GUIDELINES FOR ROAD DESIGN, CONSTRUCTION, MAINTENANCE AND SUPERVISION

Volume I: DESIGNING

Section 2: DESIGNING BRIDGES

DESIGN GUIDELINES (DG 1.2.1)

Part 1: GENERAL GUIDELINES FOR DESIGNING OF ROAD BRIDGES

INTRODUCTION

Numerous structures such as bridges, viaducts, overpasses, underpasses, culverts, tunnels, galleries, retaining walls and other civil engineering structures represent a constituent part of up-to-date motorways, highways, main roads and regional roads. These structures essentially influence construction costs and time. Traffic safety and operation costs depend to a great extent on bridge reliability, durability and safety.

The present design guidelines DG 1.2.1 allows for and unites the theoretical knowledge and the present practice of designers, contractors and maintainers of road bridges at simultaneous consideration of the legislation, rulebooks, and codes. The content of the guidelines is living, topical, and approved in both domestic and international practice. It is divided in several chapters that can be, as circumstances require, supplemented and modified in accordance with the latest civil engineering knowledge and legislation changes.

The design guideline DG 1.2.1 is mainly intended for construction of new bridges on motorways, main roads and regional roads. However, it is sufficiently universal to be partially applied in reconstruction of existing bridges.

All the road bridges are designed and constructed to be reliably safe and durable during construction as well as throughout the service life of several decades. Road bridges shall be conceived, executed, protected and maintained to achieve their durability of 80 to 120 years.

In the introduction to the General guidelines for road bridges, attention of the relevant authorities, investors, designers and contractors is attracted to take care of protection, maintenance and reconstruction of old bridges, particularly of ancient stone bridges of an invaluable monumental value.

The General guidelines for designing of road bridges DG 1.2.1 as well as all the remaining 12 design guidelines (DG 1.2.2 to DG 1.3.1) have been prepared on the basis and in accordance with the Eurocodes and European structural standards, representing their continuation and extension in order to enable and facilitate the uniformity as well as a correct bridge design and construction in accordance with the development of both theory and practice.

In case that any better or more suitable solutions are proven by documents upon application of these standards, they may be adopted on condition that they are approved by the responsible institutions or relevant authorities.

Periodically, i. e. every 5 – 10 years, the guidelines shall be renewed and supplemented in accordance with the modifications of existing and with the new Eurocodes and European structural standards, as well as with the national legislation.

C O N T E N T S

1. SUBJECT OF DESIGN GUIDELINES

The present design guidelines is intended for all the participants in the processes of planning, designing, constructing, maintaining, and rehabilitating of bridges.

The scope of this guideline is to introduce, to treat and to analyse general theoretical, constructive, design and technological cognition that can essentially influence the investment process, conception, structural design, construction, maintenance, and rehabilitation of bridges.

The topic of this guideline ensures uniting of profound theoretical and practical knowledge, information from literature including practical experience in this particular field of activity as well as technical regulations and standards.

The guideline is mainly meant for construction of new bridges. However, it is sufficiently universal to be applied in renewal, reconstruction and repair of existing bridges as well.

2. REFERENCE REGULATIONS

Bridge design, construction, rehabilitation, and maintenance are conceived on numerous regulations, standards, and guidelines. Some of them are mandatory, whereas the others are recommended only.

In Bosnia and Herzegovina as a young country, some own regulations, as well as standards from the former SFR Yugoslavia, international ISO regulations, and European Community codes are in use.

For bridge design, construction, and management the following four basic groups of regulations apply:

- Regulations in the field of construction and structures on the whole;
- Regulations dealing with design, construction, exploitation, and maintenance of roads;
- Regulations dealing with loads on road bridges;
- Regulations for materials, calculation, and structural design of reinforced concrete, prestressed, steel, composite, and timber structures.

The first two of the abovementioned groups related to construction on the whole, and to design, construction, exploitation, and maintenance of roads at the level of former Yugoslavia and of Bosnia and Herzegovina have been introduced as a whole, they are in use and already being innovated and adopted.

For loads on road bridges the following regulations apply:

- Rulebook of technical norms for assessment of magnitude of loads on bridges dated January 04, 1991.

- Rulebooks and standards dealing with materials, calculation, and structural design from former SFR Yugoslavia, which are still in use:
  - Rulebook of technical norms for foundation of structures, Official Gazette of SFR Yugoslavia No. 15.295/90;
  - Rulebook of technical norms for concrete and reinforced concrete made of natural and artificial light-weight aggregate filler, Official Gazette of SFR Yugoslavia No. 15-296/90;
  - Rulebook of technical norms for design, production, and execution of structures of precast members made of non-reinforced and reinforced concrete, Official Gazette of SFR Yugoslavia No. 14-146/89;
  - Rulebook of Yugoslav standards for timber structures, Official Gazette of SFR Yugoslavia No. 48-497/84;
  - Rulebook of technical norms for steel wires and strands for prestressing of structures, Official Gazette of SFR Yugoslavia No. 41-530/5 and No. 21-276/88;
  - Rulebook of Yugoslav standards for bases of design of structures, Official Gazette of SFR Yugoslavia No. 49-667/88;
  - Rulebook of technical provisions and conditions for erection of steel structures, Official Gazette of SFR Yugoslavia No. 29-351/70;
  - Rulebook of technical norms for load bearing steel structures, Official Gazette of SFR Yugoslavia No. 61-899/86;
  - Rulebook of technical norms for concrete and reinforced concrete in structures exposed to aggressive environment, Official Gazette of SFR Yugoslavia No. 18/92;
  - JUS U.M1.046, 1984: Load testing of bridges;

- Rulebook of technical provisions and conditions for corrosion protection of steel structures (Official Gazette of SFR Yugoslavia No. 32/70;
- Current JUS standards for steel structures.

EN 1990:2002 Eurocode: Bases of structural design:

EN 206-1:2000 Concrete-part 1: Specification, performance, production and confirmity

Eurocode 1: Actions on structures

- EN 1991-1-1 Part 2-1 Actions on structures – densities, selfweight and imposed loads
- EN 1991-2-2 Part 2-2 Actions on structures – fire loads
- EN 1991-2-3 Part 2-3 Actions on structures – snow loads
- EN 1991-2-4 Part 2-4 Actions on structures – wind loads
- EN 1991-2-5 Part 2-5 Actions on structures – thermal actions
- EN 1991-2-6 Part 2-6 Action on structures – Actions during execution
- EN 1991-2-7 Part 2-7 Action on structures – Accidental actions due to impact and explosions
- EN 1991-3 Part 3 Traffic loads on bridges

Eurocode 2: Design of concrete structures

- EN 1992-1-1 Part 1-1 General rules and rules for building
- EN 1992-1-2 Part 1-2 General rules – Structural fire design
- EN 1992-1-3 Part 1-3 General rules – Precast concrete elements and structures
- EN 1992-1-4 Part 1-4 General rules – Linghweight aggregate concrete with closed structure
- EN 1992-1-5 Part 1-5 General rules – Structures with unbounded and external prestressing tendons
- EN 1992-1-6 Part 1-6 General rules – concrete strictures
- EN 1992 – Part 2 Concrete bridges
- EN 1992 – Part 3 Concrete foundations
- EN 1992 – Part 4 Liquid retaining and containment structures

Eurocode 3: Design of steel structures

- EN 1993-1-1 Part 1-1 General rules and rules for buildings
- EN 1993-1-1/A1¸:1996 Part 1-1/A1 General rules and rules for buildings
- EN 1993-1-1/A2:2001 Part 1-1/A2 General rules and rules for buildings
- EN 1993-1-2 Part 1-2 General rules – Structural fire design
- EN 1993-1-3 Part 1-3 General rules – supplementary rules for cold formed thin gauge members and sheeting
- EN 1993-1-4 Part 1-4 General rules – supplementary rules for stainless steels
- EN 1993-1-5 Part 1-5 General rules – supplementary rules for planar plated structures without transverse loading
- EN 1993-1-6 Part 1-6 General rules supplementary rules for the shell structures
- EN 1993-1-7 Part 1-7 General rules – supplementary rules for planar plated structural elements with out of plane loading
- EN 1993-2 Part 2 Steel bridges
- EN 1993-5 Part 5 Piling

Eurocode 4: Design of composite steel and concrete structures

- EN 1994-1-1 Part 1-1 General rules and rules for buildings
- EN 1994-1-2 Part 1-2 General rules – Structural fire design
- EN 1994-2 Part 2 Composite bridges

Eurocode 5: Design of timber structures

- EN 1995-1-1 Part 1-1 General rules and rules for buildings
- EN 1995-1-1 Part 1-1/AC General rules and rules for buildings; Amendment
- EN 1995-1-2 Part 1-2 General rules – Structural fire design
- EN 1995-2 Part 2 Bridges

Eurocode 7: Geotechnical design

- EN 1997-1 Part 1: General rules
- EN 1997-2 Part 2: Design assisted by laboratory testing
- EN 1997-3 Part 3: Design assisted by field testing

Eurocode 8: Design provisions for earthquake resistance of structures

- EN 1998-1-1 Part 1-1 General rules – seismic action and general requirements for structures

- EN 1998-1-2 Part 1-2 General rules – General rules for buildings
- EN 1998-1-2/01 Part 1-2/01 General rules – General rules for buildings
- EN 1998-1-3 Part 1-3 General rules – Specific rules for various materials and elements
- EN 1998-1-4 Part 1-4 General rules – Strengthening and repair of buildings
- EN 1998-1-4 Part 1-4/01 General rules strengthening and repair of buildings
- EN 1998-2 Part 2 Bridges
- EN 1998-2/AC Part 2 Bridges: Amendment AC
- EN 1998-3 Part 3 Towers, masts and chimneys
- EN 1998-4 Part 4 Silos, tanks and pipelines
- EN 1998-5 Part 5 Foundations, retaining structures and geotechnical aspects
- EN 1998-5 Part 5 / Foundations, retaining structures and geotechnical aspects

3. EXPLANATION OF TERMS

Road structures are bridges, viaducts, overpasses, underpasses, culverts, galleries, tunnels, retaining walls, noise barriers, etc.

By function the road structures can be divided into bridges, viaducts, overpasses for vehicles, overpasses for pedestrians and cyclists, underpasses for vehicles, underpasses for pedestrians and cyclists, culverts, galleries and tunnels, retaining structures as well as noise barriers.

Bridges in a broader meaning are all the civil engineering structures such as bridges, viaducts, overpasses and underpasses, serving a safe crossing of natural and artificial obstacles.

Bridges in a stricter meaning are civil engineering structures of an opening of ≥ 5 m serving a safe crossing of water obstacles such as brooks, rivers, channels, lakes, bays, etc.

Viaducts are structures enabling roads to cross the valleys. A distinction can be drawn between valley viaducts crossing valleys, and slope viaducts running parallel with the slope of a valley.

Overpasses for vehicles are structures enabling leading of other roads across the considered road.

Underpasses for vehicles are structures enabling leading of other roads below the considered road.

Underpasses for pedestrians and cyclists are structures similar to underpasses for vehicles, only that their clear height is smaller.

Culverts are small bridges of an opening of 1-5 m.

Galleries are structures serving for a closed or partially closed passing of a road on a verge of an unstable slope, or for passing of a road through populated and protected regions.

Tunnels are confined structures serving for passing of a road through a rock.

Retaining walls are structures ensuring stability of the road body below the road vertical alignment, or of the slopes of cuts or cuts and fills above the road vertical alignment.

Noise barriers are structures protecting populated environment from an excessive noise coming up from the motorway direction.

A bridge is divided into three fundamental constituent parts:
- substructure (supporting system)
- superstructure
- equipment

Bridge substructure consists of the following elements:
- abutments with wing walls
- piers.

Bridge superstructure directly takes the traffic loading and transmits both static and dynamic actions to the substructure. Bridge superstructures can be executed of different materials, different static systems as well as different number and largeness of spans between supports.

Bridge equipment consists of the following components:
- bearings and hinges
- expansion joints
- transition slabs
- railings and barriers
- waterproofing of carriageway slab and walkway
- asphalt carriageway

- drainage of carriageway including piping for evacuation of precipitation water
- edge beams, kerbs and walkways
- installations
- equipment for maintenance of both superstructure and substructure
- traffic signs and information boards.

Bridge abutments support the superstructure at both bridge ends, and enable the transition from the bridge to the road body.

Bridge piers support the superstructure between the abutments when a bridge consists of at least two spans.

Wing walls are integral constituent elements of abutments and form a lateral confinement of the road body at the transition of the road carriageway to the bridge.

Bridge foundation can be either
- shallow, i.e. directly on foundation slabs, or
- deep, i.e. indirectly on bored or driven piles, or on wells or caissons.

Bearings and hinges of bridges are structural elements transmitting both vertical and horizontal forces from the superstructure to the substructure.

Expansion joint is a common term for a device enabling unimpeded displacements and rotations at abutments and, exceptionally, at piers.

Transition slabs are structural elements of abutments intended for a continuous transition from the bridge to the road.

Railings and safety barriers serve for protection of pedestrians, cyclists and vehicles both on bridges and below them. By purpose, structure and material, several types of railing and safety barriers can be distinguished.

Waterproofing of road bridges is a common term for waterproofing (protection) of structural load bearing elements from harmful effects of moisture and precipitation water.

Asphalt carriageway on bridges is a term indicating layers of poured asphalt and/or asphalt-concrete on the bridge carriageway surface.

Dewatering and piping is a common term for a collecting system and a controlled evacuation of precipitation water or any other liquid from the bridge carriageway to the collector or road drainage.

Gullies are elements for collecting and evacuating of water from the bridge carriageway.

Edge beams are reinforced concrete, subsequently constructed lateral elements located on bridge superstructure edges.

Kerbs are elements made of eruptive stone as a rule, serving for a separation in height of the carriageway surfaces meant for vehicle traffic from those intended for pedestrians and cyclists.

Installation space on a bridge is represented by the built-in installation ducts or by a reserved space equipped with suspensions for placing the installation ducts running along the bridge axis.

Inspection shaft to control installations on the pedestrian walkway surface is a steel element equipped with a watertight cover.

Communal chambers at the rear of abutments are confined reinforced concrete structures intended for a controlled arrangement of all types of installations to be led from the road body into the bridge.

Public lighting on bridges consists of electric installations, candelabra, and lamps.

Bridge equipment above the superstructure upper level consists of waterproofing, asphalt carriageway, edge beams, kerbs, and walkways.

Total length of a bridge is the distance between both bridge ends (between expansion joint axes or, in case of frame structures, between outer abutment edges).

Total width of a bridge is the distance between the outer edges of edge beams.

Static spans of a bridge are the lengths between axes of adjoining supports.

Clear width below the bridge is the sum of the clear widths between individual supports.

Bridge vertical alignment is identical with the road vertical alignment on the bridge.

Bridge axis is identical with the road axis on the bridge. However, the latter is not necessarily identical with the bridge superstructure axis.

Bridge height is the vertical distance between the comparative ground plane and the bridge vertical alignment.

Total height of the abutment is the vertical distance between the bottom of foundation (shallow or deep) and the bridge vertical alignment.

Total height of the pier is the vertical distance between the bottom of foundation (shallow or deep) and the superstructure lower edge.

Clear height is a clear vertical distance between the ground level (mean water level, vertical alignment of the lower road) and the superstructure lower edge.

Construction depth is the superstructure thickness that can be variable or constant.

Bridge total area is the product of the bridge total length and the bridge total width, and serves as an indicator of the bridge size.

Protective height below the bridge is the difference in height between the lowest point of the superstructure lower surface and the relevant high water level.

Bridge adaptation includes replacement or repair of bridge equipment or other bridge elements not being bearing elements.

Bridge repair includes repair of locally damaged structural load bearing elements.

Bridge reconstruction includes a more comprehensive reconstruction and replacement of structural elements to preserve the design load bearing capacity of the bridge.

Bridge strengthening includes more extensive reconstruction works, strengthening and replacement of load bearing elements due to a modified purpose and conditions of use, as well as due to an increased live load.

Replacement of a bridge means a removal of the entire bridge or superstructure and construction of a new bridge or superstructure.

Bridge rehabilitation is a common term for adaptation, repair, reconstruction, and strengthening of bridge structure and equipment.

Bridge renewal is a term for reconstruction or replacement of the bridge load bearing structure required due to action of physical agents (earthquake, flood) or war.

Small bridges are bridges of a total length of 5 – 30 m.

Medium bridges are bridges of a total length of 30 – 100 m.

Larger bridges are bridges of a total length of 100 – 200 m.

Large bridges are bridges of a total length of 200 – 500 m.

Extremely large bridges are bridges of a total length greater than 500 m.

Low bridges are bridges which vertical alignment is up to 10 m above the ground.

Medium high bridges are bridges which vertical alignment is 10 – 30 m above the ground.

High bridges are bridges which vertical alignment is 30 – 60 m above the ground.

Extremely high bridges are bridges which vertical alignment is more than 60 m above the ground.

Beam bridges are bridges which superstructure (slab, girders, box) is separated from the supports by means of bearings.

Frame bridges are bridges which superstructure is connected with the supports rigidly or by means of a hinge.

Arched bridges are bridges which basic load-bearing element is a vaulted girder (an arch) of a variable cross section.

Suspension bridges are bridges which basic load-bearing elements are parabolic cables supporting the deck via pylons and suspending steel ropes; the load is taken directly by the suspended deck.

Cable-stayed bridges are bridges where the decks of variable cross section and material is suspended (elastically supported) to pylons by means of stay cables.

