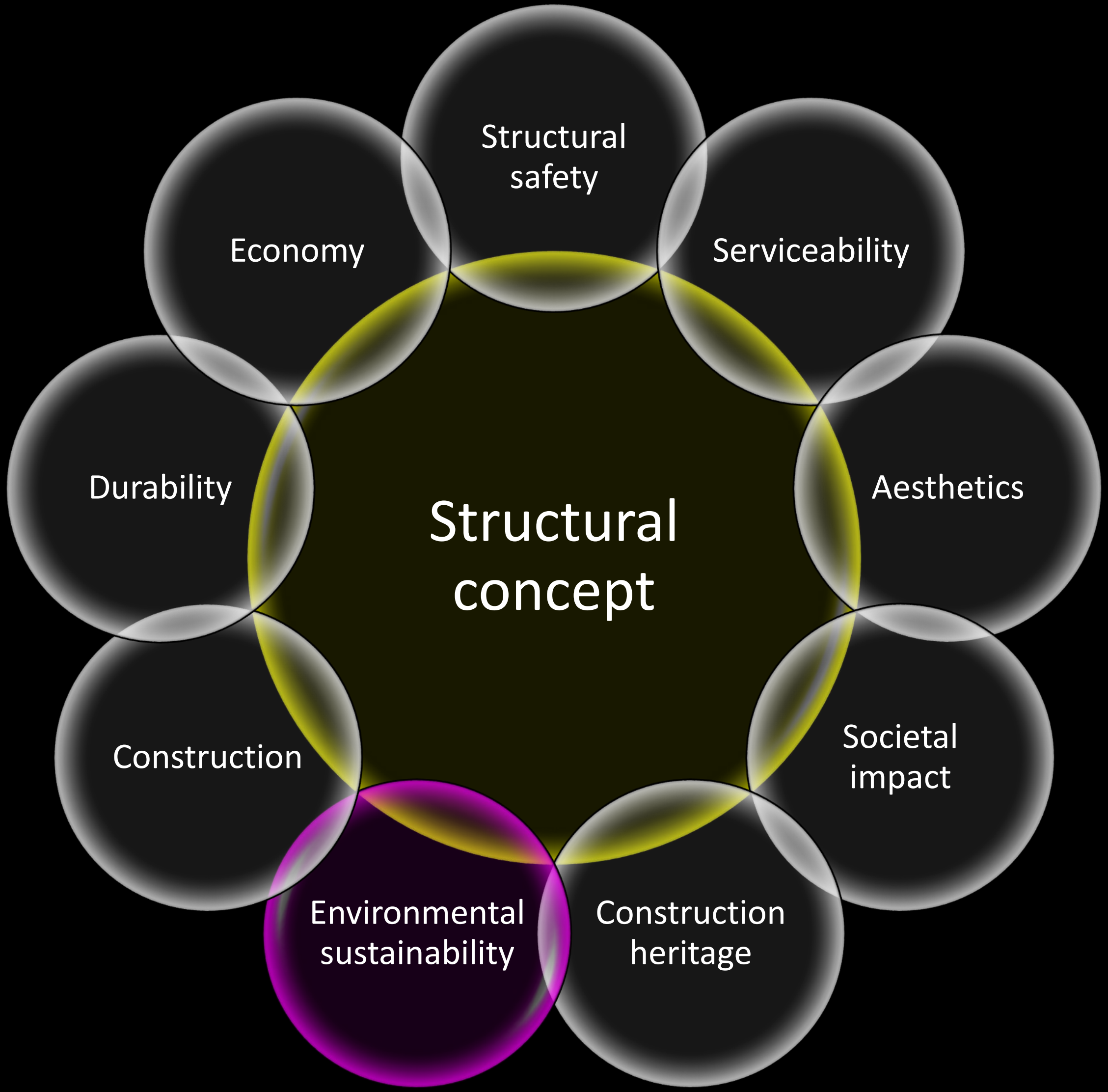
Entwurfskriterien – Ökologische Nachhaltigkeit

Design Criteria – Environmental sustainability

General aspects

- Environmental sustainability is a decisive design criterion
- Ensure respect of environmental legislation by accounting for related aspects in early design stages
- Longer bridges than strictly necessary may be required to
  … avoid nature reserves and habitats of protected species
  … protect ecologically important river banks and ensure connectivity along these (and along other obstacles)
- Longer river spans may be economical if no temporary dams facilitating access for the construction of river piers and their foundations are prohibited
- Birds are another important criterion, as they
  … use rivers (obstacles crossed by bridges) as routes
  … are attracted by bright lights on bridges
  … hit thin elements of the bridge structure in poor weather

→ Cable-supported structures require special measures or are even prevented near important bird habitats



Design Criteria – Environmental sustainability

Environmental impact of construction

- Negative environmental impact must also be minimised during construction
  … building piers and foundations from water rather
  than temporary dam (see previous slide)
  … avoid spawning season of fish and frogs
  … avoid periods where flood events are expected

Compensation measures

- Ecological compensation measures are often provided in order to mitigate negative environmental impacts, e.g.
  … renaturation of built-up banks
  … planting of native vegetation
  … providing nesting aids (for birds or bats)
  … building support structures for fish and frog spawn

Link to economy and structural efficienycy

- Minimisation of material use and emissions are important for environmental sustainability as well as for economy. They are best achieved by structural efficiency.

Conceptual Design

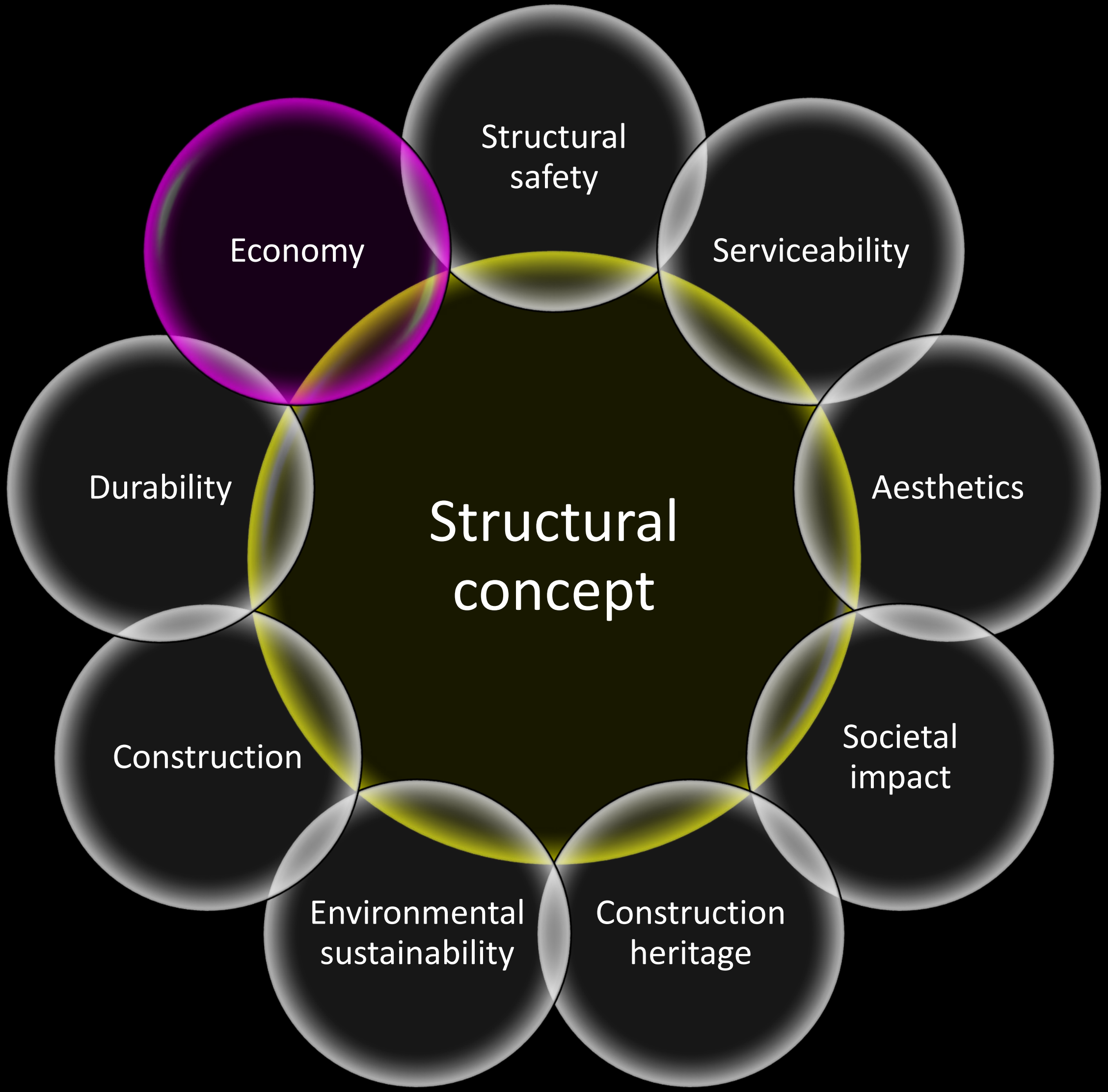
Design Criteria – Economy

Entwurfskriterien – Wirtschaftlichkeit

Design Criteria – Economy vs Environmental sustainability

Link between economy and environmental sustainability

- Environmental protection measures are often seen as a cost driver by construction industry
- While this partly applies, economy and environmental sustainability are also related: structurally efficient bridges minimise material use hence cost and emissions
- Unfortunately, the link is loose today since construction materials are too cheap, to the point where wasting material to reduce labour has become usual
- Hopefully, the current trend towards reducing material consumption and greenhouse gas emissions will reinforce the dependency of economy on structural efficiency, and hence, the connection between economy and environmental sustainability as well.



Design Criteria – Economy

General aspects of economy in bridge design

- Economy is even more relevant in bridge design than forbuilding structures, since

→ bridges are usually public works, paid by tax money

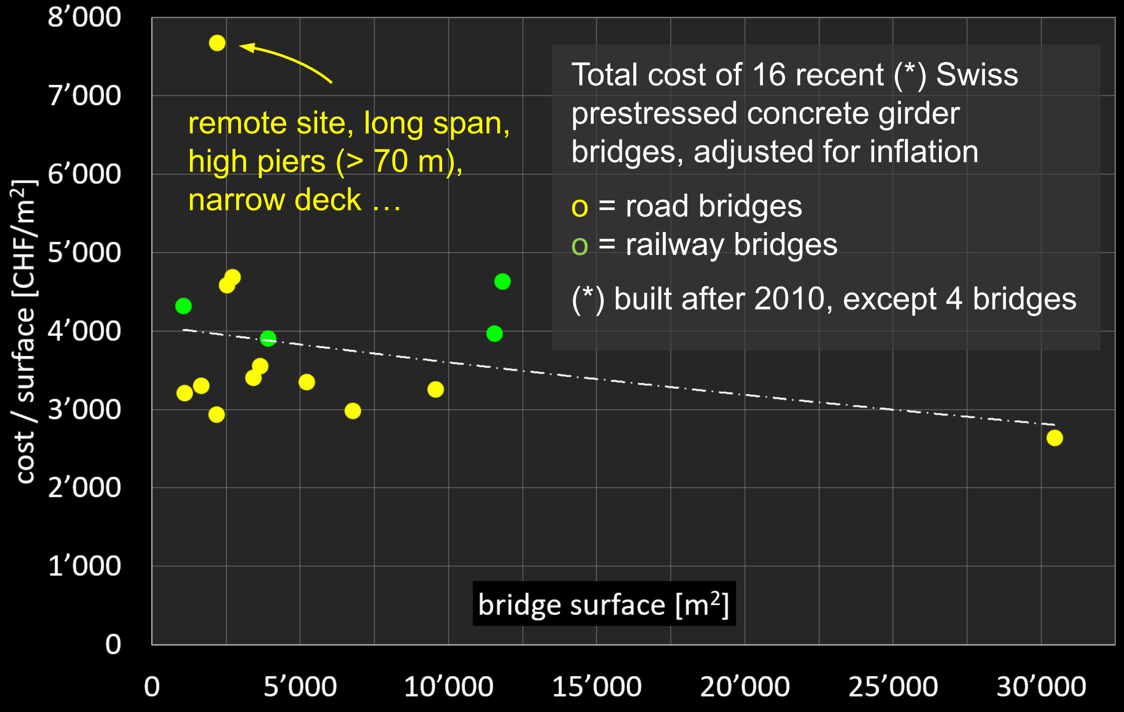
→ in bridges, the structure makes up for most of the total cost (whereas in buildings they are a smaller part)

- Though clients are aware that life-cycle costs are relevant, decisions are regularly taken based on initial cost (particularly in design-build competitions)
- In order to achieve an economic (and eco-friendly) solution:
  … account for construction method in early design stage
  … use economic, durable materials (depending on site)
  … save materials by maximising structural efficiency
  … simplify geometry and seek repetitiveness

Design Criteria – Economy

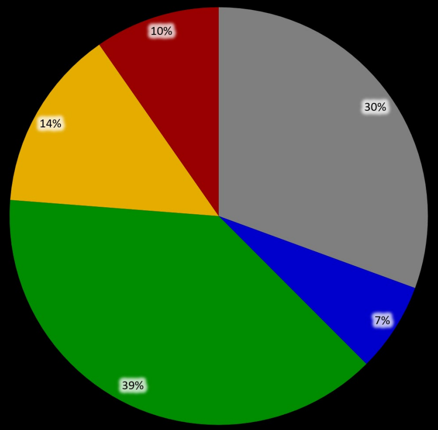
Cost estimates

- Cost estimates are essential to clients (particularly in political decision processes)
- When comparing costs, make sure to compare equivalent costs, i.e., cost with or without:
  … client/owner overhead, design fees
  … bridge equipment (surfacing, drainage, …)
  … percentages for unforeseen, VAT
- Rough estimates are possible based on the cost per bridge surface (e.g. ca. 3’500 CHF/m^2 total cost for Swiss road bridges, top figure) if reference objects with similar conditions are available regarding
  … location (cost varies strongly even among EU countries)
  … construction constraints (under traffic / over railway / …)
- Cost estimates per m^2 may be completely misleading e.g. in footbridges (recent *fib* bulletin 2’000…25’000 CHF/m^2)
- Better estimates are hardly possible by considering the share of individual components to the cost (bottom figure)



Contribution to total cost for 6 Swiss prestressed concrete girder bridges (commissioned after 2010)

Site installations, various
Scaffolds
Concrete works (concrete, formwork, reinforcement, prestressing)
Earth works, excavation pits, piles
Waterproofing, surfacing, drainage