Design model is an interpretation of the actual structure in a form that best fits the natural behaviour of taking the loading.

Internal forces and moments are the moments, shearing forces and normal forces acting within a particular design cross section.

4. BASES FOR DESIGN OF ROAD STRUCTURES

4.1 Introduction

The road structure design is based on the spatial and town planning, traffic, surveying, geological/geo-mechanical, hydrological/hydro-technical (water economy), climatic (meteorological), and seismic bases as well as on the requirements given in the design specification.

Quality, functionality, stability and economy depend to a great extent on the accuracy and the correct application of the abovementioned bases. The latter shall be prepared by specialists in the individual fields, in cooperation with authorized investor’s experts and structural designers. The structural designer can cooperate in elaboration of the design bases and in their critical assessment on equal terms only on condition that he has on his disposal a sufficient interdisciplinary knowledge in the field of all the specialized activities.

4.2 Spatial and town planning bases

When new motorways and other categorized roads are being designed, the spatial and town planning bases for the road structures are prepared within the road design. Only for larger bridges, viaducts, galleries and tunnels or when bridges and viaducts are independent structures in towns and settlements, special spatial and town planning conditions or bases are elaborated.

4.3 Traffic bases

For larger, individual and particularly urban bridges traffic volume and type during bridge construction and operation are determined in the traffic bases. The traffic data represent a base to specify the number and the widths of traffic lanes, pedestrian walkways, cycle tracks, etc.

For road structures within the framework of new routes or reconstruction of existing road special traffic bases are not necessarily required since the road structure shall comply with the conditions being valid for the road as well. Bridge railings and safety barriers must not diminish the capacity of traffic lanes.

4.4 Surveying bases

The principal surveying bases are the following:

- a key plan of 1:5000
- a detailed actual tacheometric layout plan at a scale of 1:100 for structures of a length up to 100 m and 1:200 (1:250, 1:500) for longer structures respectively
- a longitudinal section of the ground along the designed bridge axis (at the same scale for both heights and lengths).

Both the tacheometric layout and the longitudinal profile include heights above sea level and coordinates of the polygon position and location of geological boreholes.
For bridges located on slopes and in case of a severe morphology longitudinal profiles along the external edges of the bridge are required as well, which particularly applies to the areas of piers and abutments. In these areas accurate cross profiles of the ground are urgently required too.

For larger and geometrically complicated bridges it is essential to elaborate a special programme or detailed report for checking the structural geometry during construction.
The surveying expert’s detailed report can also include the elements of geometrical monitoring during the bridge operation and maintenance.

4.5 Road bases

For the design of road structures layout drawings, longitudinal and cross profiles of the road in the area of the structure as well as the characteristic cross section of the road on the bridge are required. These documents shall be elaborated at a design stage being by one stage higher than the structural design stage. Good road bases cab only be prepared in an interdisciplinary collaboration of all the participants, meaning that the road designer shall cooperate with the structural designer and, if required, with the soil-mechanics expert when conceiving the road route and the vertical alignment in the area of road structures. The final solution should be always based on a consensus of all the interested parties.

4.6 Geological/geo-mechanical bases

For the needs of the design of road structures, suitable geological/geo-mechanical bases are prepared in two stages.

The first stage of these bases intended for elaboration of preliminary designs is carried through within the road route, whereas for larger structures it is prepared independently by means of a limited number of test boreholes or other geo-mechanical investigation works. The first stage of the geological/geo-mechanical bases shall define the type and location of strata, their compressibility, and approximate bearing capacity, as well as to provide the foundation proposal. Structural engineers will use the data on the composition and the type of soil when selecting the static system, the number and length of spans, the total length of the bridge, the location of supports, and the type of foundation.

The second stage of the geological/geo-mechanical investigations is definitive. It provides all the essential data required to elaborate the road construction permit design. The load bearing capacity of the ground is specified on the basis of boreholes executed on the locations of supports, on the basis of the actual depth of the bottom of foundations, and on the basis of the dimensions of the foundation surface including the mandatory calculation of settlements. For deep foundations bearing capacities of piles shall be indicated for individual profiles.

The depth of trial boreholes shall extend at least by 5 to 6 m below the lower edge of the foundation slab or pile footing. The data on factors of both vertical and horizontal compressibility of the ground as well as on the condition and eventual changes of the ground water level are essential for the design as well.

4.7 Hydrological/hydro-technical (water economy) bases

For bridges and culverts the required clear profile for a safe discharge of high waters is

determined taking into consideration an adequate protective height difference between the high-water level and the bridge superstructure lower edge.

For bridges and culverts on motorways, main roads and regional roads the centenary water is relevant. The effect of stemming the stream due to bridge supports shall be allowed for. For local roads fifty-years of twenty-years high water is relevant.

The safety height below the road bridge superstructure varies within the limits of 40-100 cm, depending on the size and character of the river as well as on the degree of reliability of the hydrological data. The hydrological/hydro-technical conditions are given in the water economy conditions issued by the relevant water economy authority or institution.

The foundation depth of the river piers shall be specified to protect the bottom of foundation from eroding (at least 1.5 – 2 m below the riverbed bottom).
To a safe construction of bridges across wide rivers the data on the time oscillation of the water level are extremely important as well.

For a correct selection of the material for construction of river piers the data on the water velocity and on the aggressiveness of the water stream are essential too. When the concrete of river piers can be jeopardized by abrasion, or when the water is chemically aggressive, structural concrete of an adequate resistance or lining of the piers with resistant stone or with a corrosion protected steel plate shall be foreseen.

4.8 Meteorological-climatic bases

When designing and constructing road structures, the data on temperature variations, air humidity, velocity and direction of winds, cleanliness or pollution of air, and duration of freezing shall be allowed for. For the design of the bridge drainage and piping, the data on shower intensities shall be taken into consideration. The data on snow conditions are useful as well.

4.9 Seismic data

For the design of road structures seismic data from the general macro-charts and regulations shall be considered.

For larger and more important structures the actual micro-seismic activity and measures for taking the seismic loading by means of dampers shall be determined.

4.10 Design specification

The design specification shall be made by the investor or by his authorized engineer. It is a constituent part of the design or construction contract for the road structure.

The design specification shall include at least the following information, requirements and conditions:

- **General information**
  - Investor
  - Structure
  - Designation of the road
  - Designation of the obstacle to be bridged

- **Bases for bridge design**
  - Spatial-town planning bases
  - Surveying bases
  - Road bases
  - Geological/geo-mechanical bases
  - Hydrological/hydro-technical bases
  - Meteorological/climatic bases
  - Seismic data

- **Laws, technical regulations, technical specifications, rulebooks, norms and standards**

- **General technical data on bridge**
  - Purpose of the bridge
  - Micro-location of the bridge
  - Motorway or road elements on the bridge
  - Motorway or road characteristic profile on the bridge
  - Total length of the bridge
  - Bridge foundation
  - Basic materials for the bridge superstructure

- **Special conditions for bridge design**

- **Bridge equipment**
  - Drainage and piping
  - Waterproofing
  - Bearings
  - Expansion joints
  - Installations on the bridge
  - Lighting of the bridge
  - Protection from wind, noise, etc.

- **Service life of bridge**
  - Service life of the bridge
  - Maintenance design and equipment

- **Conditions for bridge construction**
  - Working plateaus
  - Access roads
  - Construction time
  - Effect of existing traffic

- **Conditions for aesthetic appearance of bridge**

- **Safety verification**

- **Stages and contents of design documents**

- **Criteria for selection of the most appropriate solution**

- **Procedure of revision and approval of design documents**

5. ROAD GEOMETRY ON BRIDGES

The carriageway geometry (vertical alignment, axis, twisting, cross-falls, angles of crossing natural or artificial obstacles) crucially influences the selection and design of the bridge, its appearance and cost as well as the required construction time.
Solutions of the vertical alignment and axis for a bridge being an integral part of a road can differ from those for an independent bridge.

Both the vertical alignment and the axis of an independent bridge are designed taking into consideration less rigorous boundary conditions and can be easier adapted to natural obstacles and structural requirements.
The geometry of bridges on new roads is a constituent part of the road geometry. Therefore, a cooperation of both road and bridge designer is urgently required. Sometimes even minor corrections of the vertical alignment and the axis essentially facilitate the construction technology and subsequent bridge maintenance.

The vertical alignment of a bridge, viaduct or overpass shall ensure sufficient space for a reasonable selection of both the constructive depth and the safety height. A vertical alignment of one-sided longitudinal fall within a range of 0.5 – 3% is wished for. Longitudinal falls smaller than 0.5% makes maintenance difficult and more expensive particularly for longer bridges. On the contrary, when longitudinal falls exceed 3%, aesthetical appearance of longer bridges is adversely affected.

Concave curvatures of the vertical alignment are not desirable on longer bridges. The same applies to the combination of curvatures of the vertical alignment and horizontal curvatures of the carriageway axis.

For larger bridges symmetrical convex curvatures of the vertical alignment with inclination of both tangents of 1.5 – 2% are wished for.

A change of cross-falls (twisting of the carriageway) on bridges and viaducts renders design and construction difficult and more expensive, and creates an unfavourable visual impression.
A combination of substantial longitudinal and cross-fall of the carriageway can lead to troublesome skidding of vehicles on a wet, snowed up or ice-covered carriageway.

A widening of bridges in the area of horizontal curvatures should be carried through to a full value along the entire bridge length, in contrast to the road where the transition is generally executed gradually from zero to the full value.
For urban bridges and at crossroads inclinations smaller than 0.5% are allowed. However, a more efficient dewatering shall be ensured in such cases.
The road axis can cross the obstacle axis at an angle of 90° or less. The smaller the crossing angle, the longer the bridge. The structure becomes more and more complicated and expensive.

Crossing angles smaller than 45° represent exceptional cases and shall be avoided. Crossing angles of at least 60° are recommended.
In case of smaller road structures such as underpasses for vehicles or pedestrians, bridges of a length up to 20 m or similar, it is recommended to lower the upper edge of the superstructure by 40-60 cm (i.e. by the thickness of the carriageway pavement structure) under the vertical alignment. In this way effects of an unfavourable geometry on the bridge structure can be avoided since all the geometry modifications can be solved by a variable thickness of the carriageway pavement structure.

With regard to the general visibility and different fields of sight, a road bridge shall be of the same standard as prescribed for the particular road.

The responsibility of the road designer for the geometrical solutions on the bridges is proportional to the length and the cost of a bridge. Optimum solutions are enabled by a balanced interdisciplinary collaboration.
Smaller road bridges can be accommodated to the road route elements, whereas for larger bridges specificities of the structure and its construction method shall be allowed for when determining the road route.

6. TRAFFIC PROFILE, CLEARANCE GAUGE AND WIDTH OF ROAD BRIDGES

6.1 Clear profile and clearance gauge

A traffic profile of a road (bridge) is the 4.0 m high space above the carriageway. It consists of the following:

- cross-section of the relevant vehicle
- space allowing a vehicle to move in both a straight line and a curve
- safety width between vehicles.

The abovementioned components are also valid for the traffic profile of cyclists as well as of both cyclists and pedestrians where its height amounts to 2.25 m.

A traffic profile consists of traffic and overtaking lanes, marginal strips, central reserves as well as widths for both pedestrians and cyclists in settlements.

A clearance gauge of the road on a bridge is the space above and at the traffic profile, i.e. the traffic profile enlarged by both the safety width and safety height. No permanent physical hindrances shall interfere with the clearance gauge to ensure the designed speed of vehicles and an undisturbed movement of other road users.

The safety width w_{saf} within a clearance gauge depends on the design speed v_{des} and amounts to the following values:

v_{des} (km/h)	50	70	>70
w_{saf} (m)	0.50	1.00	1.25

The safety height above the traffic profile amounts to h = 0.50 m. For overpasses over motorways the safety height shall be h = 0.70 m.

The safety height above the pedestrian walkway and cycle track amounts to h = 0.25m.

Exceptionally a lower clearance gauge (>4.5 m) can be foreseen for individual relevant vehicles, however not for new bridges but only for reconstructions.

Is the clearance gauge lower than usually, it shall be marked by suitable both horizontal and vertical traffic road signs.

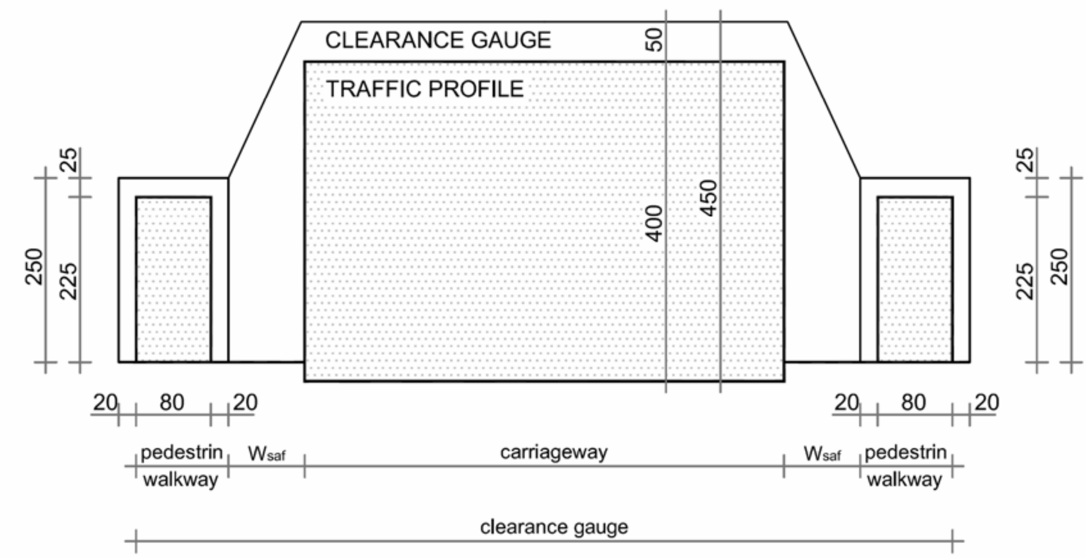


Figure 6.1: Traffic profile and clearance gauge on a bridge

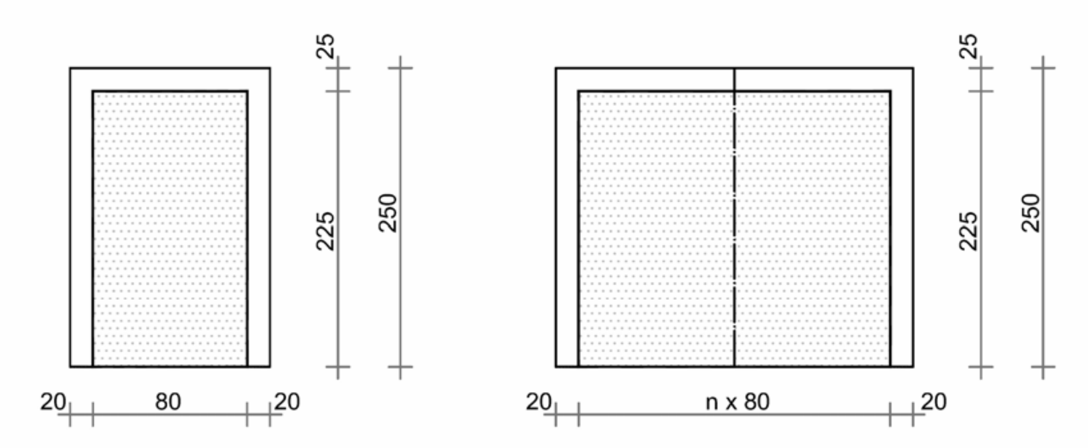


Figure 6.2: Traffic profile and clearance gauge of pedestrian walkway

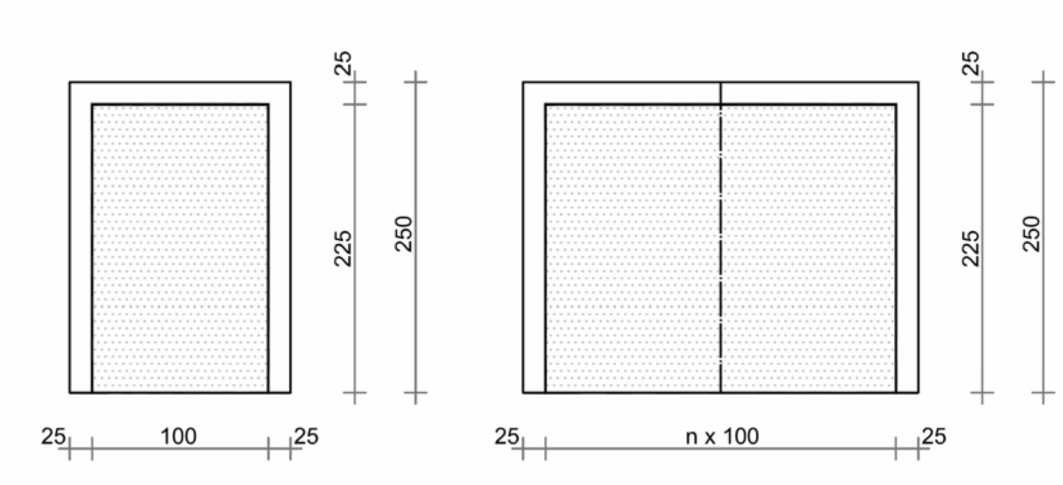


Figure 6.3: Traffic profile and clearance gauge of cycle track

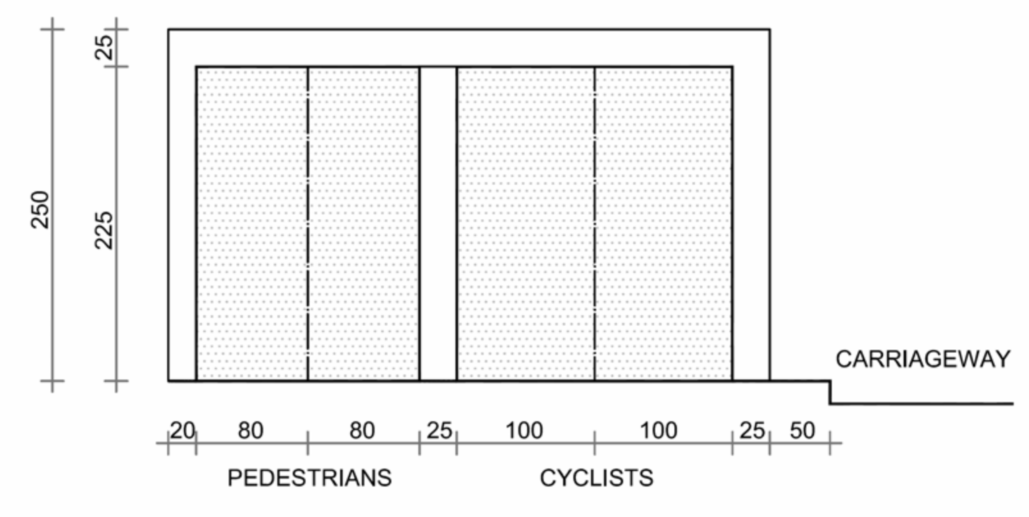


Figure 6.4: Example of combined traffic profile and clearance gauge for both pedestrians and cyclists (The minimum combined width for both pedestrians and cyclists amounts to w = 0.20 + 0.80 + 0.25 + 1.00 + 0.25 = 2.50 m)

In figure 6.5 a clearance gauge of bridges on both motorways and highways consisting of two separated carriageways is presented. The emergency lane width depends on the width of the normal cross-profile on a motorway or highway. A service walkway shall be foreseen for bridges longer than 50 m. In figure 6.5a) a clearance gauge without an emergency lane is shown whereas in figure 6.5b) the clearance gauge comprises an emergency lane as well.

In figure 6.6 a clearance gauge of bridges on main, regional and local roads out of settlements (v > 50 km/h) is presented. Figure 6.6a) includes a pedestrian walkway whereas figure 6.6b) shows both a pedestrian walkway and a cycle track.
In figure 6.7 a clearance gauge of bridges on main, regional and local roads in settlements (v < 50 km/h) is shown. Figure 6.7a) includes a pedestrian walkway whereas figure 6.7b) shows both a pedestrian walkway and a cycle track.

In figure 6.8 a clearance gauge of bridges on open (public) roads is presented. A smaller clearance gauge height (4.20 m) is feasible as well. A pedestrian walkway shall be foreseen for open roads in settlements only.

Both the shape and dimensions of clearance gauges for urban bridges shall be determined individually for each bridge in accordance with the town planning documents and the traffic regime. They depend on the traffic type and volume as well as on the needs of pedestrian walkways and cycle tracks. In certain cases it might be reasonable to foresee cycle tracks on the carriageway level. The carriageway widths of road bridges are equal to or greater than the carriageway widths of normal cross-profiles of the same category.

When determining bridge widths one shall bear in mind the fact that it is more difficult to widen a bridge than a road. Therefore it is more economical to foresee a greater bridge width from the early beginning, in particular for roads where an urbanization progress can be expected.

When widening a horizontally curved bridge the prescribed carriageway widening is relevant too.

A clearance gauge on railway bridges and roads above them (e.g. overpasses) is a limited area of the vertical plane above the track upper edge perpendicular to the track. The clearance gauge axis is the same as the track axis and is perpendicular to the line connecting the upper edges of both rails. No railway installations, structures, signs etc. shall interfere with the clearance gauge area (figure 6.9).

A clear profile is a part of the vertical plane above the track upper edge, perpendicular to the track and limited by the inner contour of the bridge cross-section, or by the superstructure lower contour (intrados) and by inner edges of supports in case of overpasses. It is determined on the basis of the prescribed clearance gauge, position and number of tracks, camber of tracks in a curve, installations on the bridge, walkway design, etc. The clear profile, taking into account structural deformations and foundation settlement, can touch the clearance gauge in certain points or lines; however it shall not interfere with it.

When designing new bridges or reconstruction of existing ones on non-electrified railway lines where no future electrification is foreseen, a clearance gauge UIC – GC up to the level of 4,300 m above the track upper edge shall be taken into consideration as shown in figure 6.9.

For electrified railway lines (existing and future), beside the clearance gauge up to the level of 4,900 mm above the track upper edge, an additional portion above that level shall be considered to enable passing of pantograph and installing of the overhead electric and supporting cables.

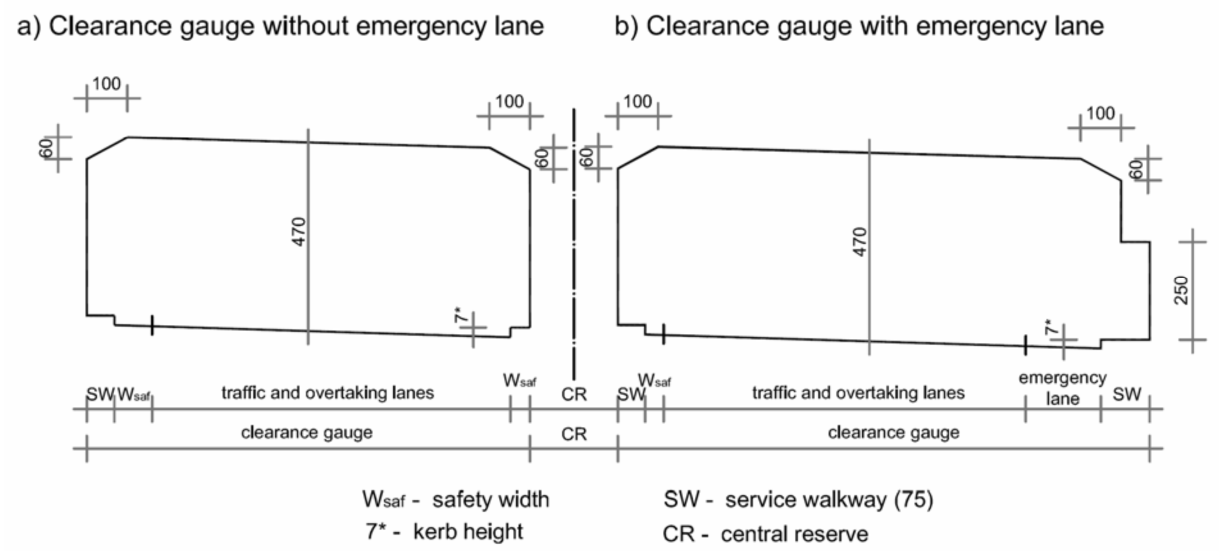
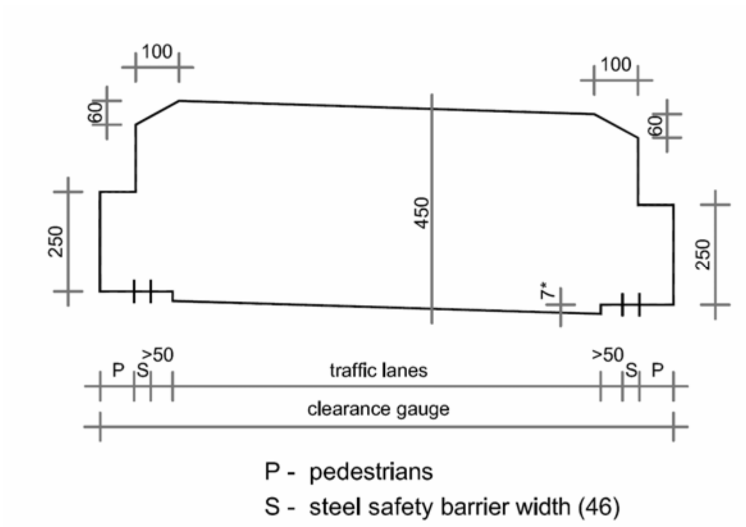


Figure 6.5: Clearance gauge of bridges on motorways and highways

a) Clearance gauge with pedestrian walkway



b) Clearance gauge with cycle track and pedestrian walkway

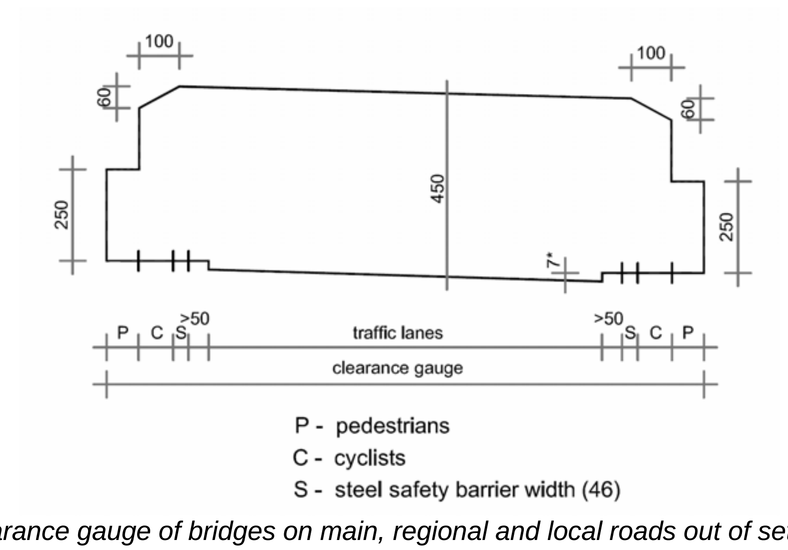
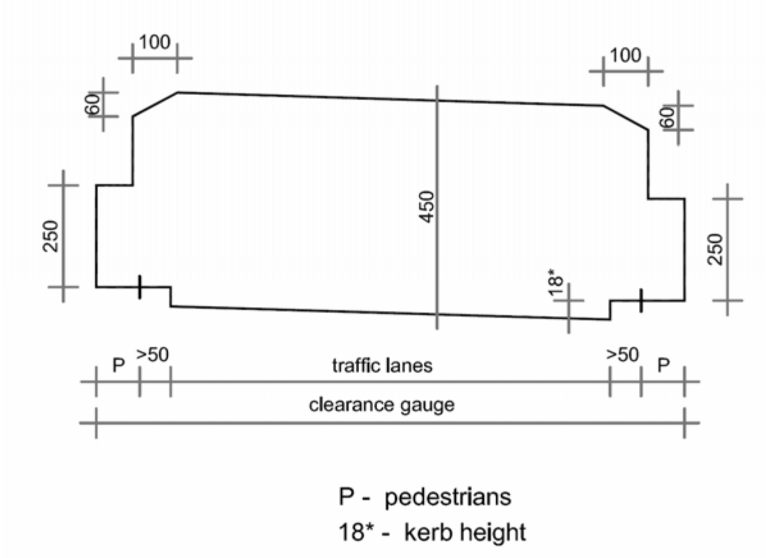


Figure 6.6: Clearance gauge of bridges on main, regional and local roads out of settlements (v > 50 km/h)

a) Clearance gauge with pedestrian walkway



b) Clearance gauge with cycle track and pedestrian walkway

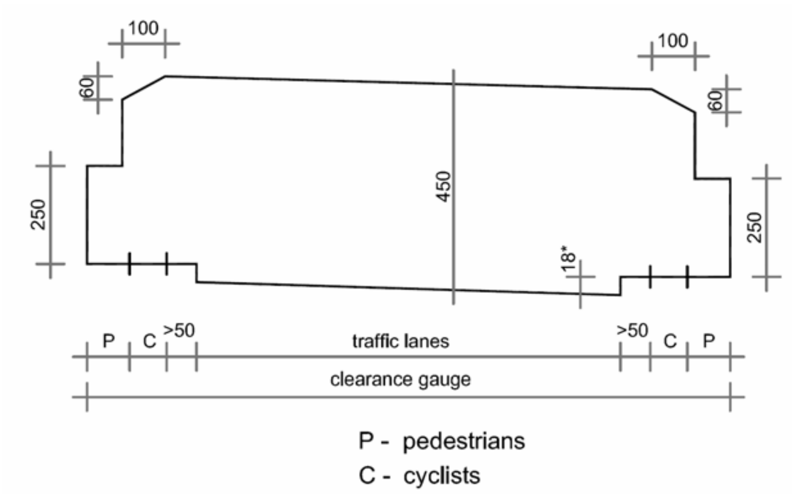


Figure 6.7: Clearance gauge of bridges on main, regional and local roads in settlements (v < 50 km/h)

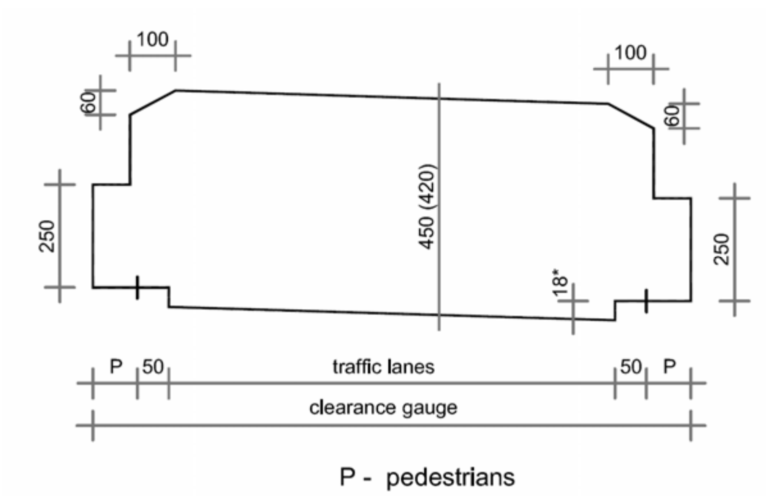
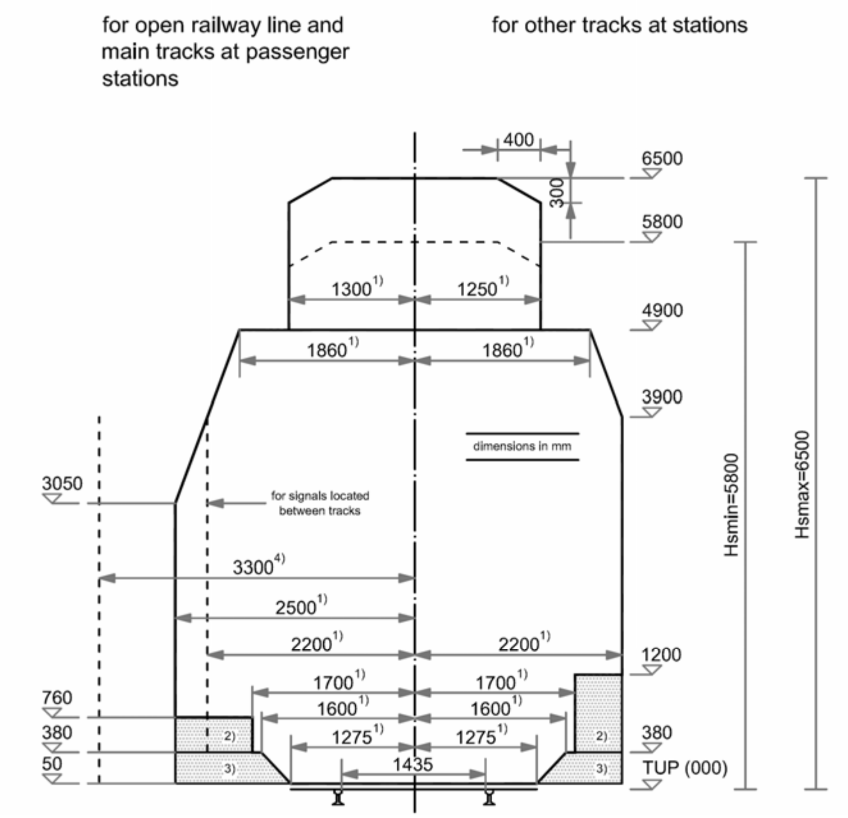


Figure 6.8: Clearance gauge of bridges on open (public) roads



1) Gauge widening at R < 250 m

Curvature radius R	At the curve inner side	At the curve outer side
m	mm	mm
250	0	0
225	25	30
200	50	65
180	80	100
150	135	170

2) Space for platforms and loading ramps at stations
3) Space for installations if required for railway traffic
4) Applies to overpass supports

Figure 6.9: Clearance gauge UIC-GC of railway bridges at R $\geq$ 250 m

6.2 Regular cross section (with) on motorways and highways bridges

Cross-profiles of bridges on motorways and highways are similar to those at both accesses to a bridge.

Cross-profiles consist of traffic and overtaking lanes, marginal strips, emergency lanes, central reserve and shoulders.