Design Criteria – Economy

Cost estimates

- More reliable cost estimates are possible once the project is defined such that the main quantities can be determined and the costs evaluated by applying unit prices based on local experience.
- The figure shows an example used in design competitions in CH, following NPK ("Normpositionenkatalog" / standardised position catalogue) main positions and quantities)
- Contractor bids may differ significantly from cost estimates not only due to uncertainty of the estimate, but also due to the current construction market (contractor in need for work or not)

223	**Belagsarbeiten**					**386'000**
	Beläge Brücke Fahrbahn	t	290	300	87'000	
	Beläge Brücke Gehweg	t	94	350	32'900	
	Beläge Strassen	t	1'400	190	266'000	
237	**Kanalisationen und Entwässerung**					**36'000**
	Brückenentwässerung	gl	1	7'000	7'000	
	Strassenentwässerung	gl	1	29'000	29'000	
241	**Ortbetonarbeiten**					**1'979'000**
	Schalung Fundationen / Pfahlbankette	m^2	170	80	13'600	
	Schalung Widerlager	m^2	150	120	18'000	
	Schalung Pfeiler	m^2	260	280	72'800	
	Schalung Überbau	m^2	1'360	140	190'400	
	Schalung Überbau rund	m^2	1'230	300	369'000	
	Schalung Total				***663'800***	
	Beton Fundationen / Pfahlbankette	m^3	190	220	41'800	
	Beton Widerlager	m^3	110	220	24'200	
	Beton Pfeiler	m^3	220	240	52'800	
	Beton Überbau	m^3	1'240	300	372'000	
	Beton Total				***490'800***	
	Bewehrungen	***t***	***460***	***1'400***	***644'000***	
	Div. Kleinpositionen	***gl***	***10%***	***1'799'000***	***179'900***	
244	**Lager und Fahrbahnübergänge**					**16'000**
	Lager	St	4	4'000	16'000	
246	**Spannsysteme**					**156'000**
	4 Kabel à 37x0.6" Litzen	m'	520	300	156'000	
247	**Lehrgerüste**					**760'000**
	Montage Lehrgerüste	gl	1	570'000	570'000	
	Absenken					

Conceptual Design

Design Criteria – Construction

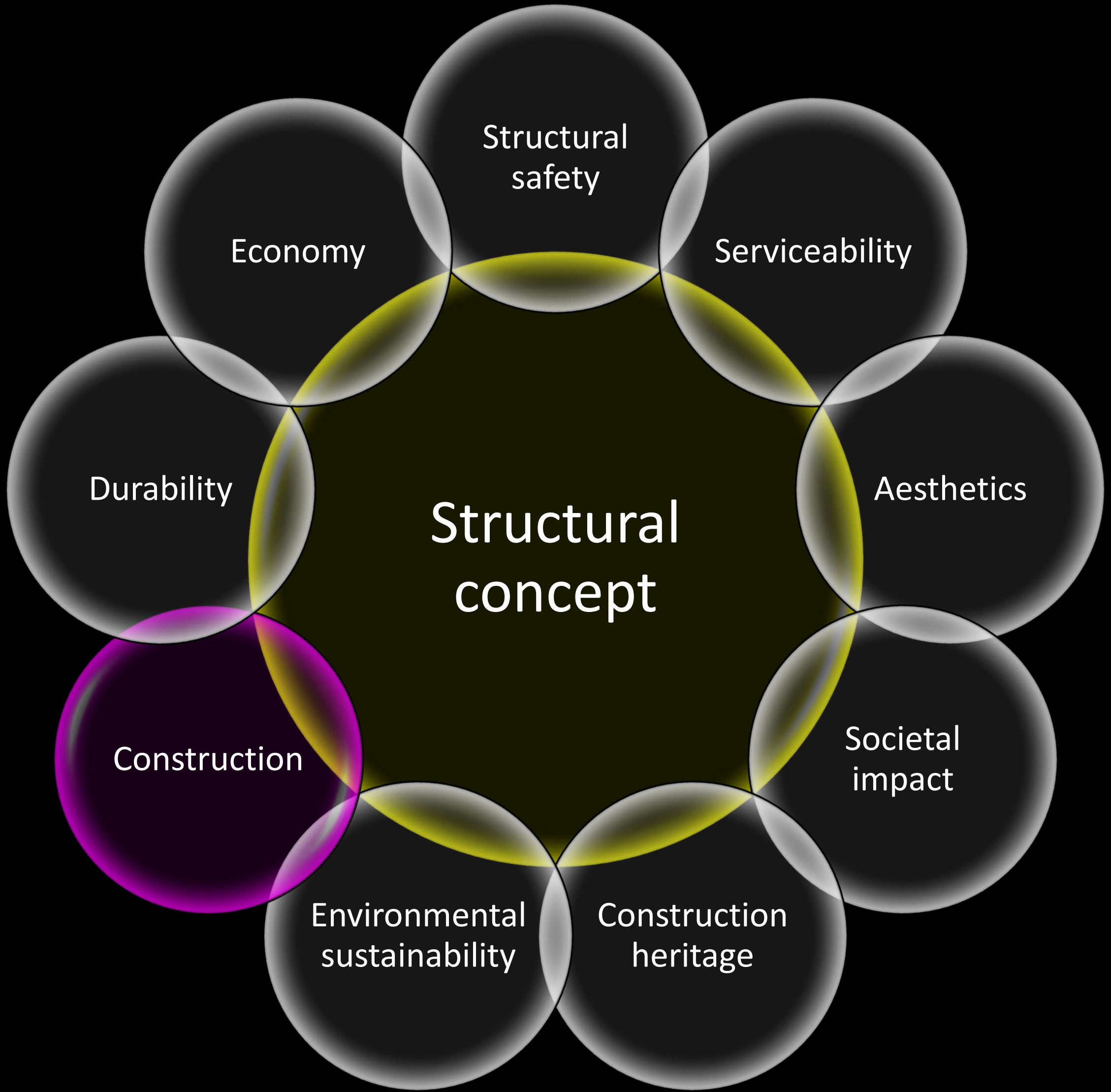
Entwurfskriterien – Bauvorgang

Design Criteria – Construction

General aspects

Construction includes:

- Erection method (most relevant aspect)
  - → casting on falsework (conventional scaffolding)
  - → lifting
  - → balanced cantilevering
  - → incremental launching
  - → Movable Scaffold System (MSS)
  - → …
- Type of production
  - → casting in-situ
  - → prefabrication (precast elements)
- Transport of materials or elements of the structure
- New technologies
- …

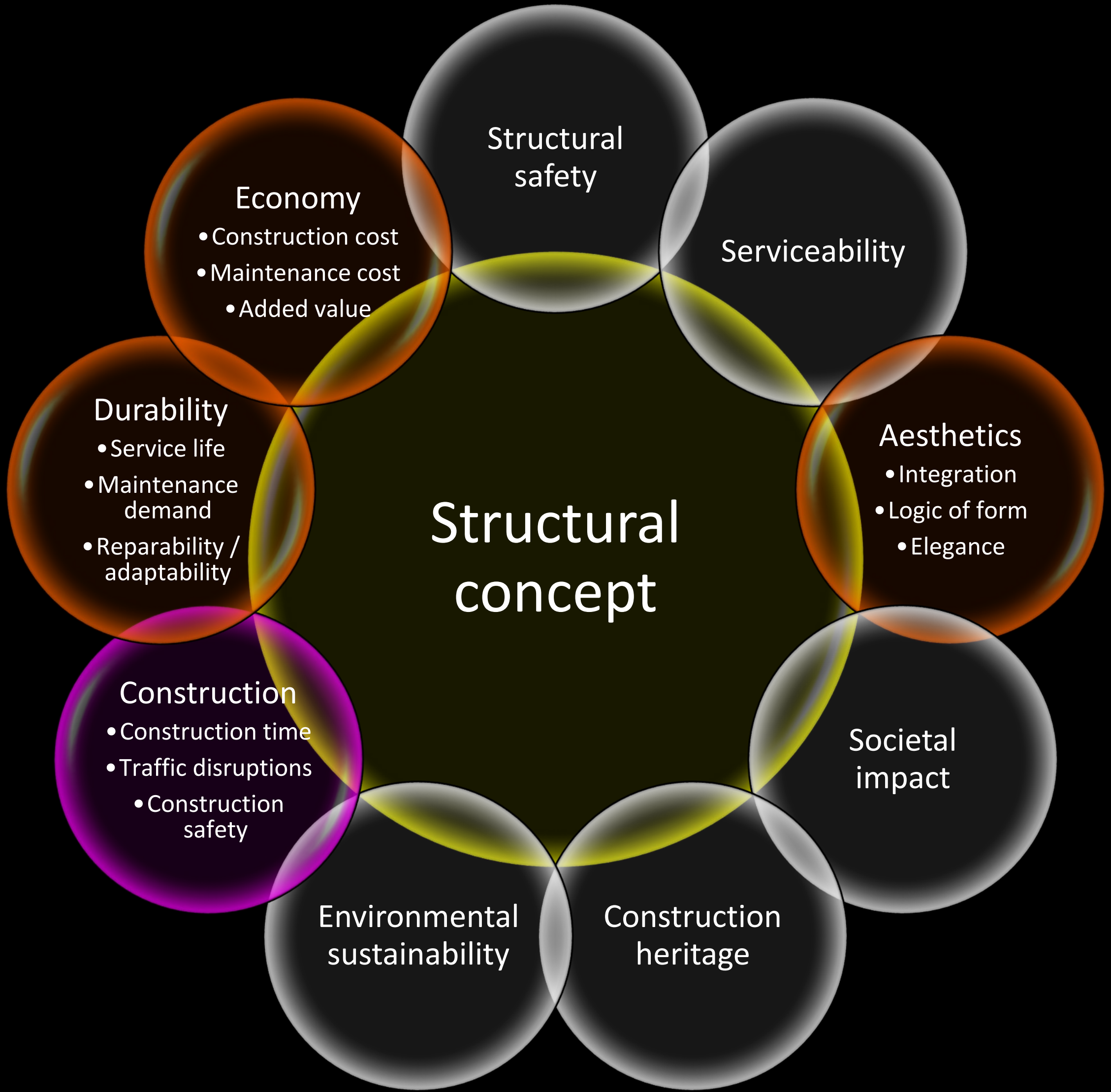


Design Criteria – Construction

General aspects

Choice of the erection method

- The erection method is selected in an iterative process in order to conceive a structure that optimises the given constraints
- Efficient construction is only one of many criteria, but affects many others (see figure)
- The main factors in the iterative process are:
  - → materials
  - → typology of the bridge
  - → topography
  - → cost
- The erection method may significantly influence the dimensioning of the structure



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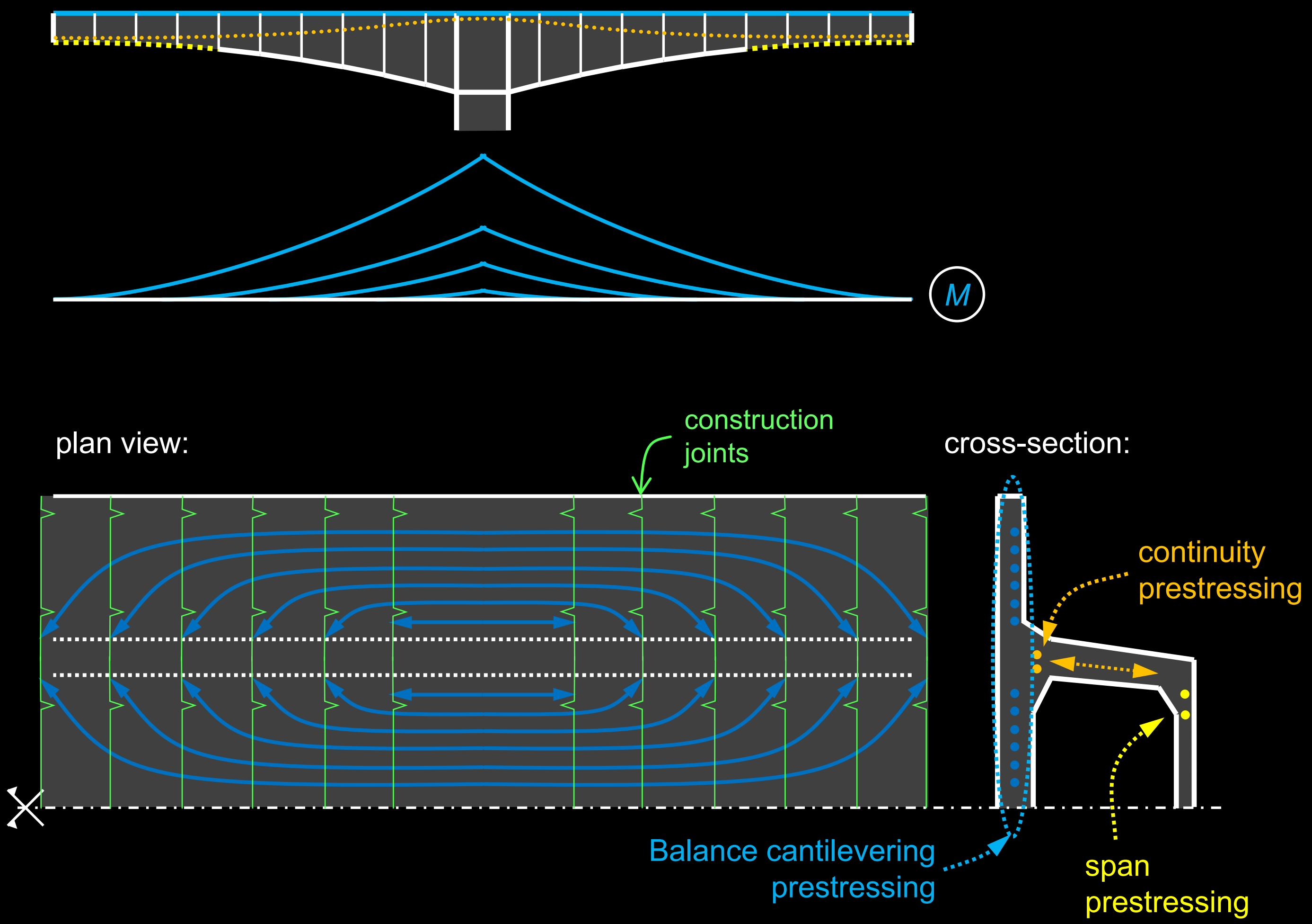