The widths w of both traffic and overtaking lanes are given as a function of the design speed v_{des} :

- v_{des} = 120 km/h   w = 3.75 m
- v_{des} = 100, 90 km/h   w = 3.50 m
- v_{des} = 80 km/h   w = 3.25 m
- v_{des} = 70, 60 km/h   w = 3.00 m
- v_{des} = 50 km/h   w = 2.75 m
- v_{des} = 40 km/h   w = 2.50 m

The marginal strip widths w_{ms} are given as a function of the traffic lane widths w_{tl}:

- w_{tl} = 3.75 m w_{ms} = 0.50 m
- w_{tl} = 3.50 m w_{ms} = 0.30 m
- w_{tl} = 3.25 m w_{ms} = 0.30 m
- w_{tl} = 2.75 m w_{ms} = 0.20 m

The emergency lane widths w_{el} amount to the following values:

- On motorways: w_{el} = 2.50–1.75 m
- On highways: w_{el} = 1.75 m

The emergency lane is a widened marginal strip thus not requiring an additional marginal strip.

For motorways where the emergency lane width amounts to 1.75 m, and for highways, broadening of the emergency lanes by 0.75 m shall be carried out at certain distances. The emergency niches achieved in this way are 2.50 m wide.

The shoulder width w_s depends on the design speed v_{des} and amounts to the following values:

- $v_{des} \geq$ 100 km/h w_s = 1.50 m

$v_{des} \geq$ 90 km/h w_s = 1.30 m
$v_{des} \geq$ 70 km/h w_s = 1.30 m
$v_{des} \geq$ 50 km/h w_s = 1.00 m

The central reserve widths w_{cr} amount to the following values:

On motorways: w_{cr} = 3.20 – 4.00 m
On highways: w_{cr} = 1.25 – 2.50 m
On multiple-lane roads in settlements: w_{cr} = 1.60 – 4.50 m

In figure 6.10A an example of a normal cross-profile of a motorway consisting of 3.75 m wide traffic and overtaking lanes, a 2.50 m wide emergency lane, 1.50 m wide shoulders and a 4.00 m wide central reserve is indicated for a speed of v_{des} = 120 km/h. The total width of a motorway running in a cut amounts to 28.00 m (a normal cross-profile of 28.00 m).

In figure 6.10b cross-sections of bridges consisting of two superstructures separated by 10-20 cm in the central reserve axis are shown. The design of bridge safety barriers shall be harmonized with the solutions on the motorway approaching the bridge ends.

In figure 6.10c an adequate cross-section on a common bridge without an expansion joint in the central reserve is presented. Such a solution can be introduced to shorter bridges such as culverts or underpasses where no differential settlement of foundations is expected.

In figure 6.10d cross-sections on bridges consisting of two structures pushed apart are shown. Such a solution is foreseen where the central reserve width is greater than 4.00 m, where the carriageways are separated due to a nearby tunnel, etc. At the outer sides of the cross-profiles service walkways for maintenance staff are foreseen. In case of separated superstructures concrete safety barriers shall be designed.

In figure 6.11A an example of a normal cross-profile of a highway consisting of 3.50 m traffic and overtaking lanes (without emergency lanes), 1.50 m wide shoulders and a 2.00 m wide central reserve is indicated for a speed of v_{des} = 100 (90) km/h.

In figure 6.11B cross-profiles on bridges consisting of two separated superstructures are indicated. In figure 6.11C cross-profiles on bridges of a common superstructure whereas in figure 6.11 cross-profiles on bridges consisting of two superstructures pushed apart are shown. These considerations apply to both motorway and highway bridges.

When elaborating preliminary bridge schemes, bridge designers conceive normal cross-profiles for each individual bridge in collaboration with road designers.

The selected concrete safety barrier on a bridge shall be of the same type as the barrier on the approaching motorway, which is particularly important to the central reserve.

In bridges on such motorway sections where the normal central reserve is widened due to a nearby tunnel or similar, each structure represents the integrity apart.

Due to the clearance gauges and widths of road bridges the superstructures of bridges and viaducts shall be separated, i.e. double. This principle applies to all the materials, static systems and deck construction methods.

Deviations from the a.m. principle are allowed only for culverts and underpasses located in the motorway bodies, especially when an overlay above the upper slab is present, so that both traffic-dynamical and visual changes are avoided. The same applies to shorter bridges where no settlement of foundations is expected.

Deviations from the a.m. principle are also permitted for extremely tall (mean pier height of 60 to 80 m) and extremely long viaducts (total length greater than 800 m) of spans longer than 100 to 120 m.

When comparing the alternatives of single and double superstructures the following aspects shall be considered:

- Function of the bridge in the motorway network
- Possibility of a by-pass in case of closure of the motorway on the bridge
- Superstructure material (concrete or steel)
- Operation/exploitation conditions of the bridge (regular maintenance, rehabilitation)
- Preservation of natural environment and incorporation of the bridge into it
- Economic aspects in view of the initial and total investment over the entire design service
- life of the bridge.

Experiences from the motorway exploitation have shown that damages of motorway bridges are a normal feature requiring a permanent maintenance as well as rehabilitations within the periods of 25 to 30 years. In rehabilitation of bridges consisting of a single superstructure the traffic diversion represents a major problem. Therefore investors usually decide on double superstructures.

Taking into account the influence of both traffic and vibrations on the maintenance and rehabilitation of steel superstructures, which is less disturbing to a double superstructure, the abovementioned considerations are confirmed.

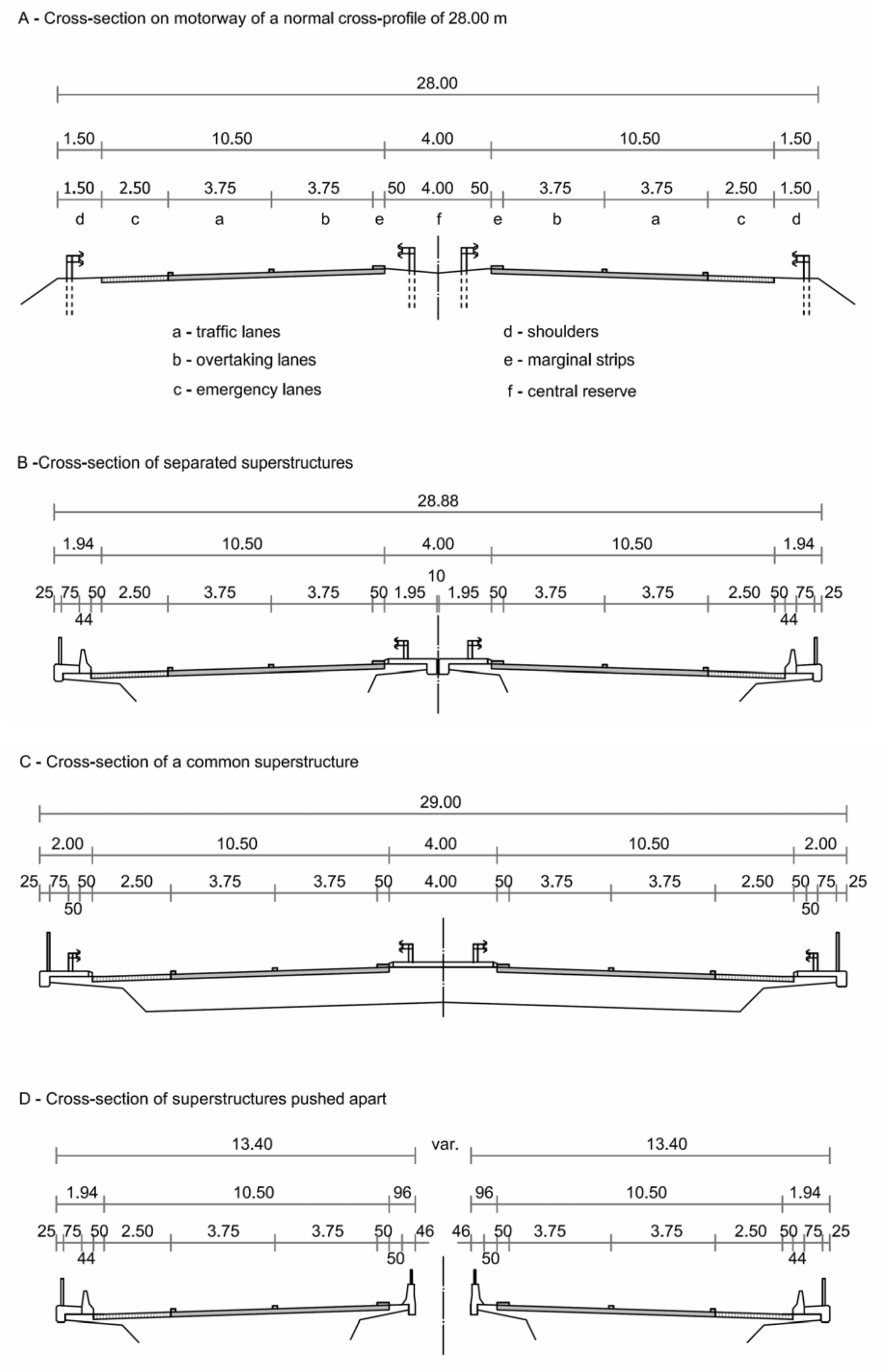


Figure 6.10: Cross-sections of bridges on motorways for a normal cross-profile of 28.00 m

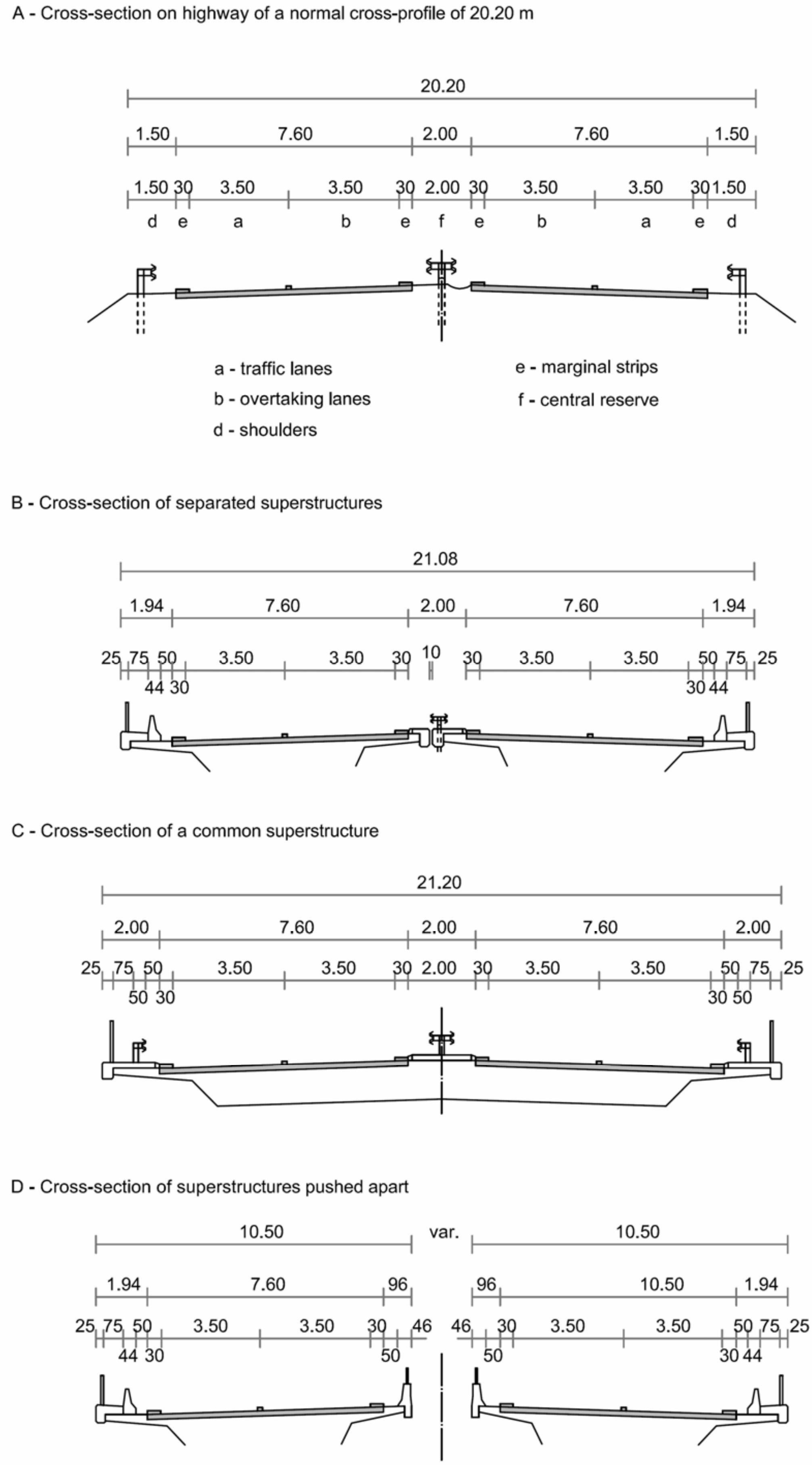


Figure 6.11: Cross-sections of bridges on highways for a normal cross-profile of 20.20 m

6.3 Regular cross section (with) on main regional and local bridges

In figures 6.12 and 6.13 widths and shapes of bridge cross-sections on main, regional and local roads are shown. The fundamental difference in the bridge cross-section design is due to vehicle speed or to position of the bridge out of settlements or within them.

In figure 6.12 widths and shapes of bridge cross-sections on main/regional and local roads out of settlements for speeds > 50 km/h are indicated. The kerb height amounts to 7 cm. A steel safety barrier placed at a distance ≥ 50 cm from the marginal strip is obligatory.

Under a) the width of main, regional and local roads is presented. B is the width of the traffic lanes plus the marginal strip width and shall amount to ≥ 5.9 m depending on the road category and other factors.

Under b) the width of bridges on main, regional and local roads is given, when a bridge is shorter than 20 m and lower than 3 m.

Under c) the width of bridges on main, regional and local roads is shown, when a bridge is shorter than 50 m irrespective of its height.

Under d) the width of bridges on main, regional and local roads is indicated, when a bridge is longer than 50 m irrespective of its height.

Under e) the width of bridges on main, regional and local roads out of settlements is shown, with pedestrian walkways or cycle tracks or both of them, irrespective of the bridge length and length. The steel safety barrier shall be equipped with a handrail.

In figure 6.13 the widths and shapes of bridge cross-sections on main, regional and local roads in settlements for speeds < 50 km/h are presented.

Under a) the width of main, regional and local roads is indicated. B is the width of the traffic lanes plus the marginal strip width and depends on the road category and other factors.

Under b) the width of bridges on main, regional and local roads in settlements is indicated. The walkway width depends on the fact whether it is intended for pedestrians, cyclists or both of them. The kerb height amounts to 18 cm. On each edge a pedestrian railing of height of 1.10 m shall be foreseen.
In figures 6.14 and 6.15 the widths of bridge cross-sections on open (public) roads are shown. One can distinguish between two-lane and single-lane open roads.

In the figure 6.14 the width of bridge cross-sections on a two-lane open road is indicated.

Under a) the width of a two-lane open road is shown, where the total width of the traffic lane and marginal strips amounts to B ≥ 5.0 m.

Under b) the width of bridges on two-lane open roads is indicated. The kerb height amounts to 18 cm. On each edge a pedestrian railing of height of 1.10 m shall be foreseen.

In figure 6.15 the widths of bridge cross-sections on one-lane open roads are presented.

Under a) the width of a one-lane open road is shown, where the total width of the traffic lane and marginal strips amounts to B ≥ 3.5 m.

Under b) the width of bridges on one-lane open roads is indicated. The kerb height amounts to 18 cm. On each edge a pedestrian railing of height of 1.10 m shall be foreseen.

The minimum width of a pedestrian bridge amounts to 3.0 m.

Bridge cross-sections (edge beams, kerbs and walkways) are discussed in detail in the design guidelines DG 1.2.2.

Both clearance gauges and widths of combined bridges depend on the decision whether for all the traffic types a common bridge is foreseen, or for different traffic types a separate bridge is designed. When determining both the clearance gauge and the width of a bridge intended for a combined traffic, particularities of each individual traffic type shall be taken into account.

Depending on the actual conditions for bridges foreseen for a combined traffic, a bridge can be executed in two levels.