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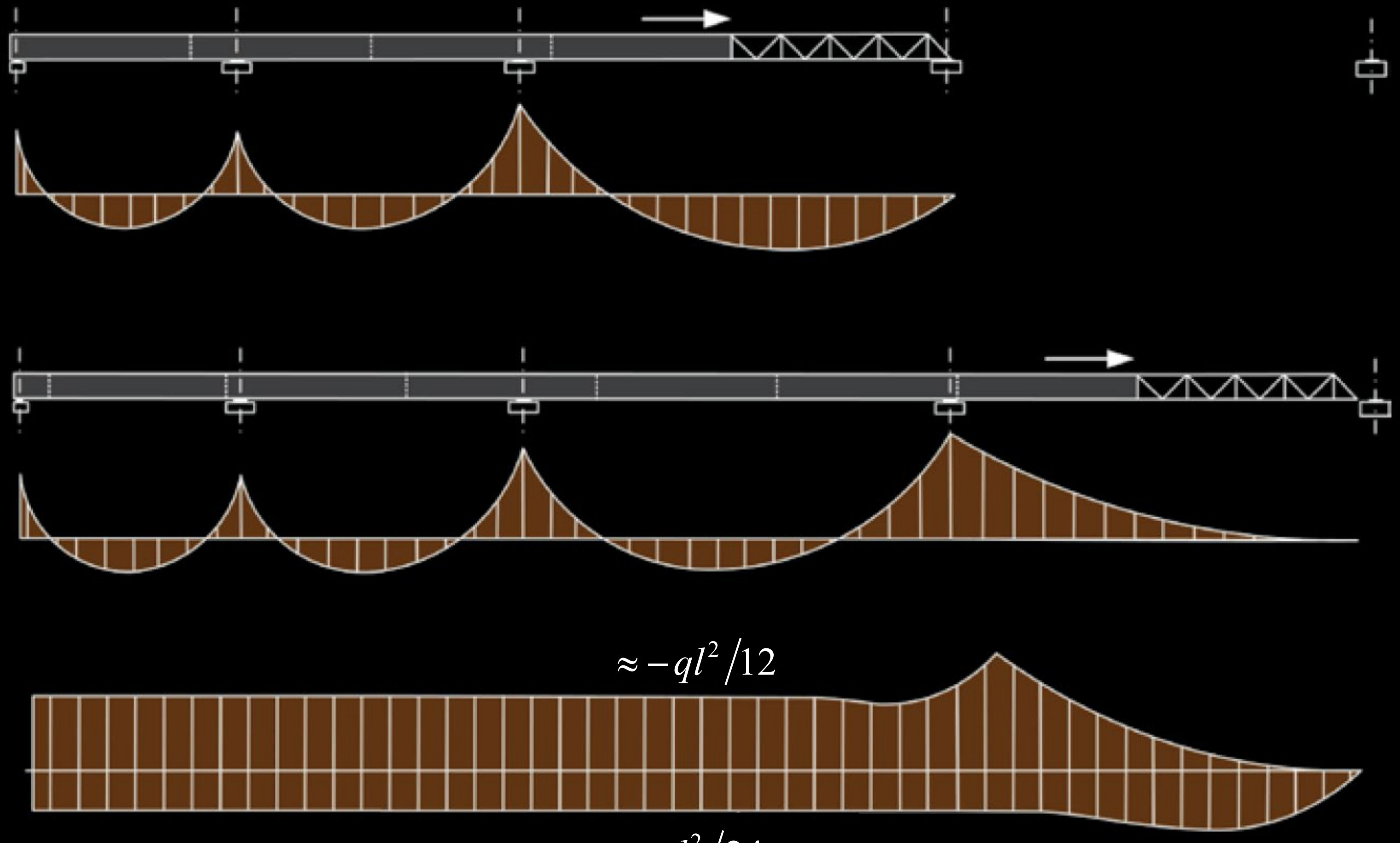
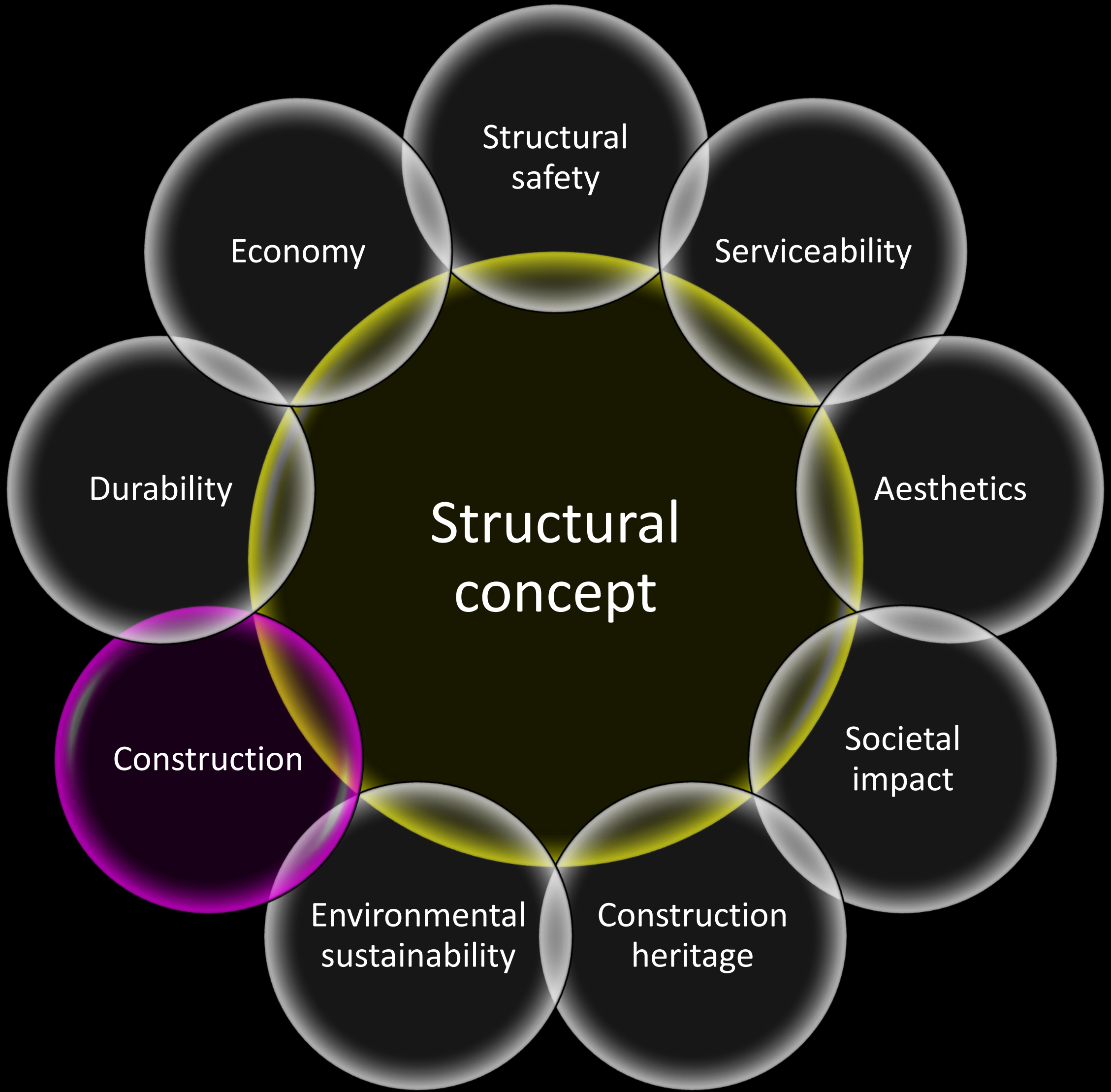


Design Criteria – Construction

Conclusions:

- The construction process is an integral part of the structural concept
- Neglecting the construction process in the early design phase may lead to excessive cost