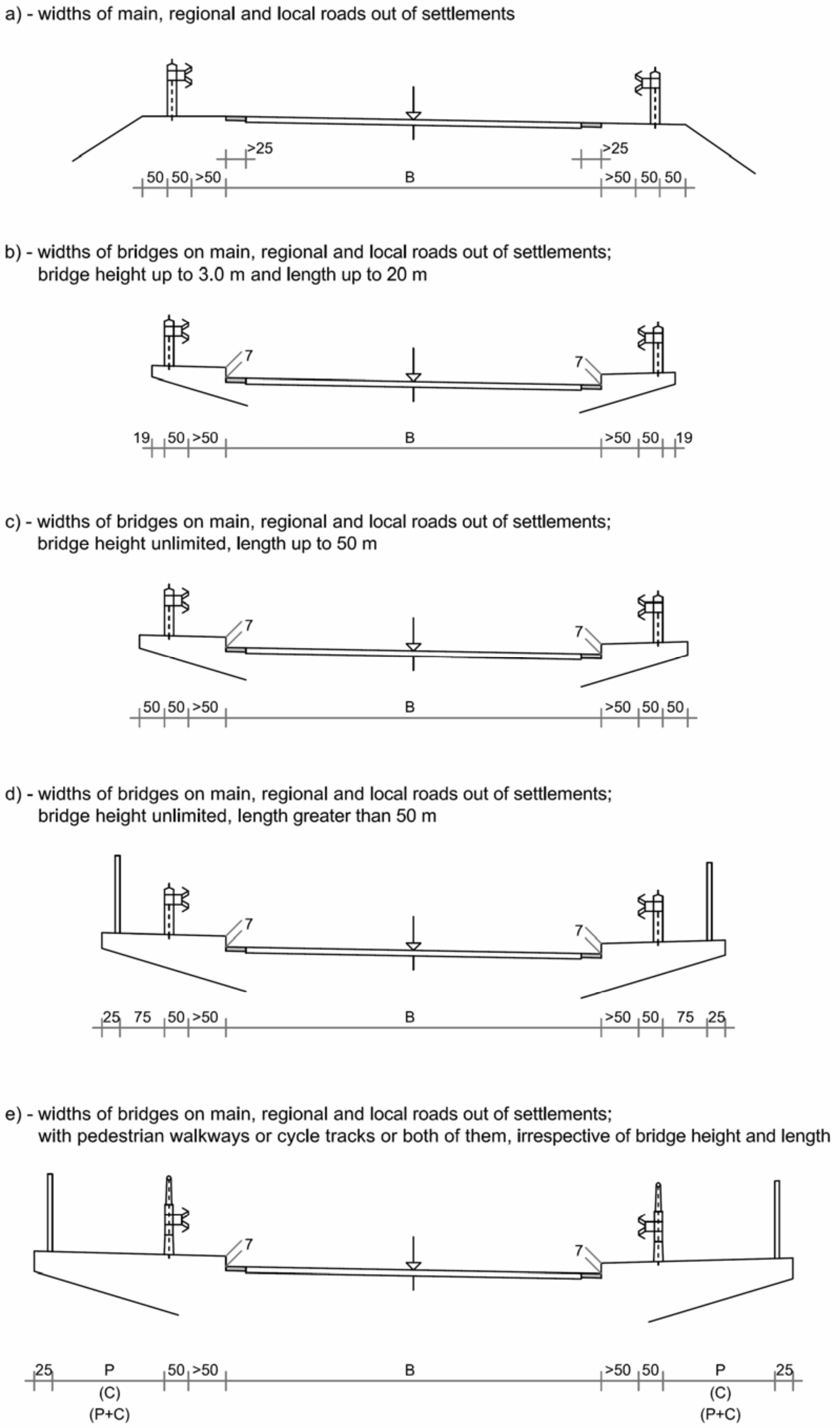


Figure 6.12: Cross-section widths of bridges on main, regional and local roads out of settlements (v > 50 km/h)

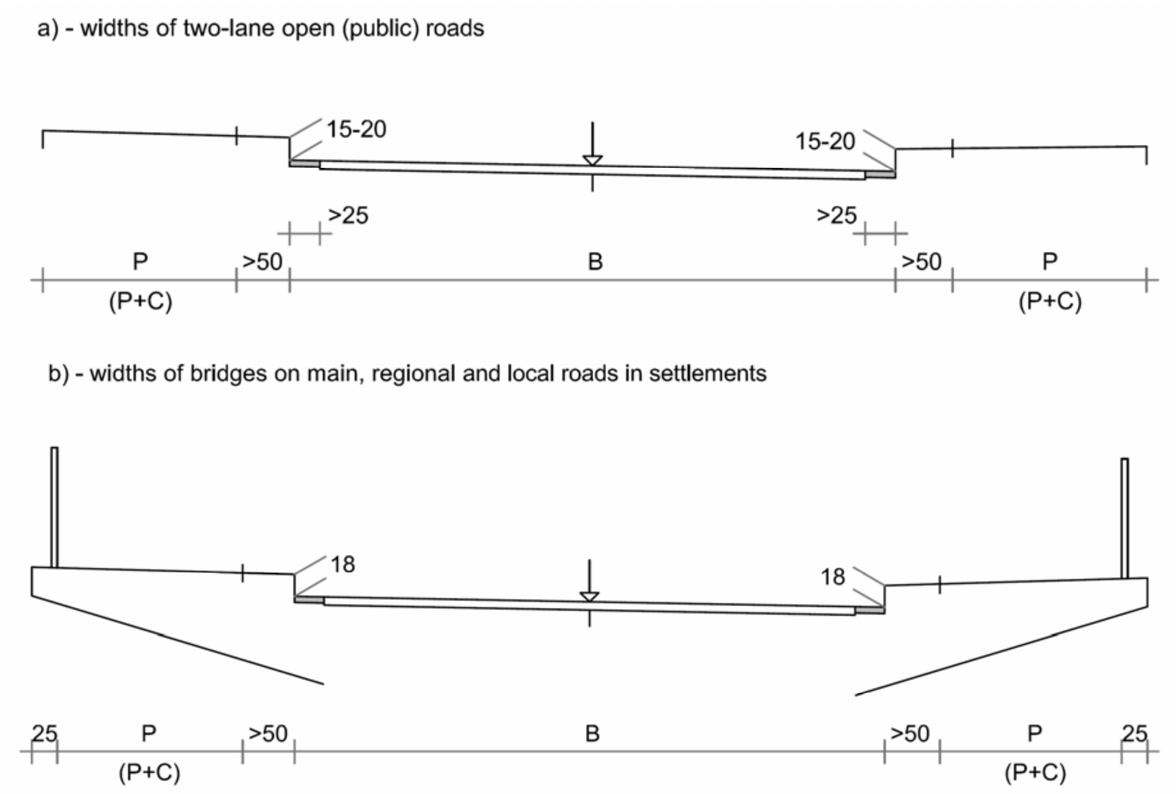


Figure 6.13: Cross-section widths of bridges on main, regional and local roads in settlements (v < 50 km/h)

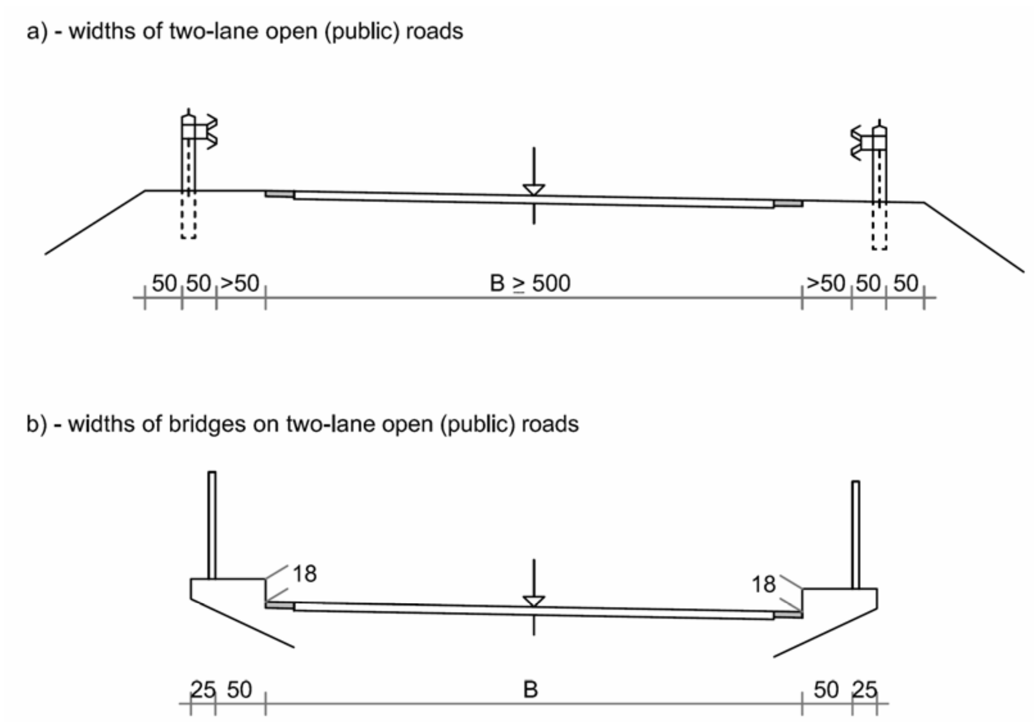


Figure 6.14: Cross-section widths of bridges on two-lane open (public) roads

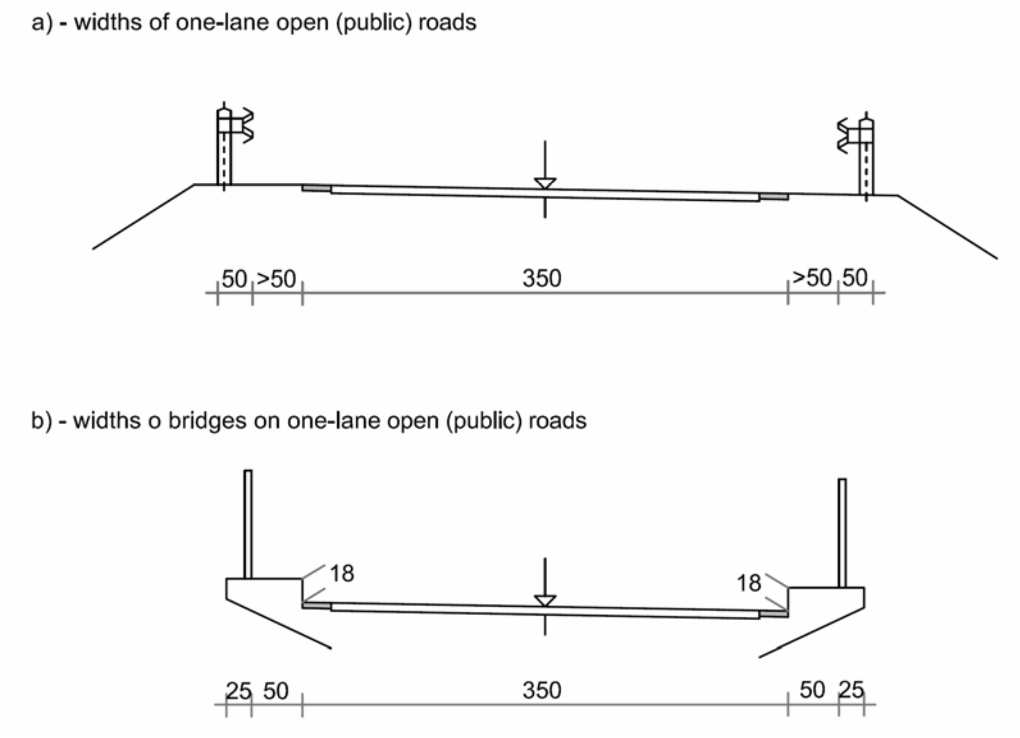


Figure 6.15: Cross-section widths of bridges on one-lane open (public) roads

6.4 Standard cross-sections (widths) of bridges for mixed road-railway traffic

On main, regional, and local roads bridges for a mixed, i.e. road-railway traffic can occur.

There are two possible solutions for standard cross-sections (widths) of such bridges:

A solution of standard cross-sections (widths) on the same carriageway is sufficient for regional and local roads of less significant traffic volume, as well as for factory railway tracks (Fig. 6.16)

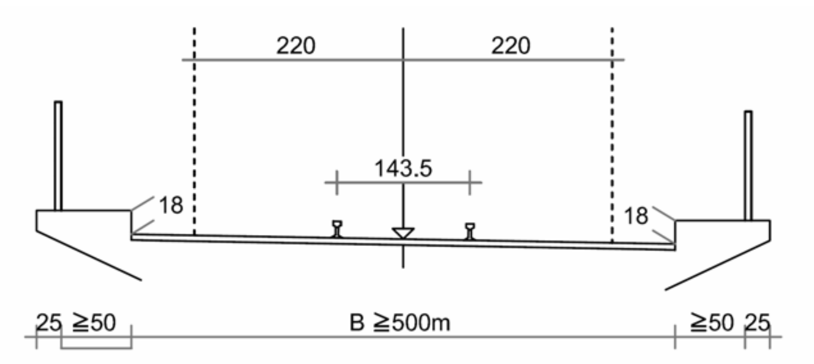
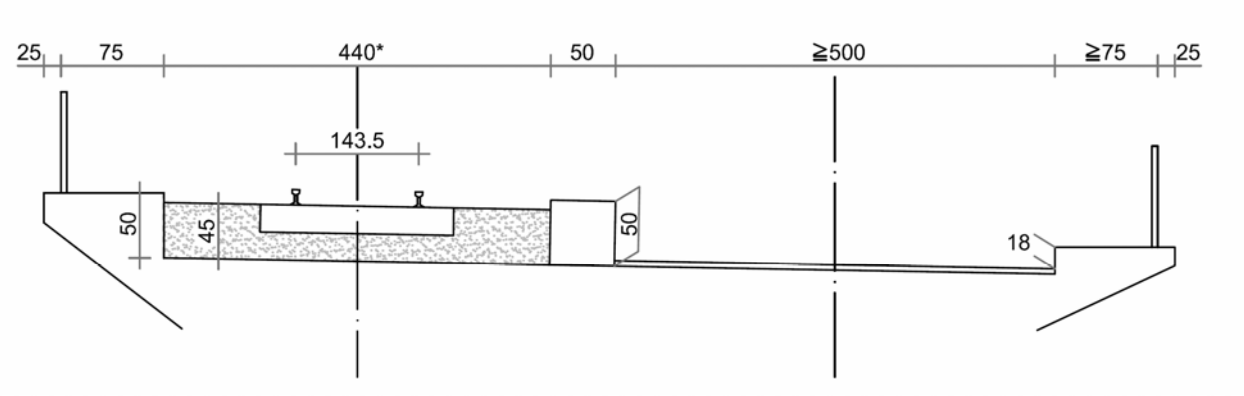


Figure 6.16: Cross-sectional widths of bridges for mixed road-railway traffic on the same carriageway

A solution of standard cross-section (widths) on the same, i.e. common bridge on separated carriageways is feasible on all national roads except on motorways and expressways. For public railways it is mandatory to keep a carriageway with gravel ballast on bridges as well (Fig. 6.17). For local railways of lower speed as well as for factory tracks it is possible to avoid the gravel ballast, so that the tracks are placed at the road carriageway level.



* for railway track running in a straight line or in a curvature of R > 250 m.

Figure. 6.17: Cross-sectional widths of bridges for mixed road-railway traffic on separated carriageways

7. CLEAR WIDTH AND CLEAR (SAFETY) HEIGHT BELOW ROAD BRIDGES

7.1 General

For bridges across natural or artificial streams the opening determined by hydraulic calculation shall be sufficient to enable a safe flow of centenary water with a damming effect in front of the obstacle, and to ensure a safety height above that level.

When determining the clearance gauge of streams and roads, eventual reserves in width for local roads, paths and other purposes shall be considered, since any subsequent widening of the clearance gauge are difficult for execution and economically unfavourable.

The profile width is harmonized with the width of the road and appurtenant paths. A reserve in width shall always be taken into account, in particular at passage of a path below a bridge, since nearby lateral obstacles can reduce both the traffic safety and the footpath capacity.

When a bridge is being constructed over a road or railway under traffic, the formwork gauge shall be taken into consideration or other suitable construction methods shall be foreseen such as pre-cast pre-stressed concrete composite structures, incremental launching etc., which not require any increasing of the clearance gauge.

7.2 Safety height below bridges

The safety height is a clear vertical distance between the $H_{1/100}$ (centenary water level) increased by the height difference as a consequence of the increased water level due to hindering piers, and the lower edge of the bridge superstructure.

The safety height amounts to 0.50 m for channels and regulated streams, minimum 1.0 m for non-regulated streams and 1.0 – 1.5 m for minor torrents. Other values of safety heights are feasible as well, if explicitly requested by the water economy guidelines. The upper surface of the bearing block on the bridge abutment shall extend by minimum 0.20 m above the $H_{1/100}$.

For navigable rivers the safety height shall amount to:

- 2.5 – 3.0 m for rafts and boats
- 3.0 – 4.5 m for major boats and sailing boats.

For ships and tugboats the relevant port authorities must direct the navigation gauges.

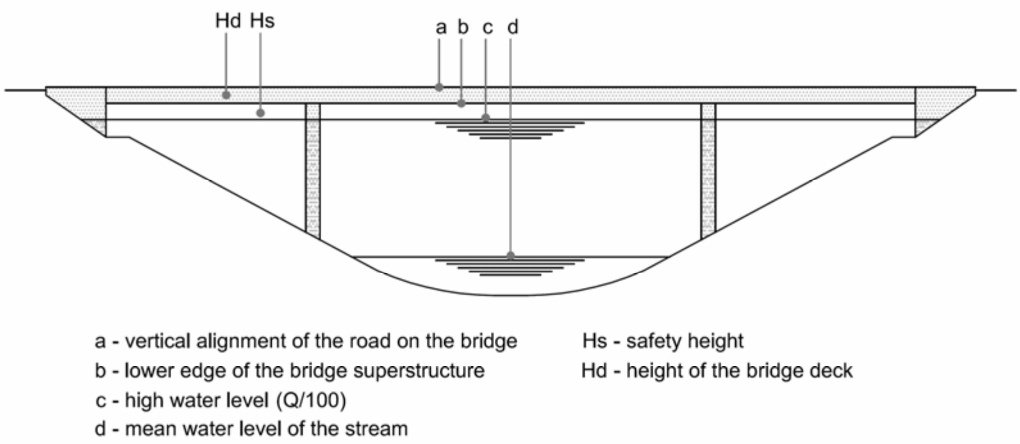


Figure 7.1: Clear profile below road bridges

7.3 Clear width and clear height of underpasses

Underpasses are structures enabling leading of other roads below the considered road.

The underpass clear width is equal to the road width (traffic lanes, marginal strips, shoulders or footpaths and cycle tracks) at both ends of the underpass.