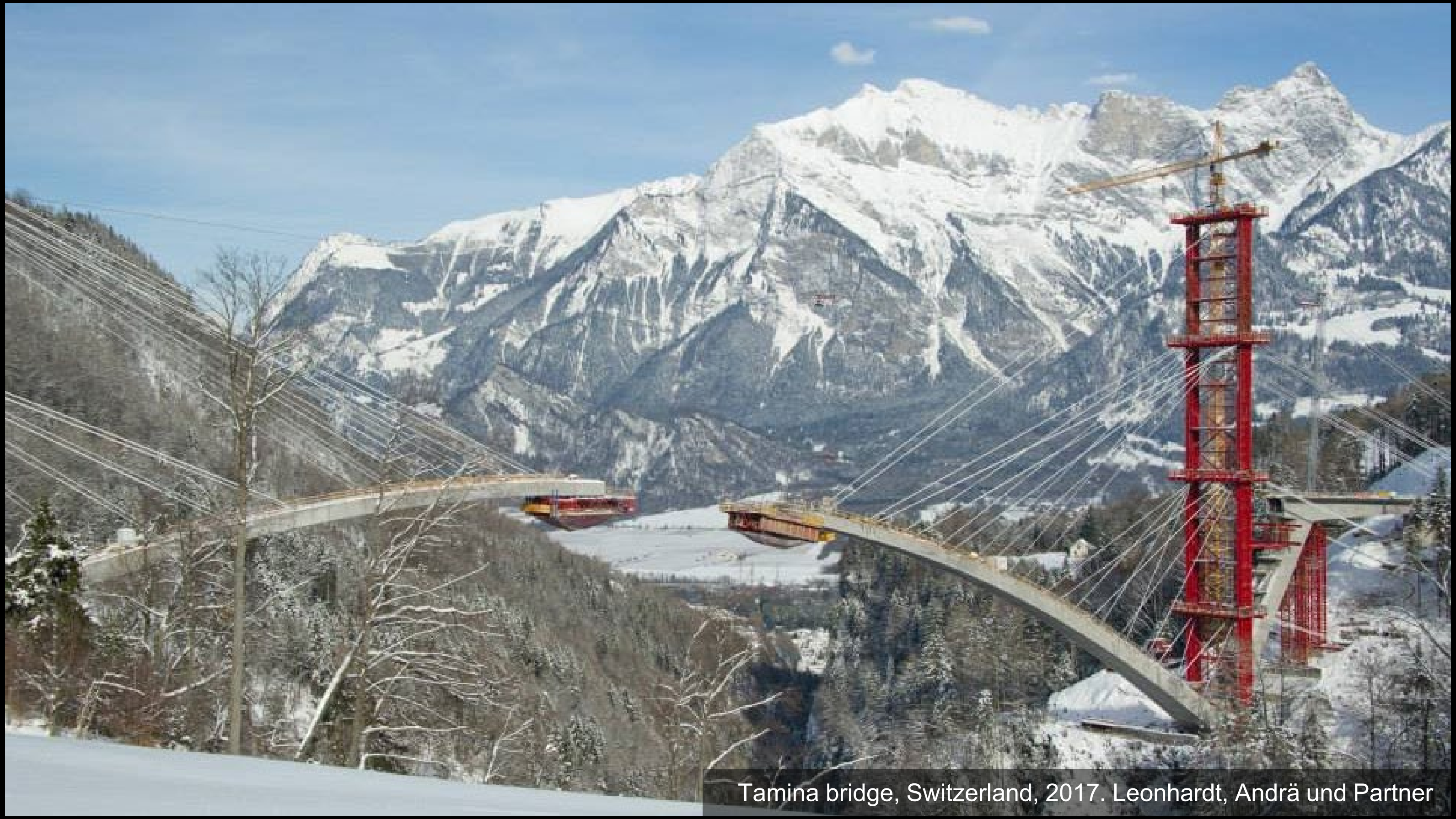
Design Criteria – Construction

In extraordinary bridges, the construction process is absolutely key…

Millau viaduct, France, 2004. Dr. Michel Virlogeux

Design Criteria – Construction

In extraordinary bridges, the construction process is absolutely key…



Tamina bridge, Switzerland, 2017. Leonhardt, Andrä und Partner

Design Criteria – Construction

Sometimes … conventional methods are still the only viable solution

Shell Pedestrian bridge over Manzares river, Spain, 2010. Fhecor Ingenieros

Conceptual Design

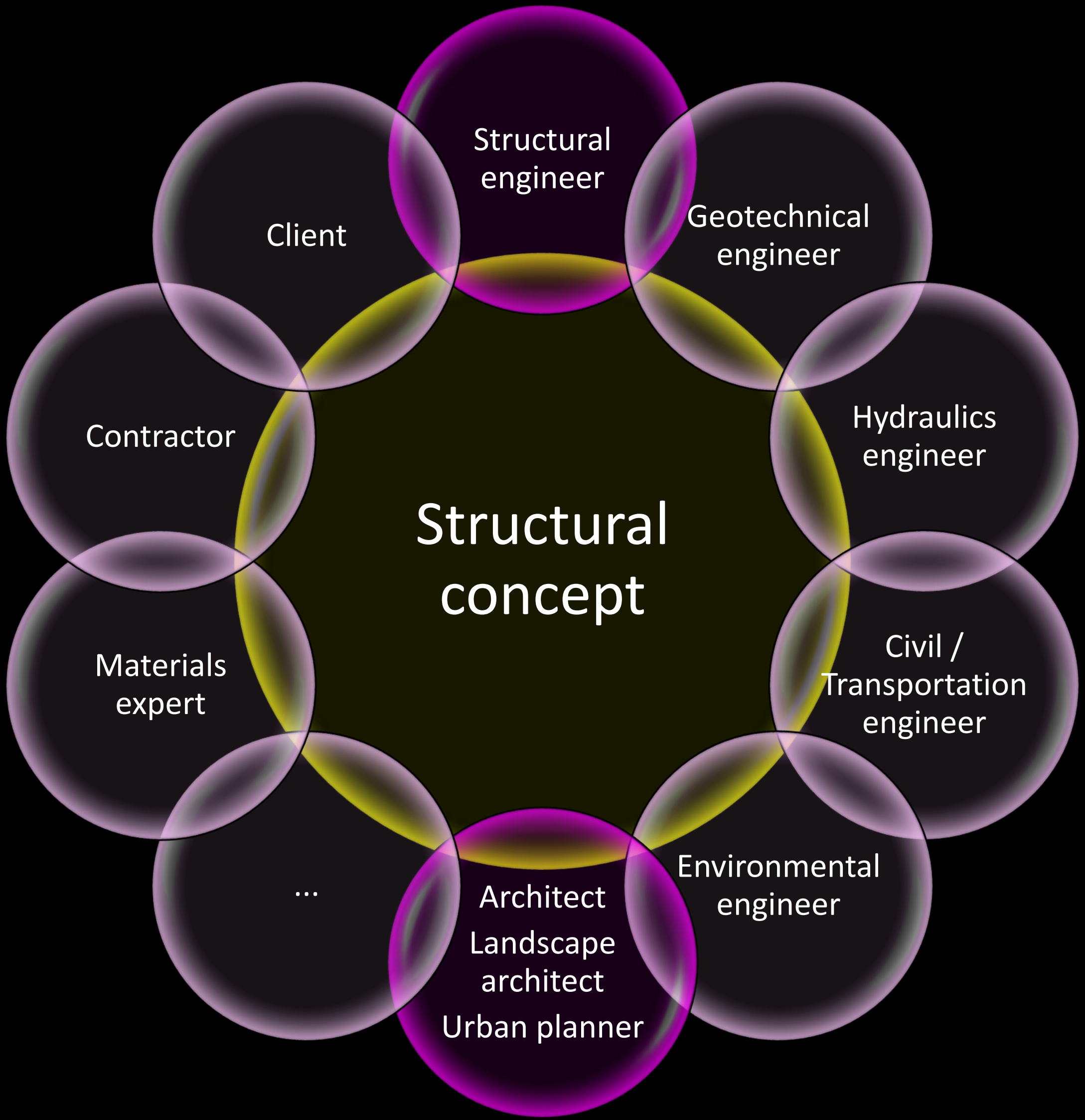
Holistic Design – Process

Ganzheitlicher Entwurf – Prozess

Holistic Design – Process

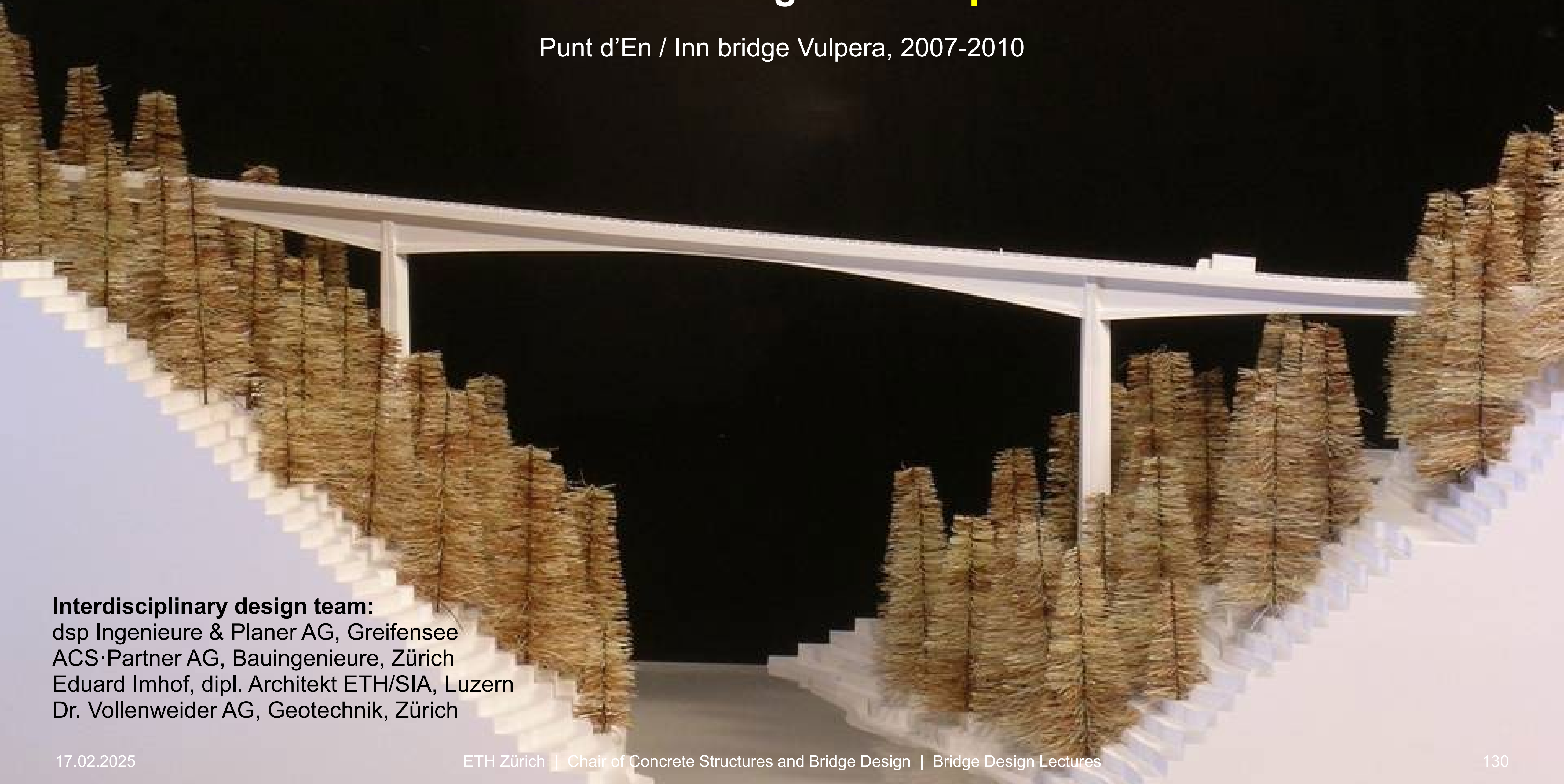
Interdisciplinary design team

Starting point / service criteria
↓
Decisive boundary conditions
↓
Design approach / potential solution
↓
Structural concept
↓
Detailing



Holistic Design – Example

Punt d’En / Inn bridge Vulpera, 2007-2010



Interdisciplinary design team:
dsp Ingenieure & Planer AG, Greifensee
ACS·Partner AG, Bauingenieure, Zürich
Eduard Imhof, dipl. Architekt ETH/SIA, Luzern
Dr. Vollenweider AG, Geotechnik, Zürich

Holistic Design – Example

Interdisciplinary design team

Starting point / service criteria

↓

Decisive boundary conditions

↓

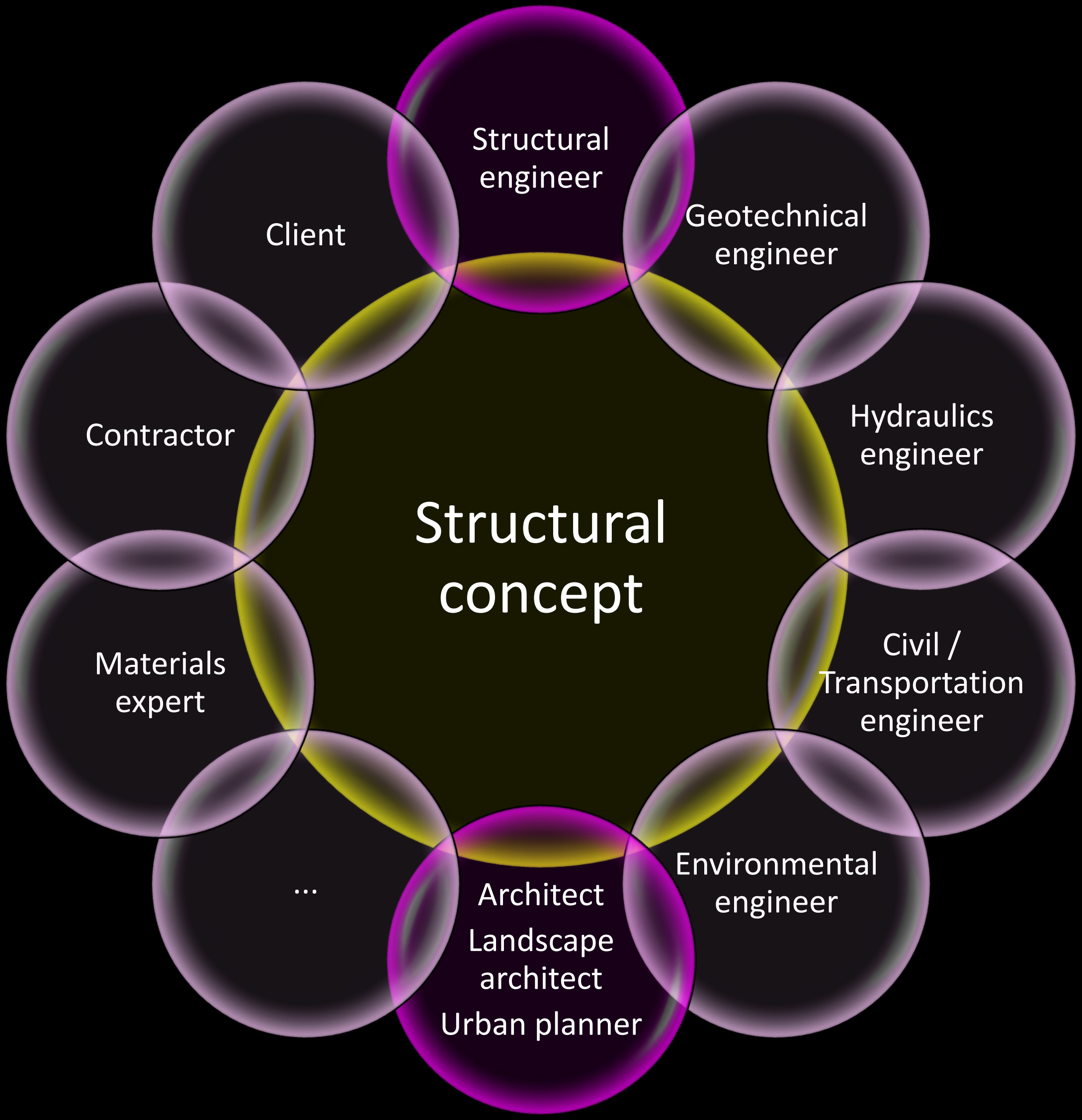
Design approach / potential solution

↓

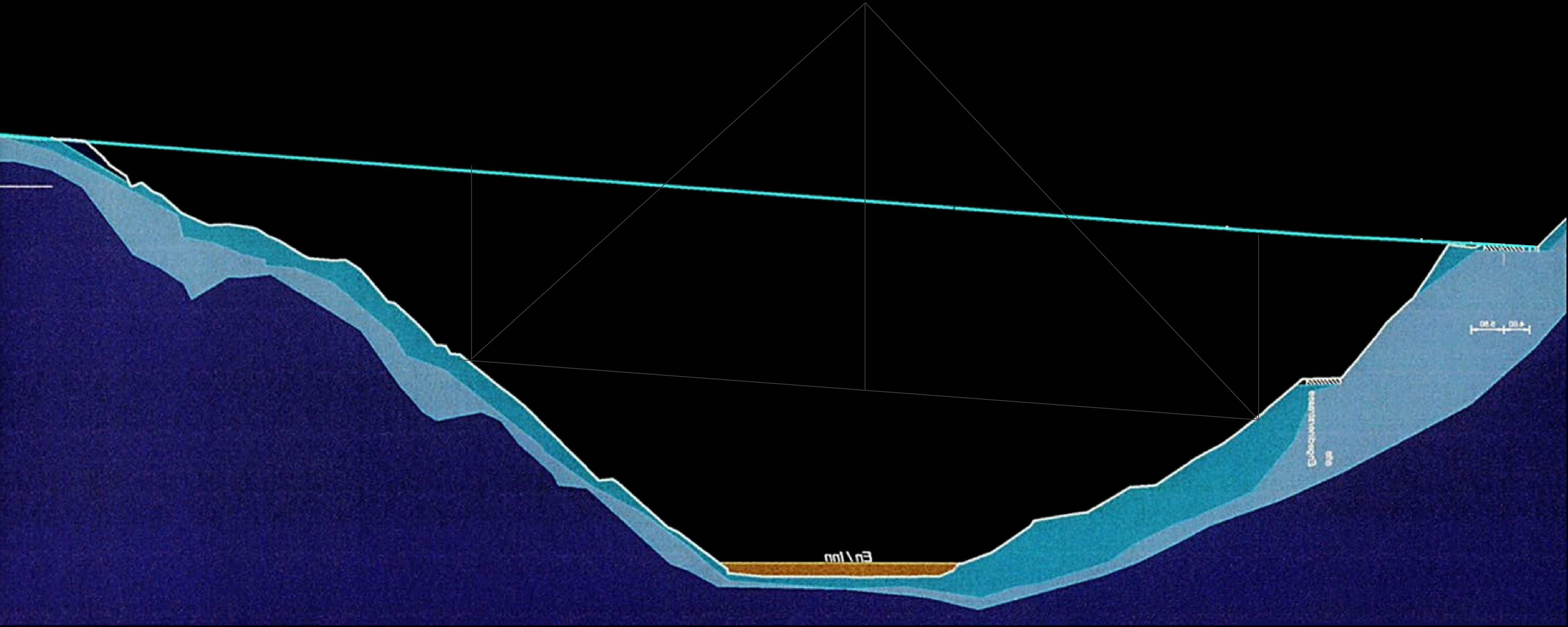
Structural concept

↓

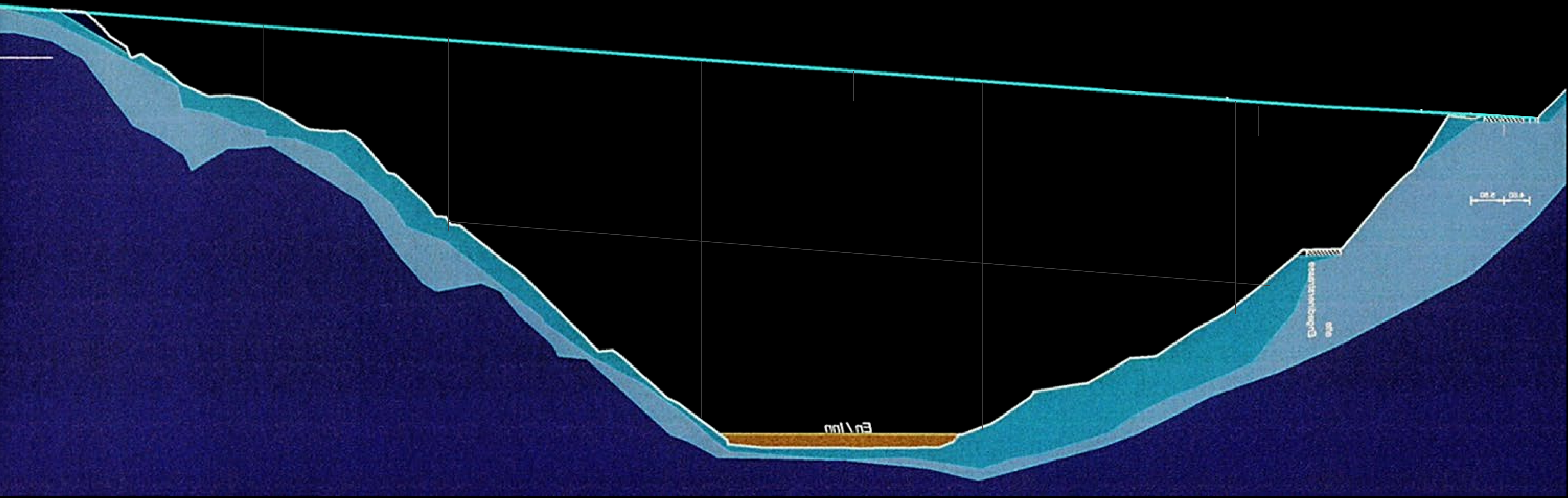
Detailing



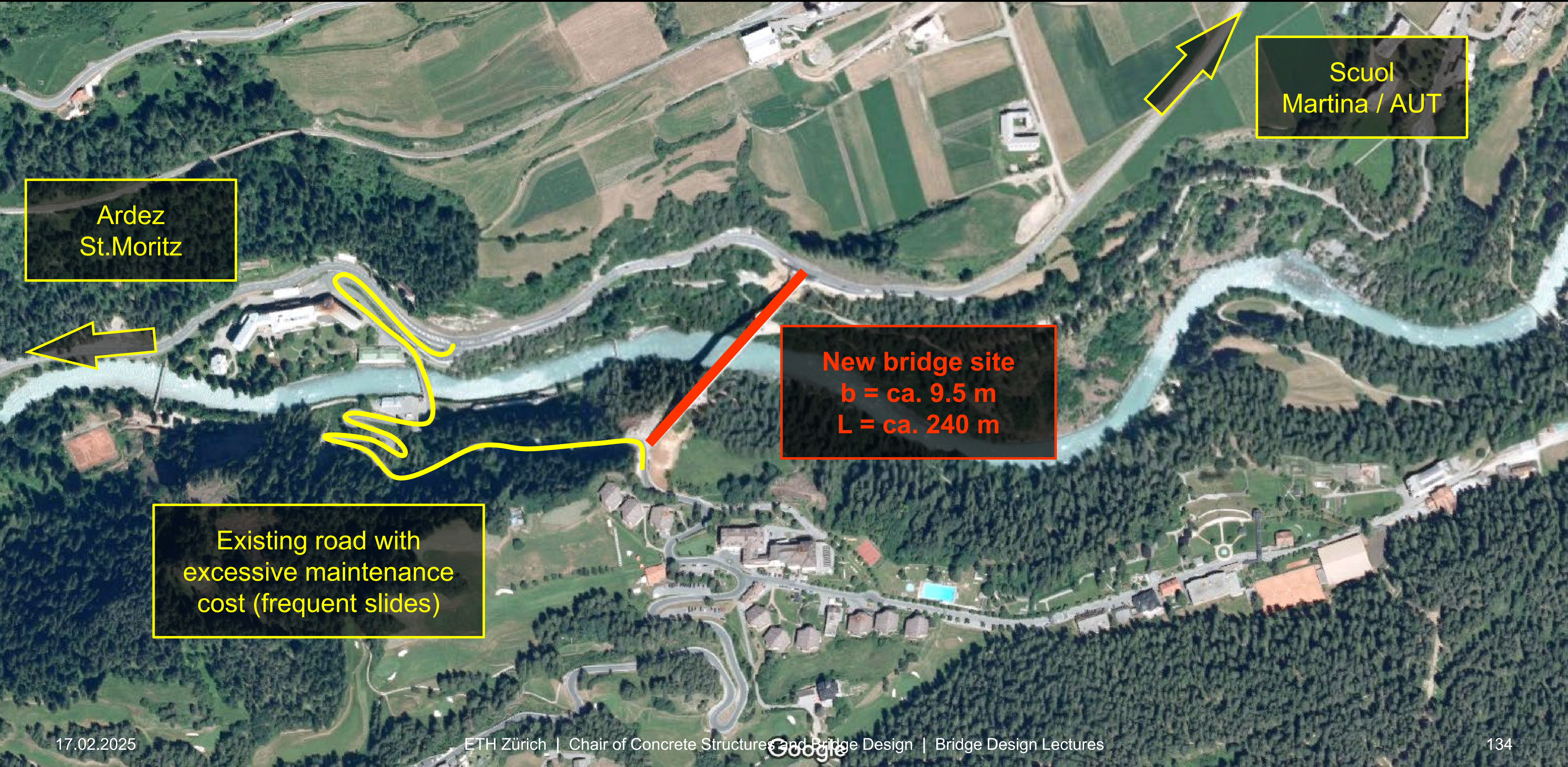
Holistic Design – Example: Obvious (?) solutions



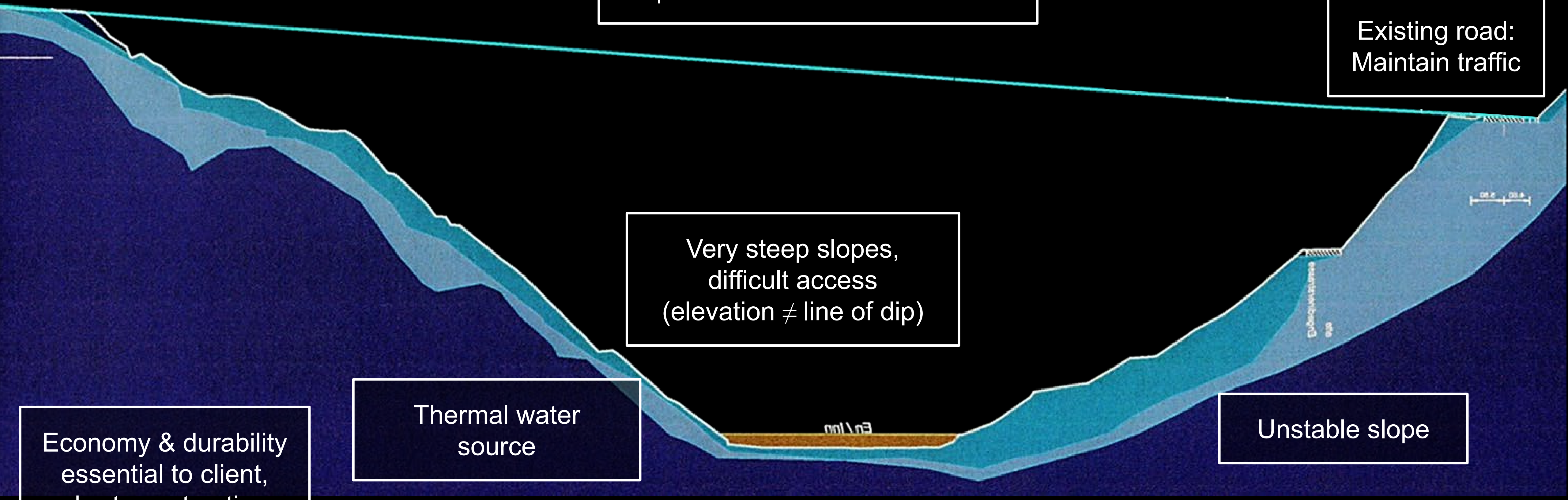
Holistic Design – Example: Obvious (?) solutions



Holistic Design – Example: Starting Point



Holistic Design – Example: Boundary Conditions



Existing road:
Maintain traffic

Far-reaching impact of new bridge on the impressive landscape, parts will be hidden in forest

Existing road:
Maintain traffic

Very steep slopes, difficult access (elevation ≠ line of dip)

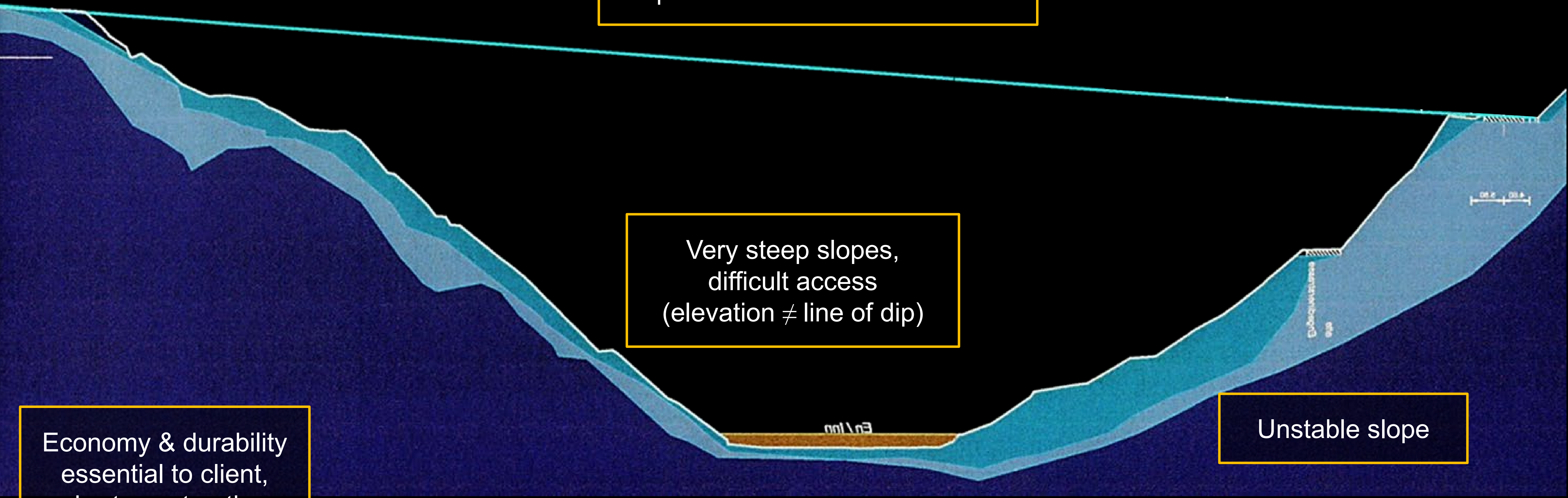
Thermal water source

Unstable slope

Economy & durability essential to client, short construction season (1250 m)

Holistic Design – Example: Decisive Boundary Conditions

Far-reaching impact of new bridge on the impressive landscape, parts will be hidden in forest

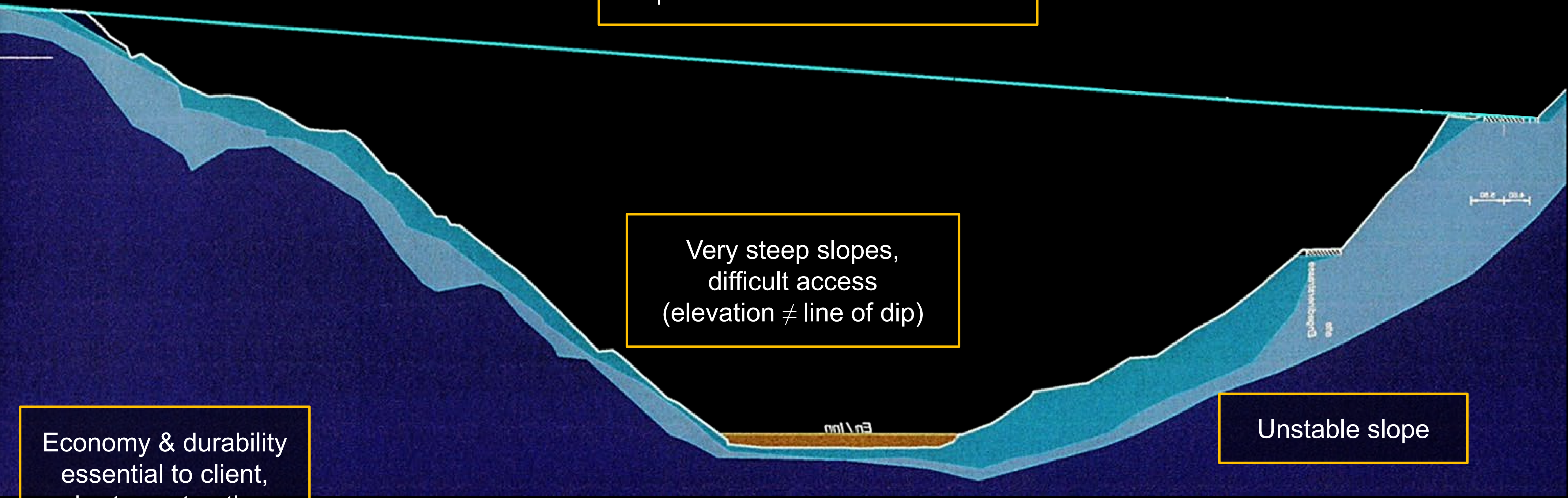


Very steep slopes, difficult access (elevation ≠ line of dip)

Unstable slope

Economy & durability essential to client, short construction season (1250 m)

Holistic Design – Example: Decisive Boundary Conditions



Far-reaching impact of new bridge on the impressive landscape, parts will be hidden in forest

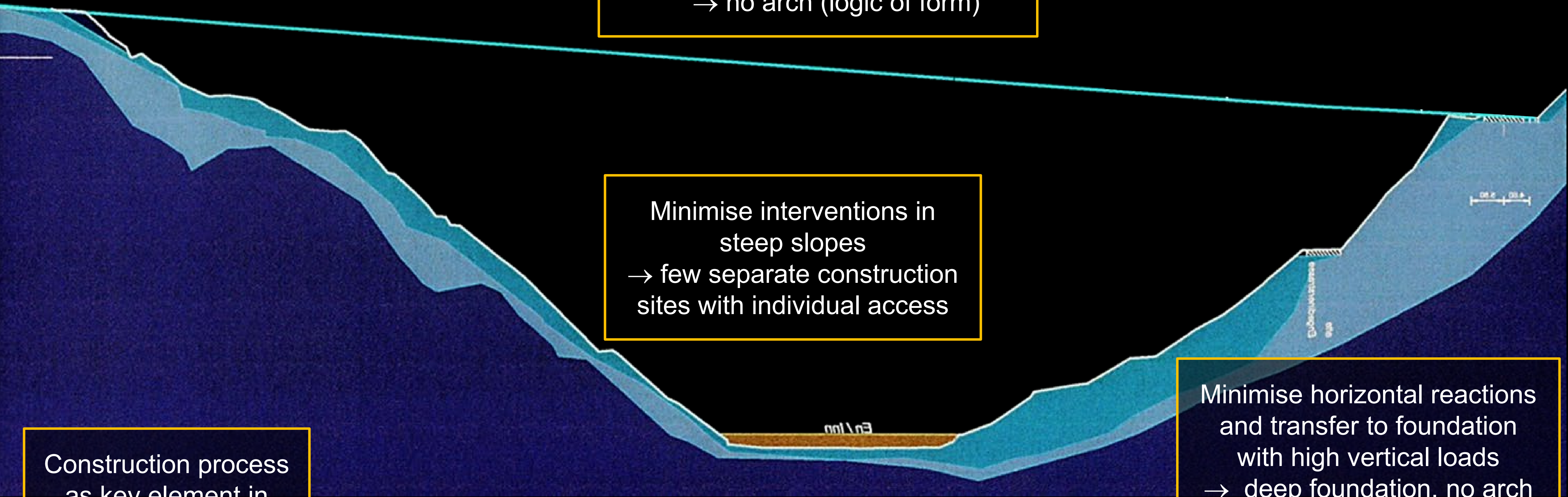
Very steep slopes, difficult access (elevation ≠ line of dip)