In the figures 7.2 and 7.3, minimum clear widths for single-lane and two-lane public paths are indicated.

Clear heights of road underpasses amount to 4.70 m for motorways as well as main, regional and local roads, whereas for public paths the clear height shall not be less than 4.20 m. For pedestrians and cyclists the clear height shall be 2.5 m. When practicable and in case of longer structures, the clear height shall be increased to 3.0 m.

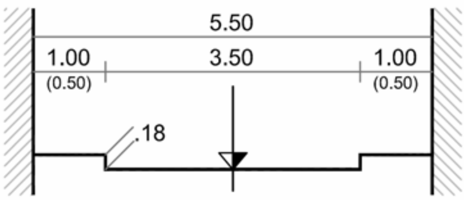


Figure 7.2: Minimum clear width of underpasses for single-lane public paths

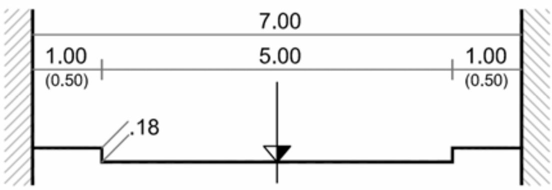


Figure 7.3: Minimum clear width of underpasses for two-lane public paths

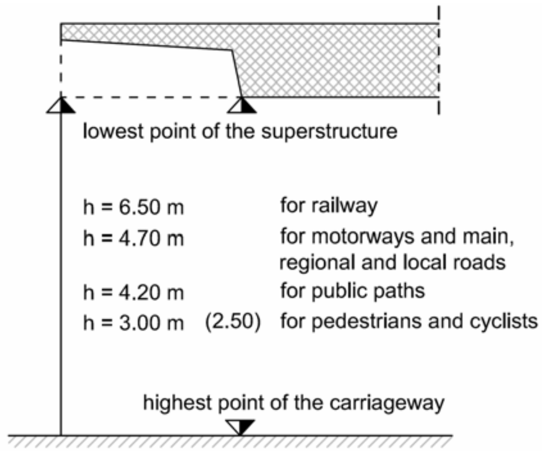


Figure 7.4: Clear height of underpasses

7.4 Clear width (opening) and clear height of overpasses across motorways and highways

Overpasses are structures enabling leading of other roads across the considered road. In practice, predominantly main/regional/local roads are led over motorways or highways.

The overpass width is equal to the width of the road entering/exiting the overpass. It is specified in the paragraph 6 of this design standard.

The clear height below overpasses amounts to 4.70 m. It is defined as the vertical distance between the lower edge of the superstructure (taking into account the drainage pipe or other installations) and the highest point of the carriageway.

When exceptional transports are foreseen on a particular road direction, a clear height of 6.50 m below the overpasses shall be ensured or suitable alternative solutions established.

The clear width (opening) depends on numerous factors. The minimum clear width is a width required by the clearance gauge of a motorway, highway or any other road. The number and length of overpass spans depends on the clear width.

The arrangement scheme of overpasses is mainly influenced by the following:
- whether a motorway/highway being crossed by the overpass is located on a flat ground or in a cut;
- the total width of the motorway/highway road body;
- the width of the central reserve and the motorway/highway geometry;
- possibility of widening of a motorway/highway or increasing of the number of traffic lanes;
- economical aspects;
- spatial/town-planning and aesthetic design aspects.

From the constructive-static point of view, frame (integral) structures without bearings and expansion joints are preferential for overpass lengths of less than 60-70 m.

Road designers should tend towards solutions where a road on the overpass crosses the motorway/highway at an angle of 90°. If such a solution is not practicable, the angle of crossing should differ from 90° as less as possible. Rectangular overpasses are shorter, cheaper as well as geometrically and visually more favourable.

The vertical alignment of the road on the overpass can be considered as favourable when it runs in a symmetrical vertical curvature or in a one-sided fall of less than 3%. A change of the cross fall on the overpass is not desirable due to an unpleasant visual effect as well as a more difficult construction and dewatering.

Full attention shall be paid to the structural design of overpasses, particularly of their piers, since an overpass is not only a functional structure but also a significant spatial element.

It is not obligatory to design uniform overpasses on a motorway. Most overpasses have their own specificities, which the designers shall bear in mind. Motorway users probably prefer logical variations and pleasant visual surprises.

When an overpass is designed with a pier in the central reserve, special attention shall be paid to the selection of the pier cross section, to its protection from the vehicle impact, to the traffic safety (a solution involving safety barriers in the central reserve), to the drainage of the central reserve below the overpass, and to the depth of the foundation block.

In the figure 7.5 possible solutions of the overpass structures are shown schematically, where a motorway or any other road runs on a nearly flat ground. In the figure 7.6 solutions are indicated when a road crossed by an overpass is located in a cut.

Single-span overpasses are suitable to motorways running in a partial cut, in particular when the width of the central reserve is less than 2.0 m. In such cases the height of the fill of the main/regional/local road is not greater than 4-5 m and the overpass opening varies within the limits of 25-40 m. Both a constant or variable depth of the frame superstructure is feasible (figure 7.5 A).

Double-span overpasses are suitable to motorways running on a flat ground or in a shallow cut, where the width of the central reserve exceeds 2.0 m. In such cases the height of the fill is not greater than 6.0 m, and the spans of the overpass frame structure vary within the limits of 15-25 m. The span length shall be selected adequately to enable execution of continuous lateral ditches and to ensure a berm of a minimum width of 1.0 before the cone (figure 7.5 B).

Overpasses consisting of three or more spans are an adequate solution for motorways on a flat ground where no pier is foreseen in the central reserve. The length of the central span of the frame structure varies from 25 to 30 m, whereas for side spans it amounts to 14-20 m. A constant construction depth of the overpass superstructure is desired (figure 7.5 C).

Overpasses consisting of four or more spans are a good solution for motorways on a flat ground where the width of the central reserve is significant and when a possibility of a motorway widening by additional traffic lanes exists. Such multi-span overpasses are suitable to motorway sections next to big cities where high fills are not welcome. The span lengths above the motorway amount to 20-30 m, whereas the side spans follow the static conditions and the characteristics of the obstacle (figure 7.5 D).

For overpasses crossing motorways or other roads located in a deep rock cut, single-span arch, quasi-arch or frame structures of spans 20-50 m are appropriate (figure 7.6 A and 7.6 B).

For overpasses crossing motorways running in a wide cut, an up-to-date scheme of a slender transparent cable-stayed single-span superstructure of 40-100 m is also feasible (figure 7.6 C).

For ever pass superstructures it is economically to design reinforced concrete for spans up to 15 m (18 m) and pre-stressed reinforced concrete for spans up to 30 m (40 cm). For overpasses of spans longer than 40 m, beside pre-stressed concrete, composite steel – concrete structures are competitive as well.

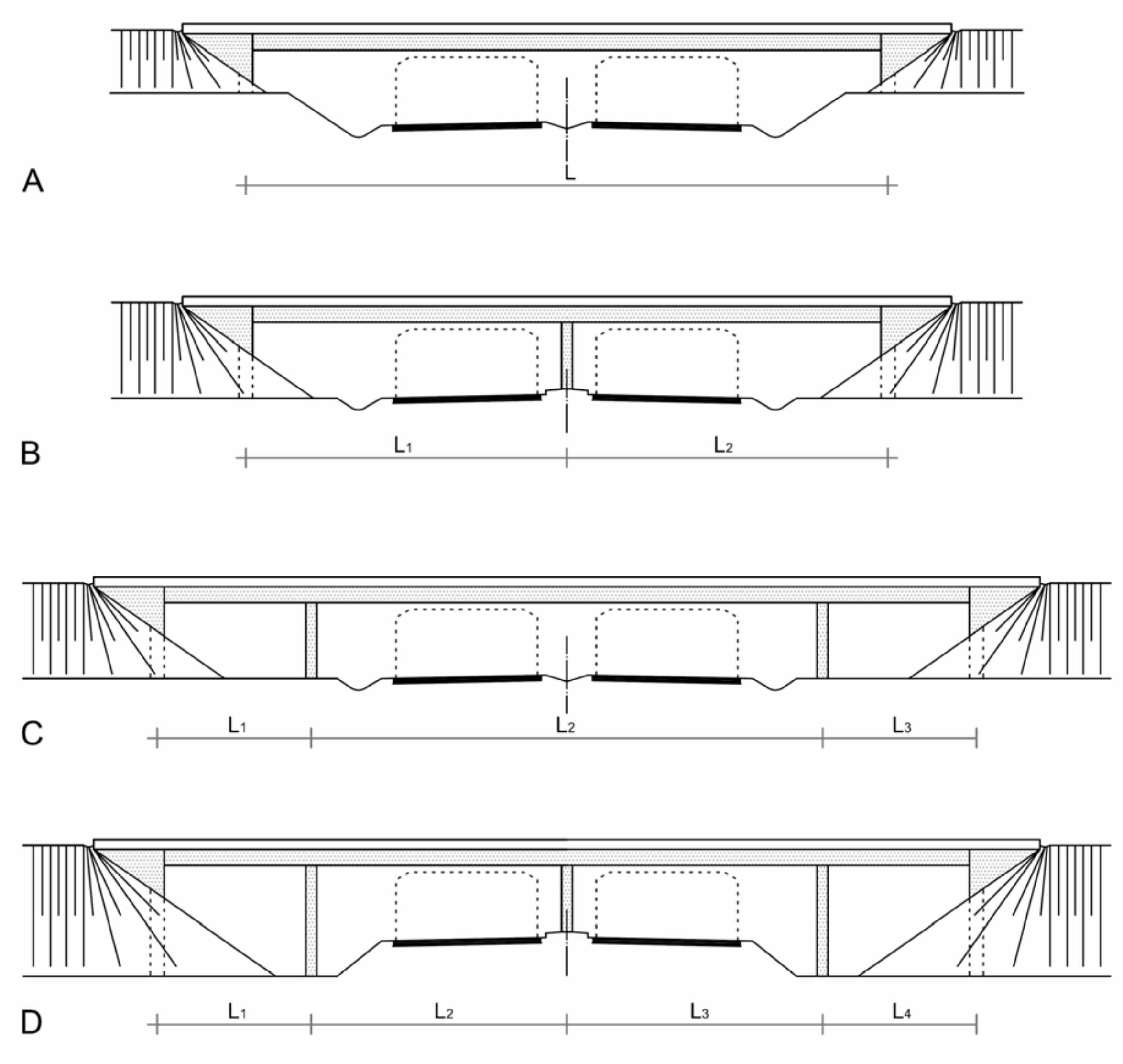


Figure 7.5: Possible schemes of overpasses where a motorway runs on a flat ground

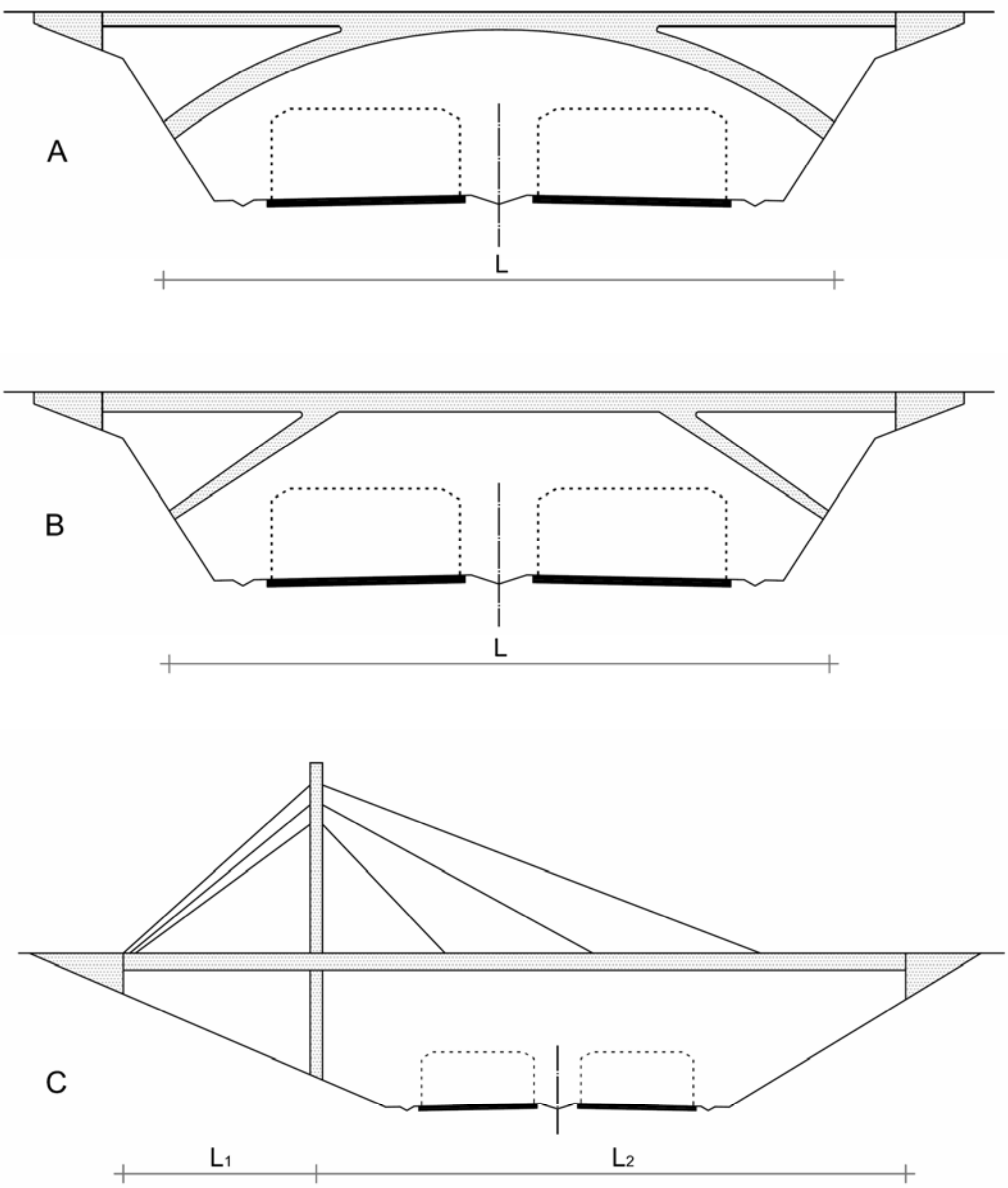


Figure 7.6: Possible schemes of overpasses where a motorway runs in a cut

8. RELIABILITY AND SERVICE LIFE OF BRIDGES

Reliability and service life of bridges are extremely important features. In the present design standard only basic items are indicated.

The term reliability unites safety (load bearing capacity, serviceability, fatigue resistance) and durability.

Structural safety is enabled by both the ultimate limit state and serviceability limit state verification as well as by the fatigue verification.

The ultimate limit state is based on the equation $R \geq S \cdot \gamma$ proving that the structural resistance is greater than the effects of external actions multiplied by the overall safety factor γ.

Structural serviceability is verified by limiting the deformations, vibrations and cracks.
Fatigue is well defined and can be verified for steel, composite concrete-steel, and partly for reinforced concrete as well as pre-stressed reinforced concrete structures. It is absolutely sure that the fatigue is increased by reducing the dead weight with regard to the live load, by increasing the deformations and vibrations, as well as by occurrence and growth of cracks.

Service life can be denoted as the time in which a bridge, within certain limits, retains all the fundamental design properties: bearing capacity, serviceability and purpose.

Bridge reliability (safety and durability) decreases during the bridge operation as a consequence of expected and accidental phenomena such as structural characteristics, quality of materials, maintenance effects, traffic loading effects, and environmental impact.

Due to a more profound knowledge of materials, in particular of the concrete, different investigations are being carried through for the present that essentially influence the bridge durability. Several phenomena are known causing material decaying. The investigations shall indicate a model applicable to calculate the service life of a reinforced concrete structure. Such calculation shall be a constituent part o the bridge design. However, research works and models for the calculation of the service life of reinforced concrete structures cannot be directly applied to bridges not only due to the material, but also because of a significant and interactive function, fatigue, and effects of the characteristics of the entire bridge structure.
For road bridges a service life of 80 to 120 years can be realistically requested, designed and realized, depending on the bridge type and the conditions of use.

For bridges on non-categorized, local and regional roads a service life of 80 years is realistic, since the period of expected use is usually shorter.
For bridges on motorway and main roads a service life of 100 years is expected as it also applies to the road itself.

For larger bridges, particularly urban bridges and bridges on strategically important road sections, a claim for a service life of 120 years is justified.
A normative determining of the bridge service life refers to the bridge superstructure and partially to the piers, depending on the static system and the structural scheme of a bridge.

For bridge equipment 20-25 years of service life can be expected. A timely replacement and reconstruction of the equipment affect the service life of the superstructure as well.

- **Safety and durability create reliability of bridges**

– ***Safety***

Load bearing capacity: Categories specified in accordance with the limit state theory.

Serviceability is ensured by limiting deformations, vibrations, cracks, as well as by the quality of materials.
Fatigue: By the fatigue resistance verification it shall be shown that the fatigue has no adverse effects on the required bearing capacity.

– ***Durability***

Durability is defined as the time in which a bridge retains all the designed properties.