Unstable slope

Economy & durability essential to client, short construction season (1250 m)

Holistic Design – Example: Design approach / potential solution

Bridge that integrates confidently in the impressive landscape
→ no spectacular gesture
→ no arch (logic of form)



Minimise interventions in steep slopes
→ few separate construction sites with individual access

Construction process as key element in conceptual design

Minimise horizontal reactions and transfer to foundation with high vertical loads
→ deep foundation, no arch

Holistic Design – Process

Interdisciplinary design team

Starting point / service criteria

↓

Decisive boundary conditions

↓

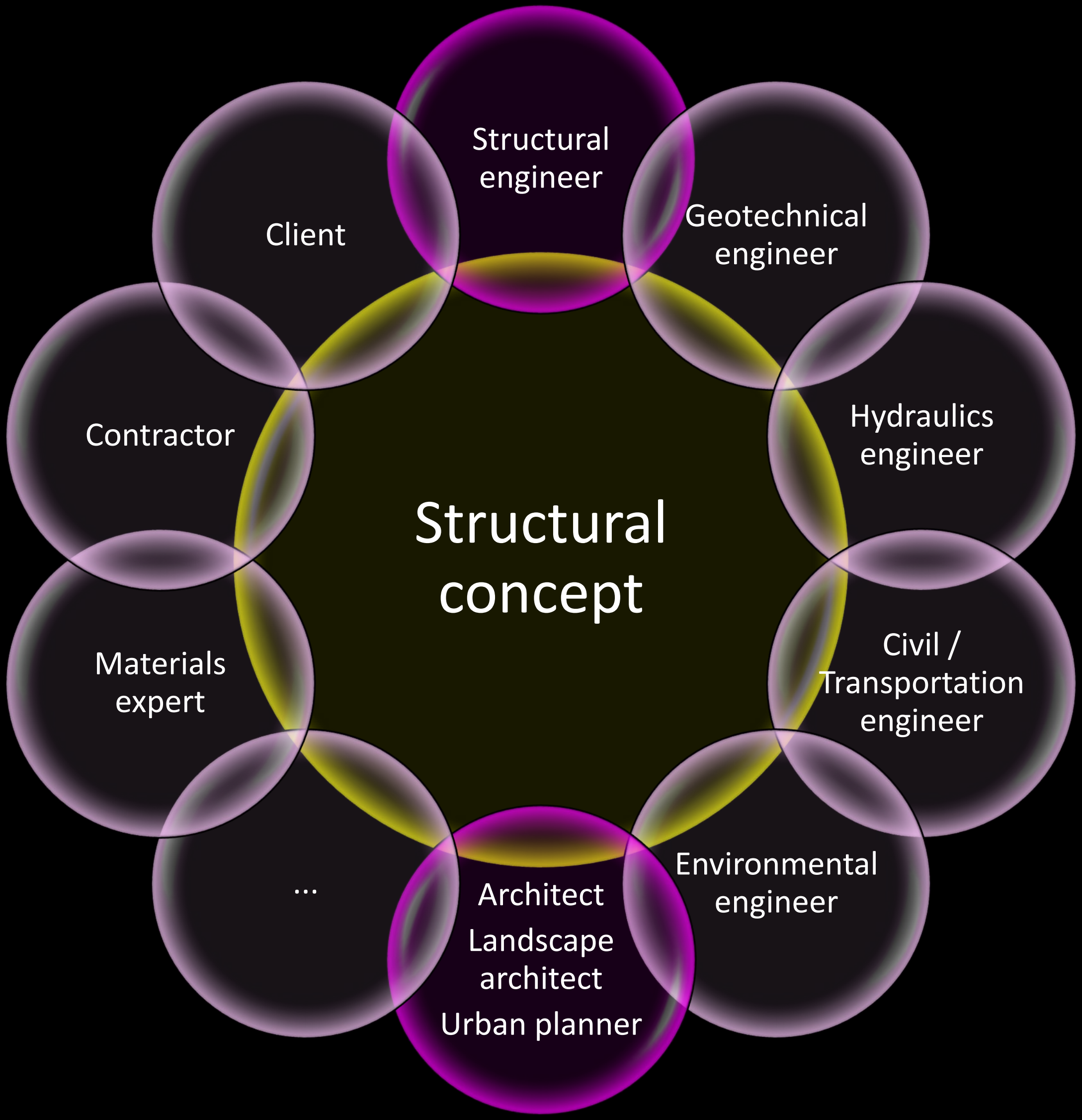
Design approach / potential solution

↓

Structural concept

↓

Detailing



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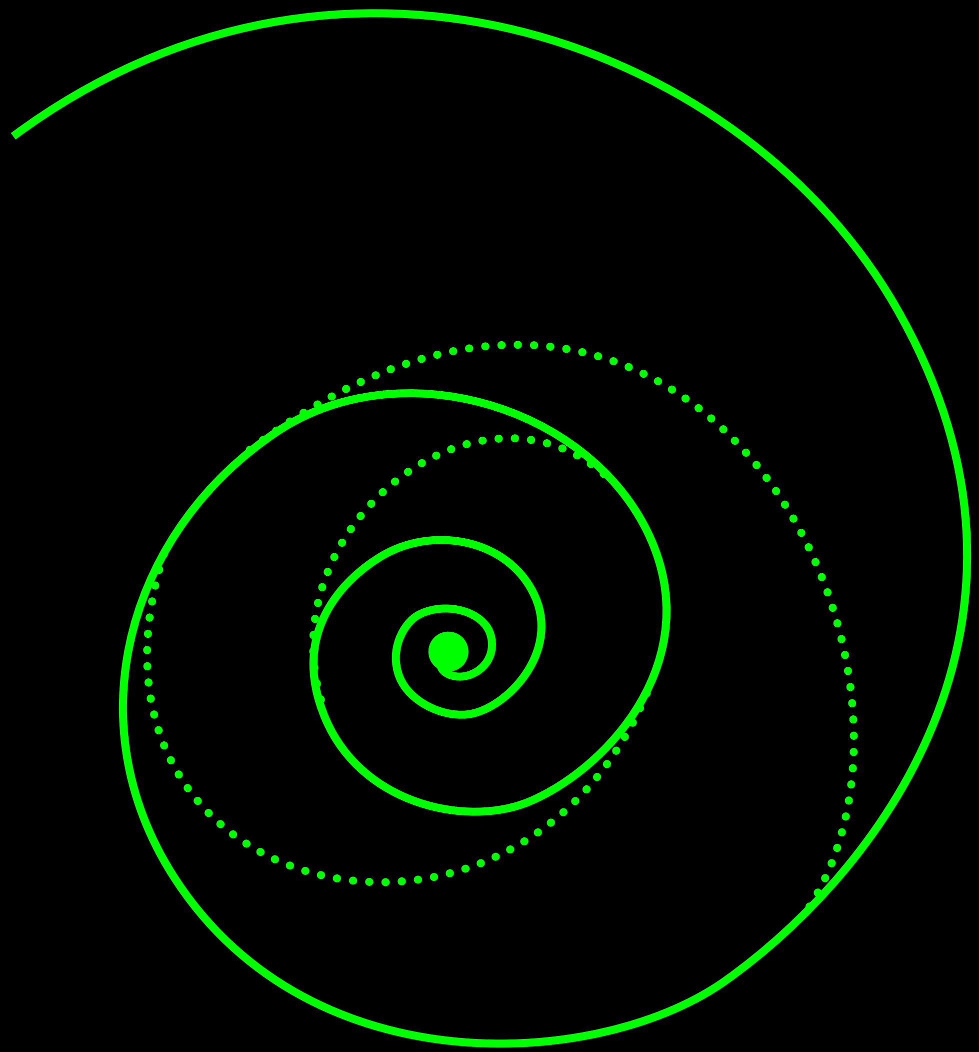

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Detailing

"Classical" structural engineering aspects
(safety, serviceability, economy, construction)

Aesthetics
(integration / logic of form / elegance)

Further site- or use-specific aspects
(ecology, traffic, …)

→ Interdisciplinary design team

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Detailing

Design team meetings / workshops

Sketches, pre-dimensioning, mock-ups (physical or virtual) of alternatives

Interdisciplinary – interactive – iterative

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Detailing

Structural engineer, architect and further experts as required develop the structural concept collaboratively, in a dialogue

A “division of tasks” is ill-suited

The collaboration is non-hierarchical

“The necessary task is to give attention to places and buildings. That is the task of ‘builders’. And the ‘builders’ are precisely the new profession that must link in a tireless and friendly dialogue the engineer and the architect, the left hand and the right hand of the art of building”

(Le Corbusier, 1966)

Holistic Design – Design Process

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Detailing

~~«The engineer develops the structural concept, the architect refines it»~~

~~is equally inappropriate as~~

~~«The architect conceives a structure, the engineer ensures its structural integrity»~~

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Detailing

Design team

High competencies in own field

Interest in, and affinity to other aspects (common vocabulary)

Ability to discourse in a dialogue

Open-mindedness (other’s standpoints and ideas)

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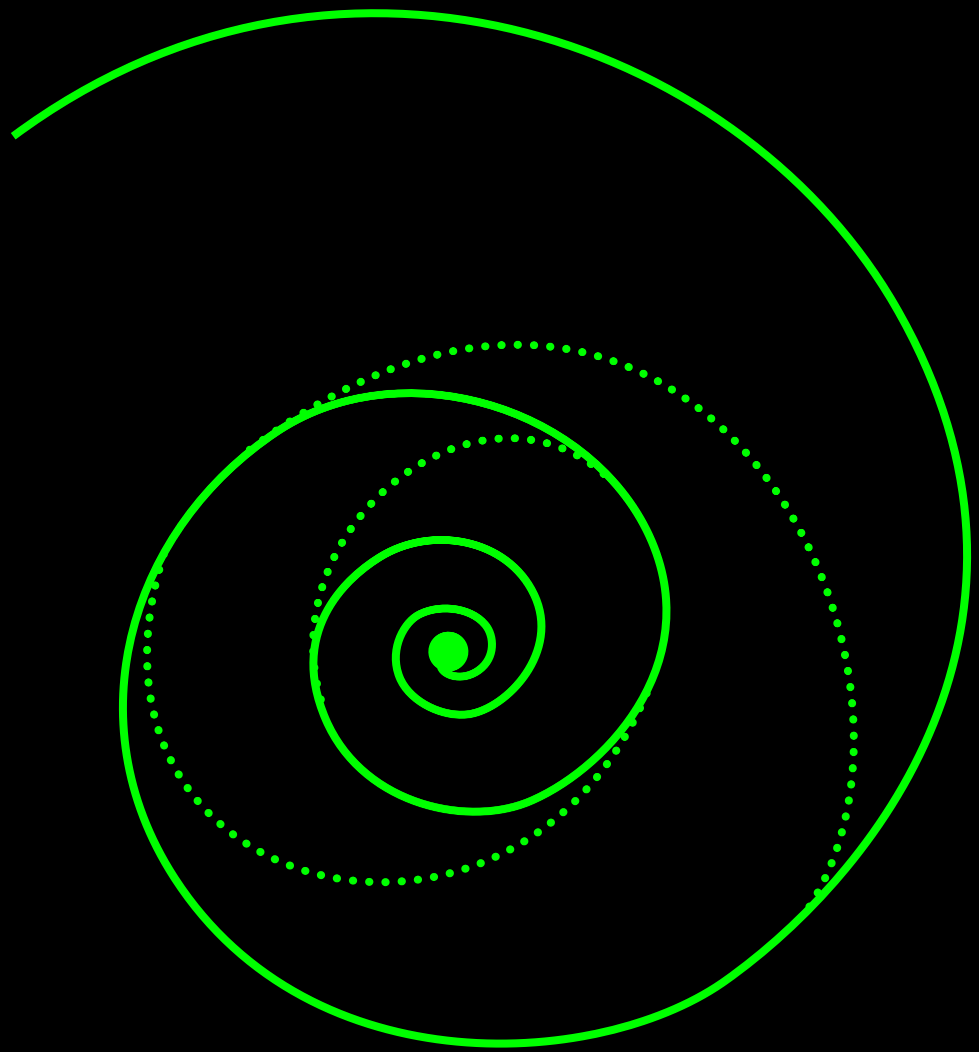
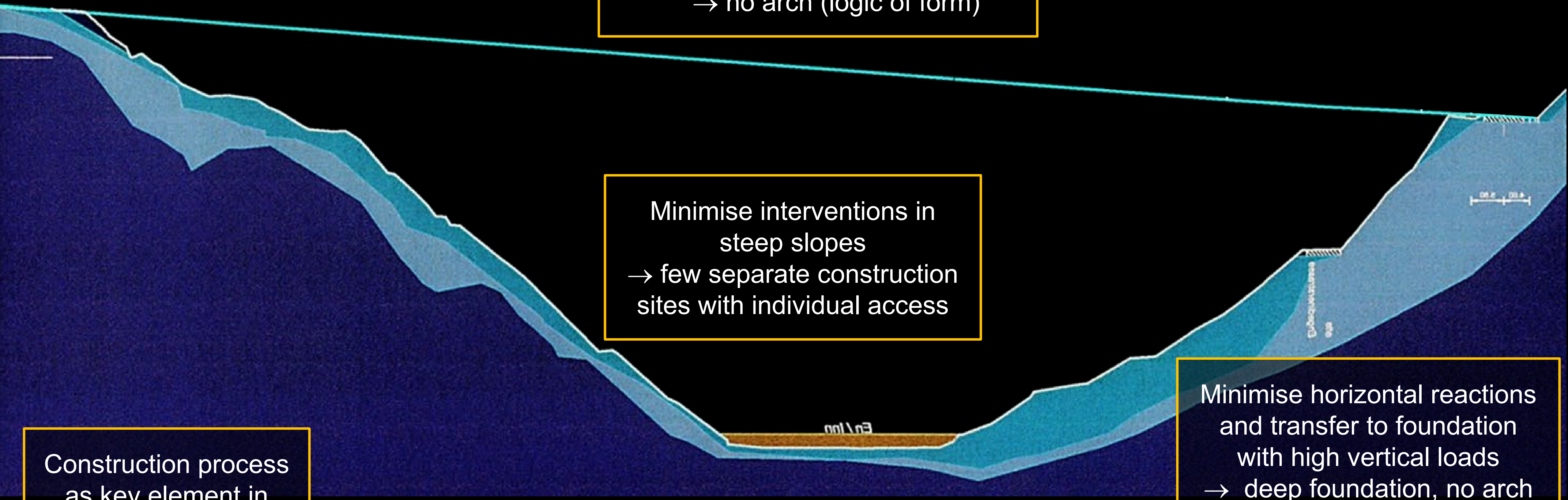