Structural properties:

Structural scheme
Structural details
Selection of materials
Construction technology
Equipment and dewatering
Protection and maintenance

Quality of materials (concrete)
Water/cement ratio
Quantity and type of cement
Quality and type of aggregate
Proper use of additives
Protective concrete cover and treatment of concrete
Porosity and permeability
All the materials affect the durability.
Main reasons of concrete decaying:

Deficiencies in concrete composition
Corrosion of steel reinforcement
Harmful chemical actions
Damage due to freeze
Inner reactions in the concrete
Restraining of displacements
Mechanical damage
Cracks

Effects of maintenance:

So far existing cognition to be taken into consideration.
Means for maintenance and repair
Bridge information system
Regular inspection
Investment maintenance
Due repairs and reconstructions

Effects of traffic loading:

Limitation of axle loads
Ratio dead weight to traffic load
Exceptional loads
High speeds
Mechanical damage
Fatigue

Environmental impact:

Atmospheric action
Chemical aggressiveness
Strewing of salt
Freezing
Temperature effects

- **Participants influencing the road bridge reliability**

Investor:

Design specification
Preparation and revision of basic documents
Selection of designer and contractor
Revision of design
Realistic price and realistic construction time schedule

Structural designer:

Proper use of basic documents
Adequate scheme
Correct static analysis
Selection of materials
Detailing
Selection of equipment
Maintenance design

Contractor:

Staff of sufficient technical experience
Up-to-date equipment, machinery and technology
Preparation and organisation
Internal control
Accurate and consistent elaboration of the as-built design

Supervising engineer:

Staff of sufficient technical experience
Control of materials built in
Control of equipment and technology
Control of construction conditions
Control of dimensions
Accurate and consistent supervision of elaboration of the as-built design

Maintenance:

Establishing of the bridge management system
1-2% of the bridge value to be foreseen annually for regular maintenance and rehabilitation
Due inspections
Regular maintenance and prevention of potential damage
Timely and quality repair and reconstruction

9. AESTHETICAL ASPECTS OF BRIDGE DESIGN

A bridge is a composition of morphological-geological particularities of the environment, civil engineering structures, purposes, materials, shaping, construction method, safety, durability, economy, and incorporation into the surroundings and/or into the urban space.

The aesthetic mission of a bridge, constructed faultlessly with regard to the composition, can only be successful in case of mental and professional maturity of the structural designer.

Endeavours to create beautiful bridges are permanently present in the bridge construction history and are as old as the bridges.

The public viewpoint related to bridges has changed in the course of time. In the middle ages stone bridges represented a kind of monumental structures being a symbol of that time and of a longest duration possible.

More than 200 years ago, introducing the steel as material and developing the structural theory, bridges commenced to be considered as static structures of a clear load transfer.

At the beginning of the twentieth century concrete became competitive. In the middle of the century it was already considered as the most important material for bridge construction.

On up-to-date roads, particularly motorways, a great number of bridges, viaducts, overpasses and other structures to cross natural and artificial obstacles as well as to create out-of-level crossroads can be found.

A major concentration of bridges handicaps the environment, therefore aesthetical design aspects and a harmonized incorporation into the rural and urban space are of extreme importance.

When a bridge is being designed, the structural designer is the leading engineer, meaning that not only a functional and reliable (safe and durable) but also a harmonized and aesthetical civil engineering structure is achieved, unaided or in cooperation with an architect.

An arrangement scheme of a bridge (in particular a selection of the load bearing system) results from the study of the bridge function, morphology of the obstacle, geological properties of the ground, road geometry, utilization of the ground in the bridge area, material properties, available construction methods and many other important factors, arising from the bases for designs.

For the selected load bearing system (beam, frame, arch, suspension, etc.) spans, total length and pier arrangement are specified, structural material selected, and possible construction methods indicated. The fundamental dispositional elements enable an analysis and a design of alternatives of bridge superstructure cross-sections. When a bridge superstructure is designed well and correctly, it is usually logically and harmonically shaped as well.

Shaping of bridges is not an independent objective neither it can be considered apart from the load bearing structure. The fundamental principles of the bridge aesthetics are the following:

- selection of a suitable form of the basic load bearing system of a bridge;
- harmonized proportions of individual elements as well as of the bridge as a whole;
- simplicity of forms and functionality of both the individual elements and the bridge as a whole;
- statically fair structure;
- quality of executed works and colour of visible surfaces;
- harmonized incorporation of the bridge into the natural or urban environment.

10. LOAD BEARING SYSTEMS OF BRIDGES

Bridges can be classified by different criteria: purpose, material, location, position with regard to the obstacle etc. For the structural design, static analysis and operation, the most important classification of bridges is based on their load bearing systems.
In view of structural scheme, shape, taking and transmitting of forces to the bearing ground, five basic types of load bearing systems can be distinguished:

- beam systems
- frame systems
- arch systems
- suspension systems
- cable-stayed systems.

10.1 Beam bridges

The basic characteristic of beam bridges is the separation of the superstructure from the substructure. Loads are transmitted from the superstructure to the substructure via bearings.
The superstructure cross-section depends on the span lengths, disposable construction depth and geometrical relations.

With regard to the static model beam bridges can be statically determinate or statically indeterminate structures.
Beam bridges can be constructed of any material (timber, reinforced concrete, pre-stressed reinforced concrete, steel, or composite concrete – steel) except stone.

A beam resting on two supports is the most employable system for smaller bridges of any material. By an increased application of pre-stressed reinforced concrete and composite steel – concrete, the limits of economical use of a beam resting on two supports have essentially changed. A deficiency of the system of one beam on two supports is the necessity of bearings and expansion joints, which increases the construction and maintenance costs thus favouring frame systems.

A beam with cantilevers with or without a counter-load is a suitable system for urban bridges as well as for bridges on both local and regional roads.

A system of simply supported beams with or without expansion joints above piers has been employed for pre-stressed reinforced concrete systems of a major number of spans for a long time. Damages above piers caused by water action have led to omission of expansion joints and to creation of continuous superstructures to take live loads.

A system comprising hinges is known under the name “Gerber’s beam” and has been typical of the era of reinforced concrete and steel bridges from the twenties to the fifties of the 20^{th} century. In the up-to-date bridge construction such systems are designed only exceptionally.

Statically indeterminate systems such as beam bridges consisting of two, three or more spans are most frequently designed systems of all the materials available. The span lengths as well as the span ratios depend on the morphology, particularly on the obstacle height, on the foundation conditions, and on the construction method. The most important advantage of continuous systems is based on the fact that expansion joints on very long bridge superstructures can be avoided. The number of spans is unlimited.

10.2 Frame bridges

A frame load bearing structure is created when a superstructure is connected with supports rigidly or via a hinge.
Single-span frame bridges with or without hinges are very economical for spans of 5-60 m in reinforced or pre-stressed reinforced concrete. A frame system is more convenient as a single-span beam system, since the entire frame system takes the ground pressures. Bearings and expansion joints are not required. The maintenance of such bridges is simpler and more economical. By rigid linkage of the superstructure and abutments the superstructure moments and thus the construction depth are reduced. Modifying the moments of inertia along the span, the field moments can be additionally diminished and a pleasant visual effect achieved.

A closed frame is a primary system of an opening of 2-5 m, and for minor reinforced concrete bridges and underpasses of an opening of 5-8 m to be constructed on a soil of poor bearing capacity. An advantage of this system is a good and balanced distribution of actions as well as an adaptation to settlements.

Frame systems comprising braces and inclined supports enable longer spans as well as a combination of a pre-cast and a monolithic construction. They are suitable to overpasses and bridges made in reinforced concrete or pre-stressed reinforced concrete, in steel or composite steel-concrete material. Cantilevers with braces and inclined piers reduce field moments and consequently the construction depth of the superstructure cross-section as well.

Frame structures consisting of two or more spans and of vertical supports are very frequent in the up-to-date bridge construction, particularly in reinforced concrete and pre-stressed reinforced concrete. In case of multiple-span structures the connection superstructure-substructure can be either rigid or via hinges or bearings depending on the bridge total length, span length, deviation of system symmetry axis etc., so that these systems are more or less similar to the continuous beam systems. By an adequate combination of a rigid connection, hinges and bearings the designer can significantly influence the bridge economy.

10.3 Arch bridges

Arches are bearing systems especially for bridges across rivers and viaducts over deep valleys with steep hilly slopes. Forces can be taken from the arch base without any settlement.

The durability of ancient arch stone bridges is almost unlimited.
An arch axis shaped according to the dead weight pressure line is the most appropriate bearing system for stone and concrete, i.e. materials of high compressive strength and low tensile strength.
Up-to-date arch bridges are constructed of reinforced concrete, steel or composite steel-concrete cross-section for spans of 40-100 m.
Due to the new arch construction methods, particularly cast-in-situ free cantilever construction of long spans, arch bridges have become competitive. The progress in the research of plastic properties of concrete has expanded the limit spans of reinforced concrete arch bridges.

In the modern arch bridges the superstructure above the arch is a beam system, i.e. a cast-in-situ or incremental launched structure. Such methods reduce costs and time of arch bridges of longer spans.

Up-to-date computer software enables the analysis of a 3D-structural model to obtain a realistic stress and strain condition upon interaction of the arch and the superstructure. Arch bridges of longer spans shall be calculated in accordance with the 2nd order theory.

A fixed arch has represented a basic system for bridges made of stone, brick and concrete, and has remained a basic system for the reinforced concrete as well.
In stone or brick arches the front walls were webbed or contained relieving openings. In reinforced concrete arches instead of webbed front walls a beam or frame structure above the arch occurs which span was only 5-6 m at first. Later on the span of such pre-stressed reinforced concrete structure above the arch was increased up to 50 m.

An elastically fixed arch of a sickle shape where a harmonized form is enabled by a planned change of the moments of inertia along the span, is an up-to-date way of application of arch reinforced concrete systems of bridges of shorter and medium spans, i.e. of 40-150 m. The arches is linked with the superstructure to a uniform cross-section at approximately central third of the span. The superstructure above the arch includes no piers or only a minimum number of piers.

Systems of continuous reinforced concrete or steel arches have become competitive to bridge broad rivers particularly in towns. To structural designers introducing this system, several possibilities of variations in the design of the span vs. camber of the arch as well as of the arch cross-section vs. piers and abutments are offered.

A double-hinged arch is the fundamental system for steel arch bridges.
Fixed or double-hinged arches with a partially lowered carriageway enable long spans and a favourable relation between the span and the camber of the arch irrespective of the type and shape of the obstacle. Such systems are suitable to shallow obstacles when the position of the vertical alignment is determined.

A beam strengthened with a slender arch, or a slender arch strengthened with a beam, are known as “Langer’s beam”, which is an explicit representative of steel arch bridges of longer spans and limited construction depth crossing rivers and other obstacles. Due to its slenderness the arch is loaded almost entirely with axial force whereas bending is taken by strengthening beam acting as a stay as well. Modern versions of such a system can comprise one arch in the cross-section centre.

10.4 Suspension bridges

Suspension bridges consisting of parabolic load bearing cables, suspension cables, and a stiff deck are systems designed only for road steel bridges of longest spans of 400-2,000 m.

After the cable-stayed bridges of 500 m of length or more had become competitive, the suspension bridges moved towards the longest spans possible.

Suspension bridges with an elastic deck can be interesting and competitive for footbridges, provisional bridges and bridges carrying pipelines of spans of 50-150 m.

The load bearing cable of a suspension bridge is anchored into the ground and takes the entire dead load and live load via deck.
When the suspension cables are vertical, the force in the load bearing cable is constant.
Suspension bridge decks shall be calculated in accordance with the 2^{nd} order theory. Since the deck is subject to vibrations, it shall be dynamically analysed for both wind actions and moving load.

10.5 Cable-stayed bridges

Cable-stayed bridges are systems where the superstructure of variable cross-section and material is suspended to one or two pylons by means of stays.
The modern use of cable-stayed bridges began in 1955. So far this system has become very frequent for bridges of spans of 100-1,000 m.

The development of the cable-stayed system has advanced towards shorter distances between elastic supports and greater number of stays. Such a trend has been a result of the request to construct beam structures not only of steel and composite steel-concrete cross-section (as this was practised in the first decades of the modern application of this system), but also of pre-stressed reinforced concrete.

A greater number of stays arranged in a shape of a harp or a fan can cause that the system is considered as a cantilever one where the carriageway slab is the lower compression flange, whereas the stays represent a cantilever tension flange.

Such a density of stays enables extremely small construction depths, without any risk of flexure due to the traffic load. Moreover, the concrete as material is competitive for short-span bridges as well.
In the longitudinal scheme, cable-stayed systems with a single pylon and those with two or more pylons are known. In both cases the pylons shall be anchored backwards.

Pylons can be steel, composite steel-concrete or reinforced concrete individual columns or frame structures, depending on the bridge span and width, the pylon height, the number of planes as well as aesthetical and other conditions.

The bridge deck can be of different cross-sections. Since a high torsional rigidity is required, the cross-section of the deck is a box in most cases. It is designed in steel for the longest, in steel-concrete for medium, and in pre-stressed reinforced concrete for medium and shorter spans.

Stays consist of parallel wires or strands of high-strength steel. Their special anchorages shall be designed and executed to resist the fatigue perfectly.

Wires and strands are inserted into HDPE sheathings. After tensioning the latter are grouted with cement mortar or other approved material.

It is not appropriate to offer more detailed guidelines related to this system, since the latter is still being developed intensively. Designers can find adequate instructions and information in the latest books and professional dealing with the cable-stayed bridges in detail.

11. CONSTRUCTIVE CONDITIONS OF BRIDGE DESIGN

11.1 Introduction

The constructive conditions of the bridge design shall be stated in a logical sequence of structural planning and designing.
Constructive conditions enable updating and making uniform the bridge design criteria, which has a favourable influence on construction, durability and maintenance.
Constructive conditions relate mainly to reinforced concrete and pre-stressed reinforced concrete beam and frame bridges, since these materials and systems are employed at the most.
A bridge shall not be conceived on the basis of insufficient, incomplete or inaccurate documents.
In the table 11.1, twelve steps of bridge design are indicated.

Bases for design and the design specification are presented in the chapter 4. Herein it is only emphasized that designers have to study the design specification and all the bases for design in detail. They must accentuate all the conditions that have an essential influence on the bridge conception and design. In case that the designer finds out any inconsistencies or contradictions when analysing or, later on, applying the bases for design, he is obliged to inform the investor of this fact in due time.

Table 11.1: Design procedure flow chart

1	BASES FOR DESIGN DG 1.2.1, chapters 4.1 – 4-9	Defines purpose, location, load, gauges and durability of a bridge
2	DESIGN SPECIFICATION DG 1.2.1, chapter 4.10	Spatial – town planning, traffic, geometrical, surveying, geological/geo-mechanical, hydrological/hydro-technical bases
3	STUDY OF BASIC LAYOUT ELEMENTS DG 1.2.1, chapters 5, 6, 7	Vertical alignment, cross falls, clearance gauges below and above the bridge, relation bridge – road, relation bridge – obstacle
4	STUDY OF POSSIBLE SYSTEMS AND DEFINITION OF WUITABLE LOAD BEARING SYSTEM OF A BRIDGE DG 1.2.1, chapter 10	Beam, frame, arch, suspension, cable-stayed static systems of bridge load bearing structure
5	- ANALYSIS OF ALTERNATIVES OF SELECTED SYSTEM - SELECTION OF SPANS AND TOTAL LENGTH OF A BRIDGE	In one or more selected static systems, spans, total length and position of piers are combined
6	ANALYSIS AND DETERMINATION OF BRIDGE LOAD BEARING STRUCTURE MATERIAL DG 1.2.1, chapter 11	Reinforced concrete, pre-stressed concrete, steel, composite cross sections
7	ANALYSIS AND DETERMINATION OF BRIDGE CONSTRUCTION TECHNOLOGY DG 1.2.1, chapter 13	In-situ construction, pre-cast – monolithic methods
8	DESIGN OF BRIDGE CROSS SECTION AND SUPERSTRUCTURE DG 1.2.1, chapter 11.6	Determined in connection with selected material (6), construction technoloy (7), system and span of a bridge (4) and (5)
9	- DESIGN OF BRIDGE ABUTMENTS AND PIERS - STUDY AND DETERMINATION OF FOUNDATION DEPTH AND TYPE DG 1.2.1, chapter 11.7	For the position of abutments and piers specified in (5), the latter are designed depending on (6), (7), and (8); method and solution of foundation are selected: deep, shallow
10	STATIC ANALYSIS OF BRIDGE LOAD BEARING STRUCTURE DG 1.2.1, chapter 12	Critical sections of superstructure, of piers and of their connection with foundation, or bearing capacity of piles, are analysed
11	- BRIDGE EQUIPMENT - SOLUTION OF CONNECTION BETWEEN BRIDGE AND ROAD - SPATIAL ARRANGEMENT AT BRIDGE DG 1.2.1 – DG 1.2.2	Selection of bearings, expansion joints, walkways, edge beams, waterproofing, dewatering. Connection bridge – road body. Spatial arrangement next to bridge.
12	- ANALYSIS OF QUANTITIES AND COSTS OF BRIDGE ALTERNATIVE SOLUTIONS - SELECTION OF ALTERNATIVE	Quantities and costs of main materials for superstructure and piers are analysed 8concrete, reinforcement, tendons, steel, piles), without equipment and other works that are the same for all alternatives

11.2 Selection of load bearing system, span and total length of a bridge

Five basic load-bearing systems of bridges, i.e. beam, frame, arch, suspension, and cable-stayed bridges, are discussed in chapter 10.