Holistic Design – Example: Design approach / potential solution



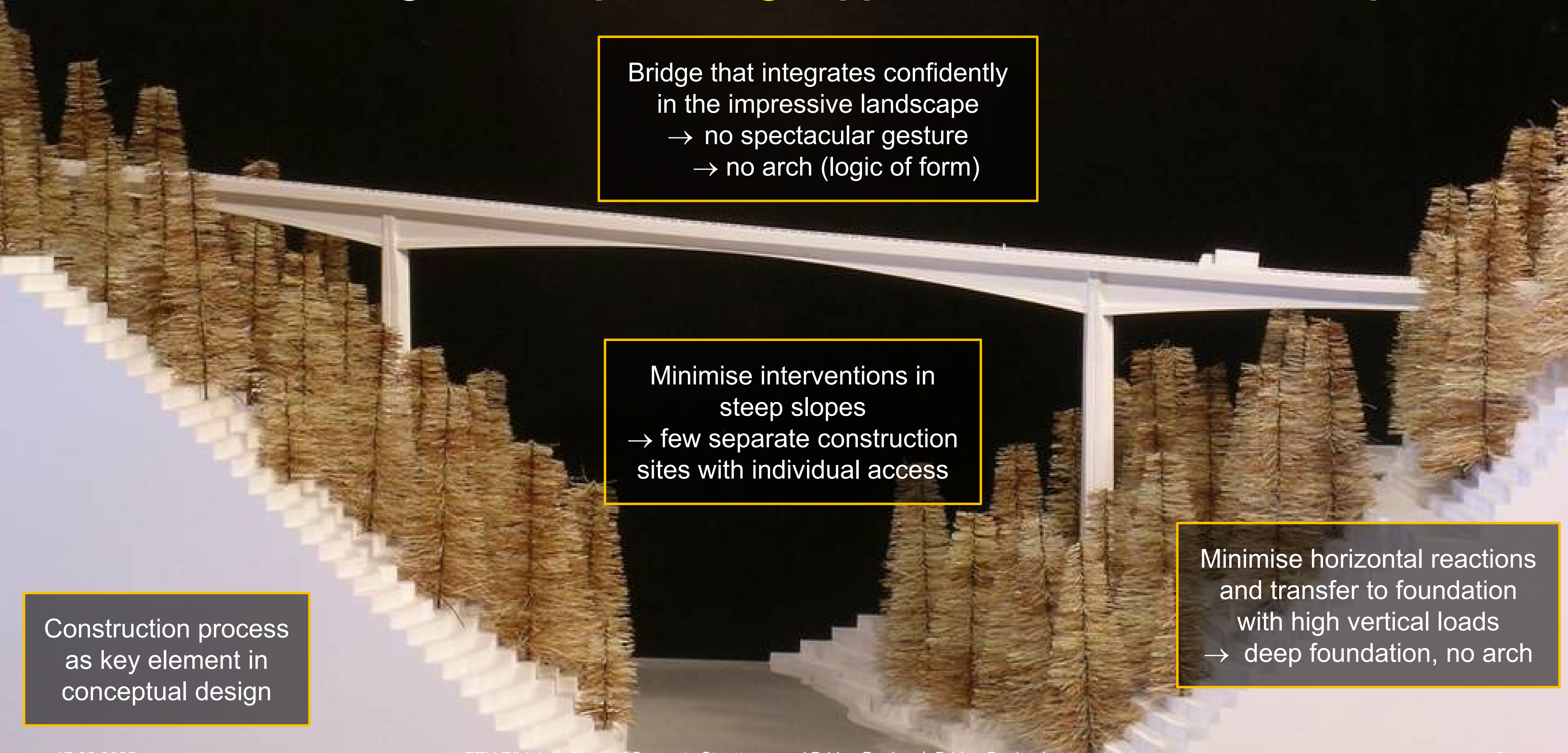
Bridge that integrates confidently in the impressive landscape
→ no spectacular gesture
→ no arch (logic of form)

Minimise interventions in steep slopes
→ few separate construction sites with individual access

Construction process as key element in conceptual design

Minimise horizontal reactions and transfer to foundation with high vertical loads
→ deep foundation, no arch

Holistic Design – Example: Design approach → Structural Concept



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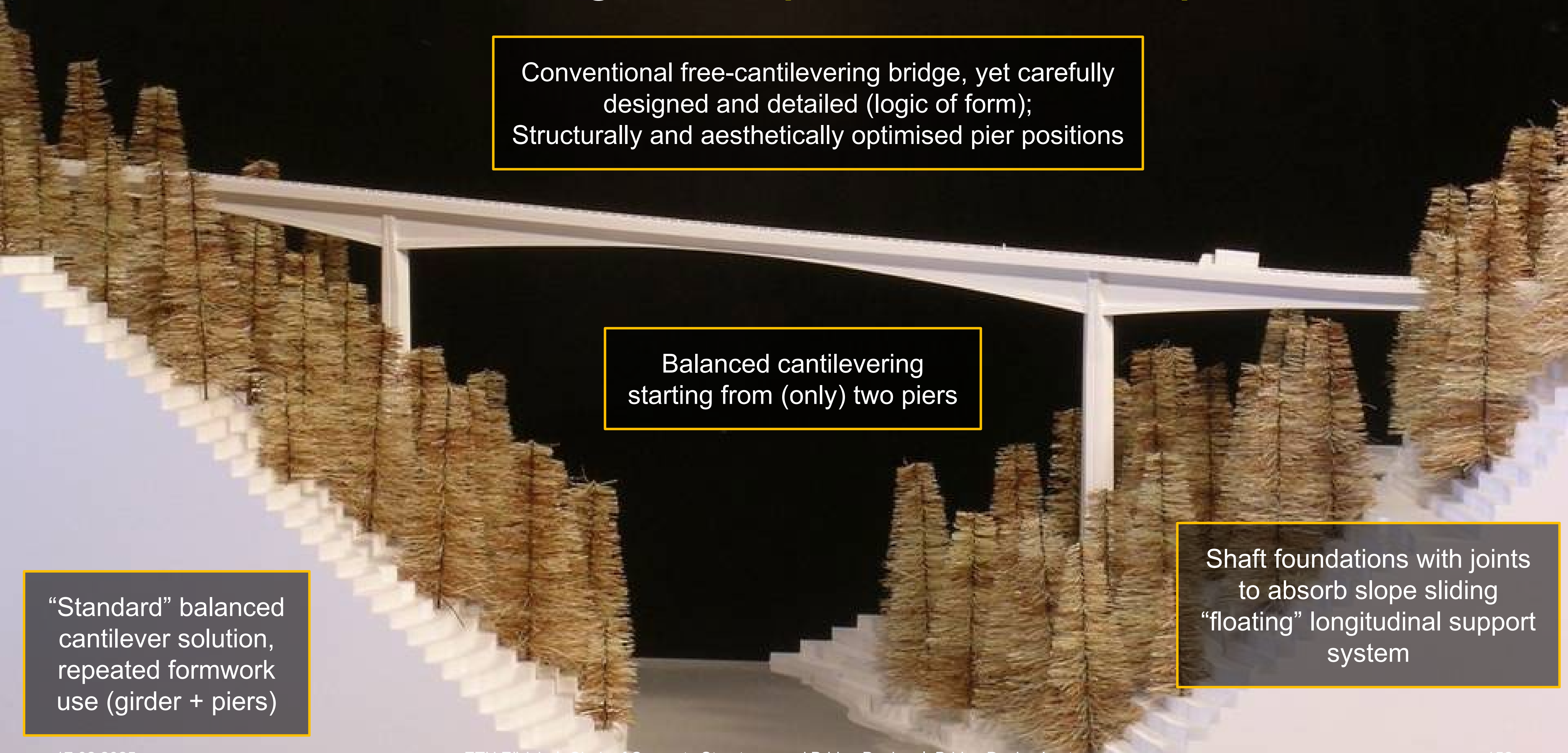
Holistic Design – Example: Structural Concept



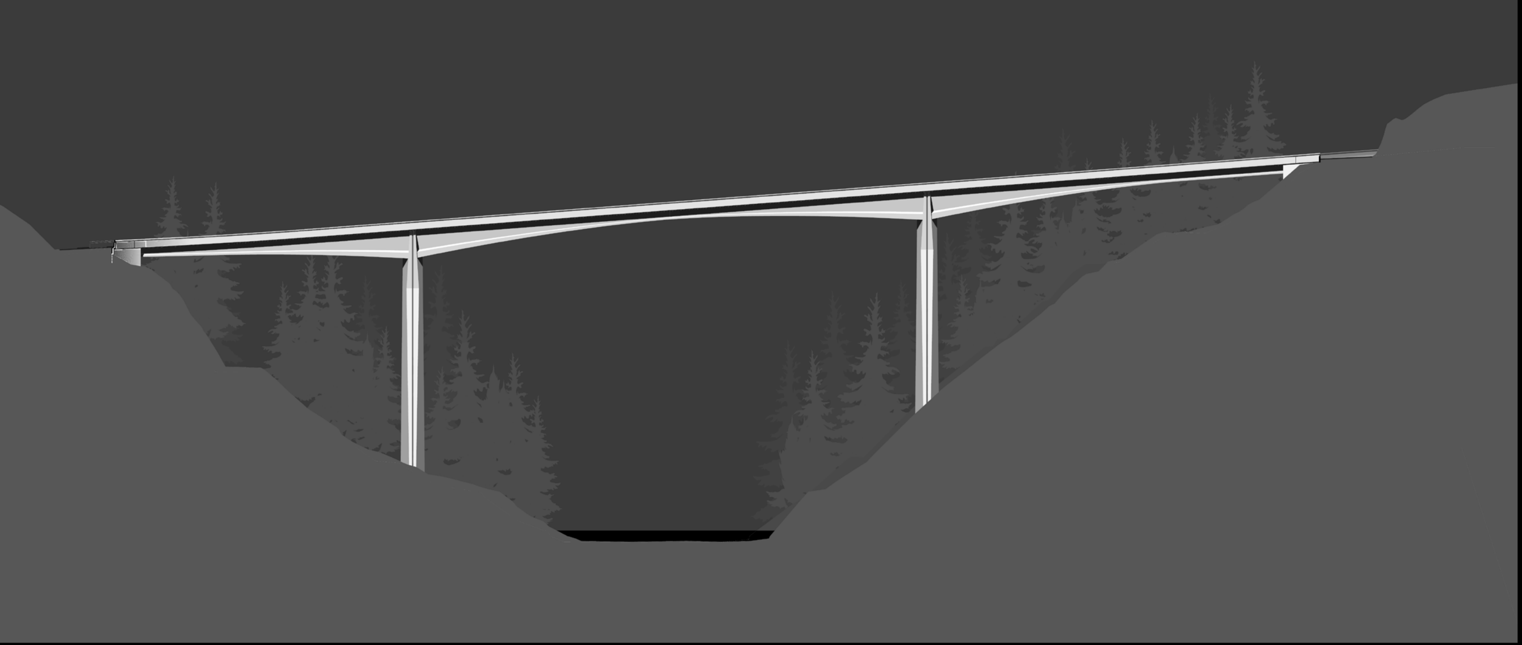
Conventional free-cantilevering bridge, yet carefully designed and detailed (logic of form);
Structurally and aesthetically optimised pier positions

Balanced cantilevering starting from (only) two piers

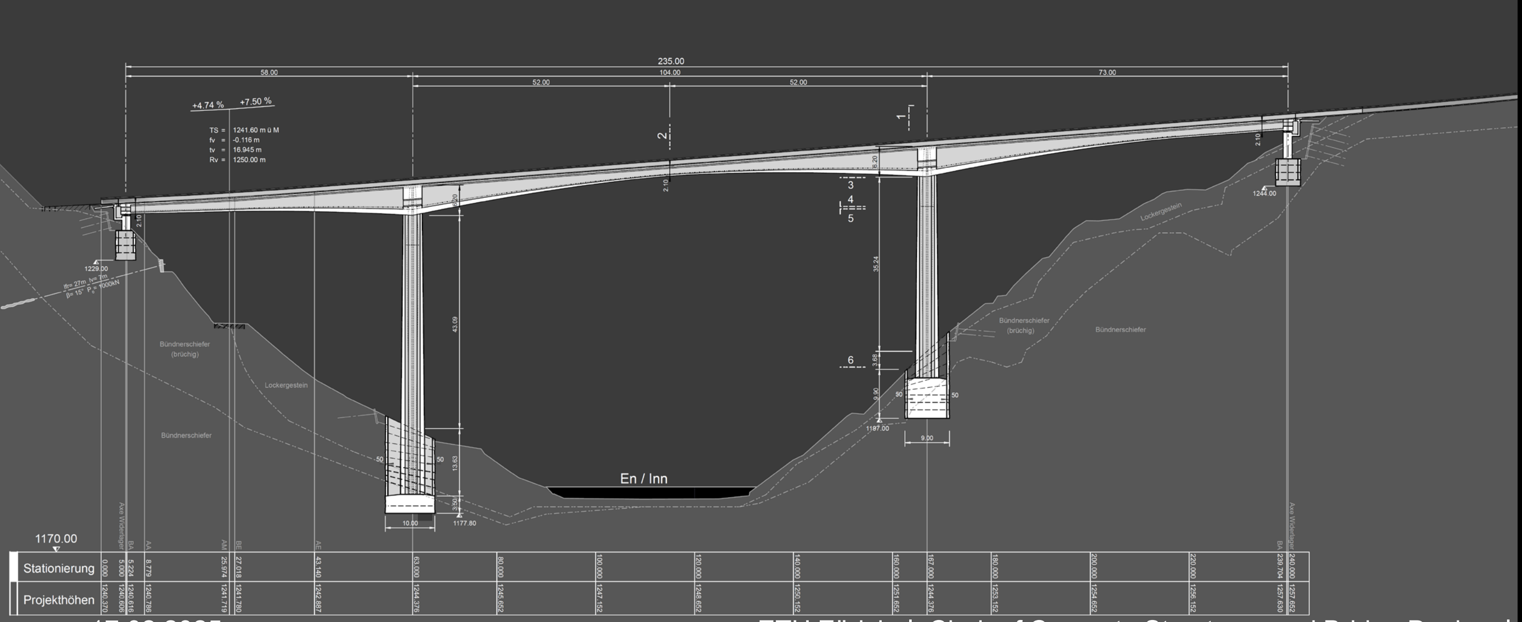
“Standard” balanced cantilever solution, repeated formwork use (girder + piers)

Shaft foundations with joints to absorb slope sliding
“floating” longitudinal support system

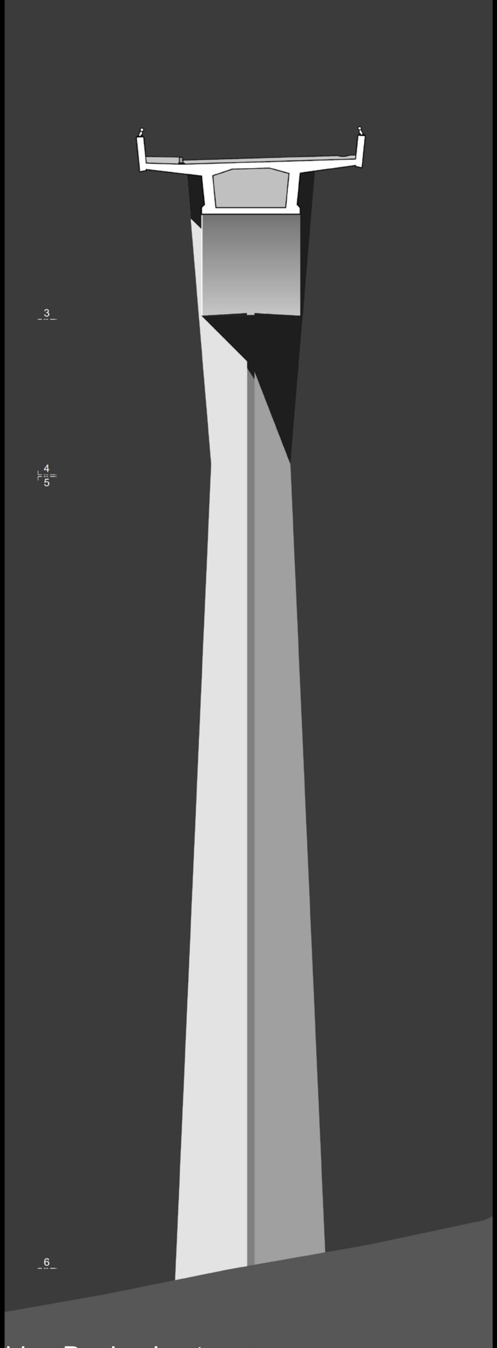
ANSICHT 1:500
RICHTUNG SÜDOSTEN



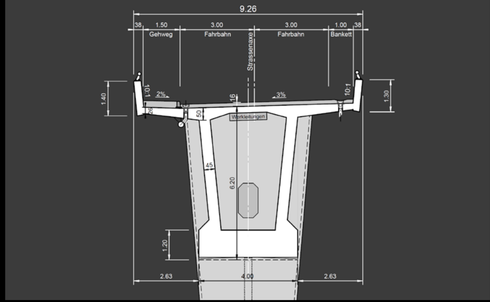
LÄNGSSCHNITT 1:500



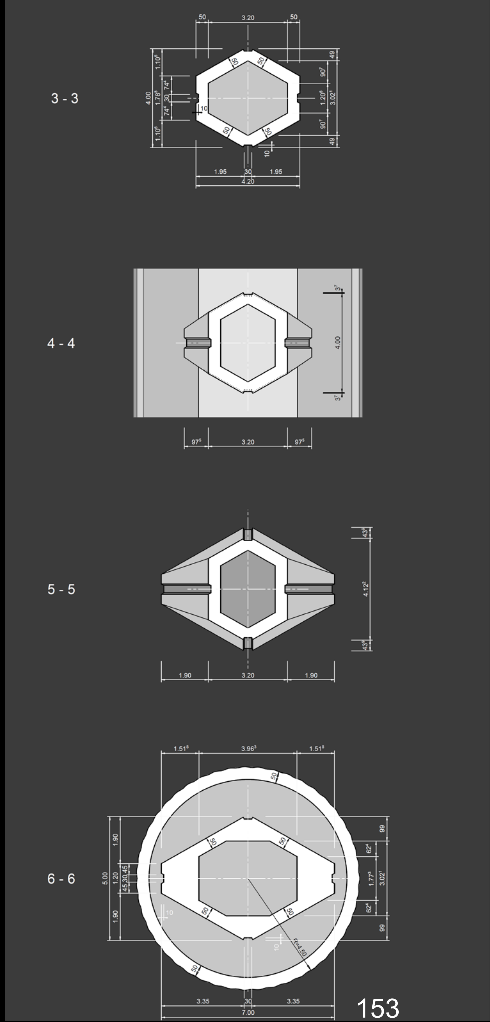
QUERSCHNITT 1:100
FELDMITTE



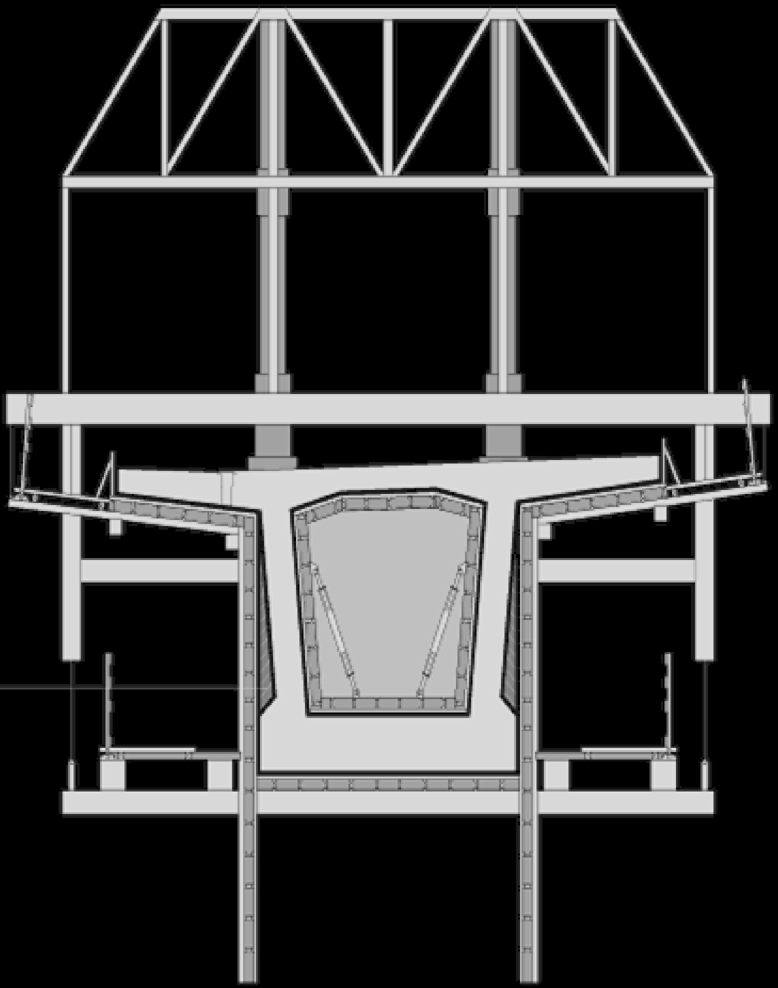
QUERSCHNITT 1-1 1:100

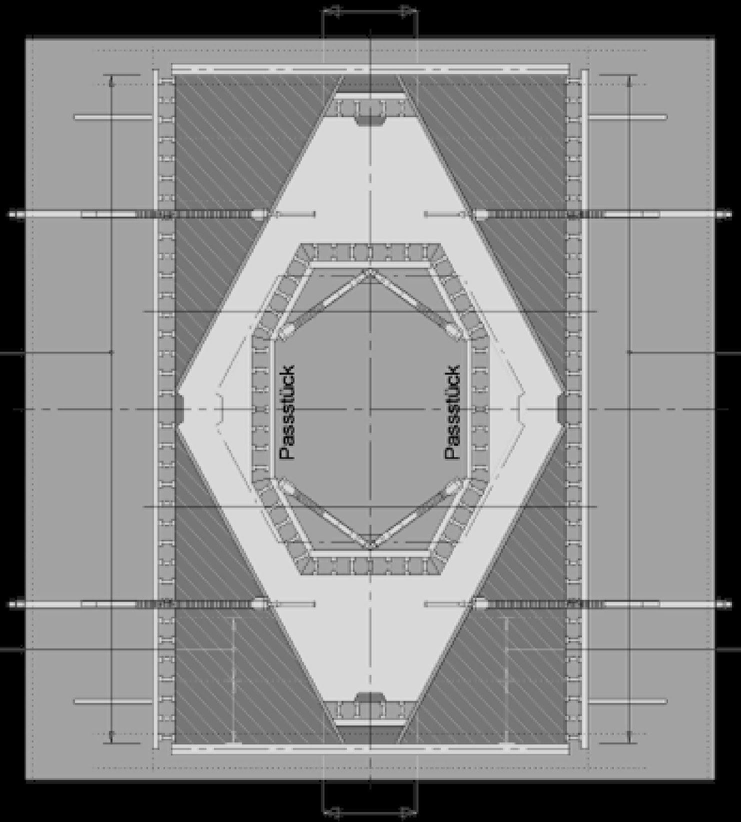


PFEILERQUERSCHNITTE 1:100






Schalungseinlage
(etappenweise reduzierbar)


Passstück
wieder-
verwendbares
Schalelement
Passstück
Passstück
wieder-
verwendbares
Schalelement
Elemente für
obere Etappen
abnehmbar
Elemente für
obere Etappen
abnehmbar
Passstück


ZÜBLIN





Conceptual Design

Holistic Design – Concluding Remarks

Ganzheitlicher Entwurf – Schlussbemerkungen

Holistic Design – Concluding Remarks

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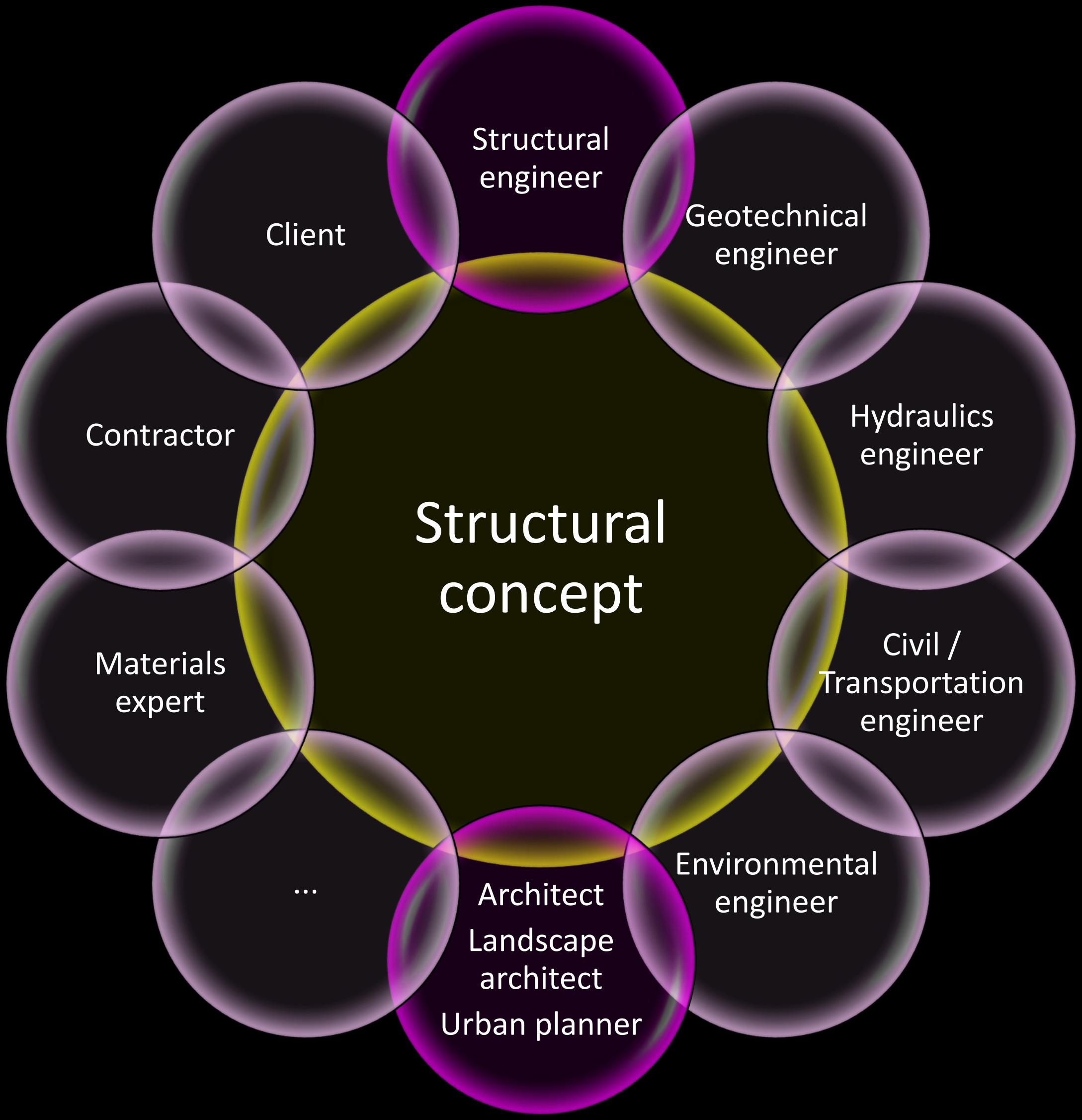

Holistic Design – Concluding Remarks

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Detailing

Depending on the project,
technical or aesthetical aspects are more decisive
for the development of the structural concept

Both aspects should receive a minimum of attention
in all cases to avoid banality and arbitrariness

Irrespective of the importance of structural and
technical or aesthetical aspects,
the structural engineer – who carries the
responsibility – is the author of the project


ERNI
LAZZARINI
ZÜBLIN
MURER
BEZZOLADENOTH
FOFFA + CONRAD SA

Holistic Design – Concluding Remarks

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responsibility – is the author of the project

(this does not mean that structural engineers should
strive for fame as “star architects”)