The selection of the bridge load bearing system is influenced by the following:
- morphology of the obstacle, ratio length : height below the bridge;
- geological/geo-mechanical ground properties and foundation conditions;
- type of the communication (motorway, main road, regional road, local road, footpath, railway, mixed traffic) and its geometry (vertical alignment, route);
- data indicated in the design specification and in the bases for design (town-planning/spatial conditions, aesthetical design aspects, hydrological/hydro-technical conditions, meteorological data, seismic data);
- information of equipment and capability of potential contractors, of construction period, of time schedule, etc.
- information of current prices (construction, materials, equipment);
- own experience and world literature about similar bridges

For larger bridges and in case of special conditions it is obligatory to elaborate several alternatives of load bearing systems.

For the load bearing system already selected, e.g. beam, frame, arch or cable-stayed or a combination of those systems, two or three alternatives of preliminary schemes are usually elaborated.

For large and significant bridges and viaducts it is mandatory to elaborate two or three alternatives of preliminary design shall be elaborated. It is also possible to obtain suitable solutions by competition.

After the load bearing system is selected, dimensions of individual elements, their interrelations, and the total bridge length shall be determined.

Both the length and the ratio of spans are determined on the basis of internal forces and moments, cross-section dimensions, and material quantities. For beam and frame superstructures the length and the number of spans depend on the ratio of superstructure cost: substructure cost. In the table 11.2 recommendable static systems of beam and frame bridges are presented.

The total length of river bridges depends on the bridge opening required for high-water flows.

For all the bridges it is possible to specify the terminal points of the structure, i.e. the bridge total length, by means of a cost comparison of 1 m of bridge to 1 m of fill.

The abutment height varies within the limits of 5-10 m.

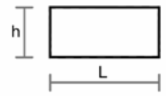
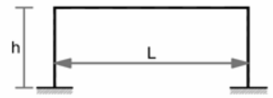
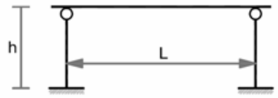
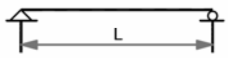
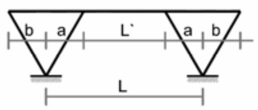
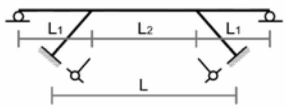
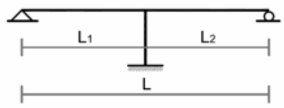
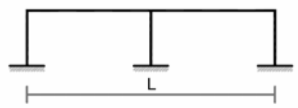
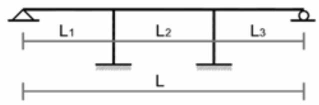
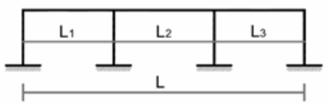
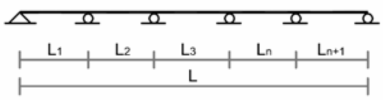
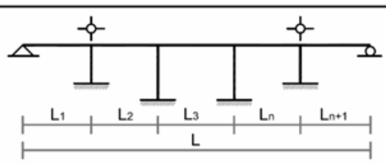
For roads and railways running through settlements or on areas to be populated in the near future or on agricultural land, solutions requiring longer bridges are advantageous. The fill height should not exceed 5-7 m, since the fills represent earth barriers being obstacles to a further urbanisation of the space.

When riverbanks or hill slopes are steep, high abutments with cones shall be avoided, since these are expensive and less stable structures having an adverse effect on appearance of the bridge as well.

By shifting the abutments away from riverbanks local paths can be executed along the river, and the construction of bridge foundations is facilitated.

A cooperation of the bridge designer with the road designer is required when the transition from the bridge to the road is designed. Only in this way the clearance gauge, walls, railings, dewatering, lighting, signalling and construction sequence can be adequately designed.

RECOMMENDABLE STATIC SYSTEMS OF BEAM AND FRAME BRIDGES **TABLE 11.2**

STATIC SYSTEM		DENOMINATION OF STATIC SYSTEM	LIMITS OF RATIONAL SPANS (L in m)	
			REINFORCED CONCRETE	PRE-STRESSED REINFORCED CONCRETE
1		closed frame	2 - 5 (8)	——
2		open frame	5 - 25	20 - 60
3		frame with hinges on top of piers	5 - 15 (20)	——
4		beam on two supports	——	25 - 45
5		frame with triangular piers, supported via hinges or elastically fixed	——	40 - 70
6		three-span frame structure with inclined piers	20 - 35	40 - 150
7		two-span structure	15 - 20	25 - 80
8		two-span frame structure	15 - 25	25 - 80
9		three-span structure	15 - 30	30 - 150
10		three-span frame structure	15 - 30	30 - 60
11		multi-span continuous beam	15 - 30	30 - 150
12		multi-span frame structure	15 - 30	30 - 150

11.3 Achieving of optimum supporting

When conceiving and designing reinforced concrete or pre-stressed reinforced concrete bridges, particularly of beam and frame systems, a rigid connection between the superstructure and the pier shall be foreseen for all or at least for a major part of the supports. A rigid connection is appropriate when effects of deformations due to thermal actions, shrinkage, creep and pre-stressing are of the same order of magnitude as the effects occurring when the superstructure is connected with piers via bearings. The flexural length of piers shall be analysed as well; however it depends on the type of the abovementioned connection. Up-to-date computer programs enable a rapid and complete static analysis of different alternatives of the load bearing structure with the aim of optimising the connection between the superstructure and substructure.

When hinges are indispensable for connection with stiff piers, reinforced concrete hinges shall be considered as the most advantageous. For the connection of reinforced concrete piers with steel or composite steel-concrete superstructure by means of hinges, the latter shall be made of steel. By employing a hinge both flexural length of slender piers and actions on foundations are reduced.

Bearings, hinges or rigid connections at piers and abutments in beam, frame and other systems of bridges shall be adequately arranged to ensure stability, constant position, deformability in all the planes as well as moving capacity in both longitudinal and transversal bridge direction, depending on the bridge length and width, on material, and on environmental climatic conditions.

The decision whether a rigid connection of the superstructure with the substructure or connection via bearings should be foreseen, depends on several factors such as:
- load bearing system of the bridge
- total length of the bridge, number and length of spans
- pier height
- foundation depth, quality of bearing ground, foundation method
- material of both superstructure and substructure.

Three types of supporting of superstructures are known:
- rigid connection
- connection by means of hinges
- tangential or ball-jointed bearings with a full or limited moving capacity.

Rigid connection between superstructure and substructure

A rigid connection can be employed in both abutments and piers. A decision which supports should be connected rigidly depends on several conditions.
A rigid connection takes both flexural and torsional moments as well as both vertical and horizontal forces, depending on the stiffness ratio, and transmits them via piers into the foundation and ground respectively.

Connection or supporting by means of hinges

In view of function in the bridge structure the following can be distinguished:
- tangential supporting by means of hinges
- supporting via hinges in all directions
- supporting by means of ball-jointed bearings.

A tangential supporting by means of hinges enables rotation of the superstructure in one plane, and is usually employed to connect abutments with single-span superstructures and stiff piers with the superstructure where bearings are not recommendable.

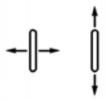
In beam bridges of longer spans the connection via hinges can be foreseen for tall piers where, among others, the flexural length should be reduced.
Supporting via hinges in all directions and supporting by means of ball-jointed bearings is used where rotation of the superstructure in all the planes should be enabled. Ball-jointed bearings are usually made of steel.

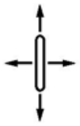
Tangential or ball-jointed bearings

Bridge bearings as elements located between the superstructure and he substructure perform three fundamental functions:
- to take vertical and horizontal reactions from the superstructure and transfer them to piers and abutments;
- to enable deformations of the superstructure;
- to enable superstructure expansion in bridge axis.

To fulfil the abovementioned requirements bridge designers can foresee the following:

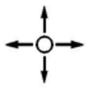
 - fixed tangential bearing

 - tangential bearing free in one direction

 - tangential bearing free in one plane

 - fixed ball-jointed rocker bearing

 - ball-jointed bearing free in one direction

 - ball-jointed bearing free in all directions

 - elastic damper to amortize impacts due to seismic actions

Special design guidelines DG 1.2.6 *Bearing for bridges* serving to select and design the bearings has been issued. Moreover, the European standard *EN 1337-3-10 Structural bearings* shall be taken into consideration as well.

11.4 Integral bridges

Integral bridge is an up-to-date term for concrete bridge consisting of frame structure without expansion joints and bearings. The integral bridges are constructed monolithically, and the dimensions of structural load bearing elements are more abundant. Damages of such bridges are less intensive due to elimination of the main sources of damages, discontinuity areas, expansion joints and bearing zones. The maintenance costs are lower while the traffic is safer. Frame structures contain system reserves in load distribution and static actions.

When an integral bridge is conceived, dimensional disproportions are not welcome in order to avoid concentration of stresses and cracks. For structural elements of bridges that deteriorate faster, possibility of replacement must be ensured.

Designing bridges in accordance with rules and codes is not a sufficient guaranty for a good and durable bridge. A correct conception is required taking into consideration experiences of modern practice and return information from bridge maintenance and management.

Integral frame bridges are not recommendable for oblique structures when the angle of obliqueness amounts less then 30°, as well as for longer structures supported by low and rigid piers. The interaction bridge – foundation soil is an essential component of behaviour of an integral structure with respect to deformation and load bearing capacity. Therefore, a good cooperation of structural designer and soil mechanics expert is required for determination of realistic soil mechanical parameters.

A great number of bridges and viaducts have a transversal discontinuity above piers. (Figure 11.1)

A relatively simple and rational technology of production and erection of main girders of 15-40 meters of length was uncritically used from 1950 to 1990. Twenty to thirty years after construction deficiencies of such structures appeared. Due to that reason and because of damaged equipment, their rehabilitation was required.

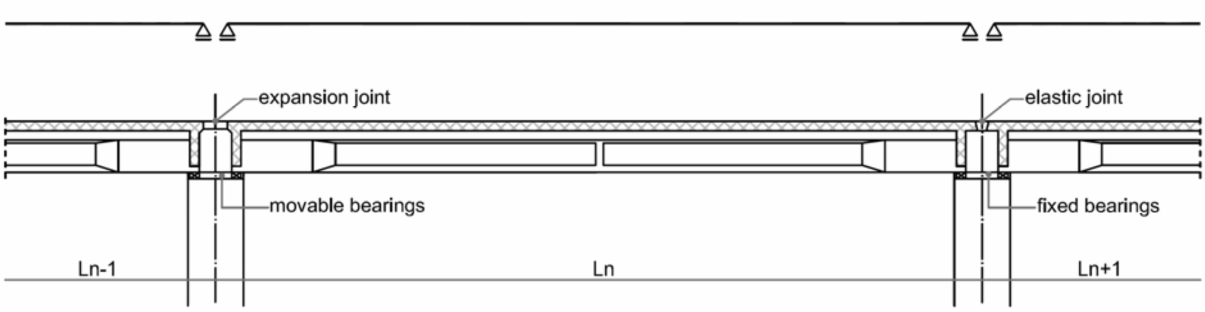


Figure 11.1: Scheme of discontinuity of pre-stressed reinforced concrete bridges

In many European countries discontinuous bridge systems are prohibited. Therefore only continuous superstructures along their entire length up to 3 kilometres and more are designed and constructed having expansion joints only above abutments and integral bridges of a total length up to 80m.

Integral bridges without bearings and expansion joints follow the modern trends in bridge construction with an aim to build more durable bridges and to reduce the construction and maintenance costs. The static systems of integral bridges consisting on one or more spasm are shown in table 11.2 (static system 1, 2, 5, 8, 10, 12).
In practice, the most used static systems are closed frame for culverts and minor structures of spans up to 8 meters, frames with one span of 5-40 meters, and frames with two three and more spans of a total length up to 70 meters.

Integral bridges are advantageous for the following reasons:
- Lower construction costs,
- Lower maintenance and repair costs as such bridges do not comprise elements, which require an intensive maintenance,
- Simplified and more rapid construction as there are no bearings and expansion joints, which require extremely strict building-in tolerances and an exact sequence of placing,
- Higher level of travel comfort,
- Permanent and maintenance independent prevention of direct access of de-icing salt to structural members below carriageway,
- Reduced hazard of differential settlements and lateral deviations of piers,
- Equalization of eventual superstructure lifting forces by abutment dead weight,
- In case of three-span decks, shorter end spans allow design of a larger central span,
- Higher load bearing capacity reserves due to possible redistribution of internal forces and moments at the ultimate limit state.

The magnitude of occurring constraints depends to a great extent on the structural geometry, on the ratios of superstructure stiffness to pier stiffness, as well as on the foundation soil stiffness. It is of an essential importance that modelling of stiffness of both structure and foundation soil is realistic, so that actual internal forces and moments are comprehended by means of the design model. If a too low value of foundation soil stiffness is assumed, the constraints, which are a consequence of both thermal action and pre-stressing, will be underestimated. Therefore, in case of integral bridges, it is generally required to carry out two independent calculations of constrained forced and moments, taking account upper and lower limiting values of soil characteristics.

Omission of a monolithic connection between abutment and superstructure is reasonable where constraints due to the mobilized earth pressure and due to an extremely stiff foundation can be mastered with difficulty only. When only piers are connected monolithically with the superstructure, a semi-integral bridge is in question.

Figure 11.2 shows a scheme of pre-stressed reinforced concrete frame structure of an overpass of spans of 30-50 meters across motorway. A characteristic feature is the widening on the top of the piers to avoid collision of the frame reinforcement and the anchoring zone of the deck tendons.

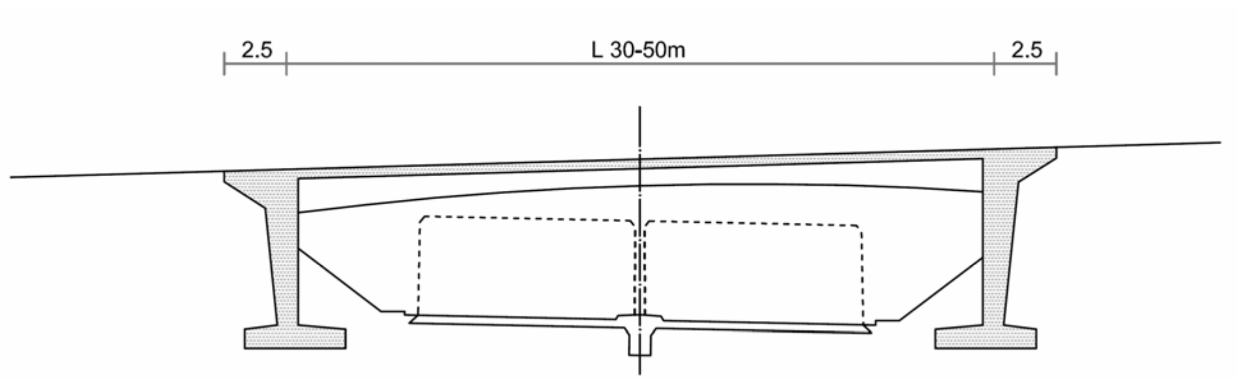


Figure 11.2

In figure 11.3 a scheme of an integral arch structure of an overpass with an arch span of 35-70 meters running over motorway is shown.

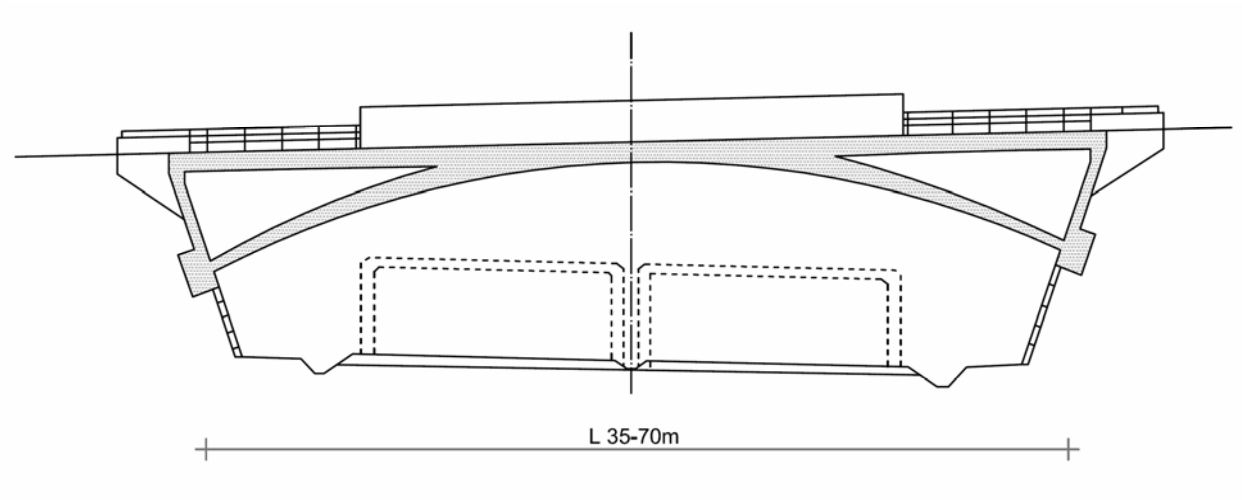


Figure 11.3

Figure 11.4 shows a scheme of pre-stressed reinforced concrete integral frame overpass structures of four spans of a total length up to 70 meters without bearings and expansion joints. At the contact of the transition slab and the overpass structure it is necessary to foresee a joint of 1-2 centimetres to be filled up with asphalt mixture in order to prevent uncontrolled crack in the asphalt layer or asphalt expansion joint.

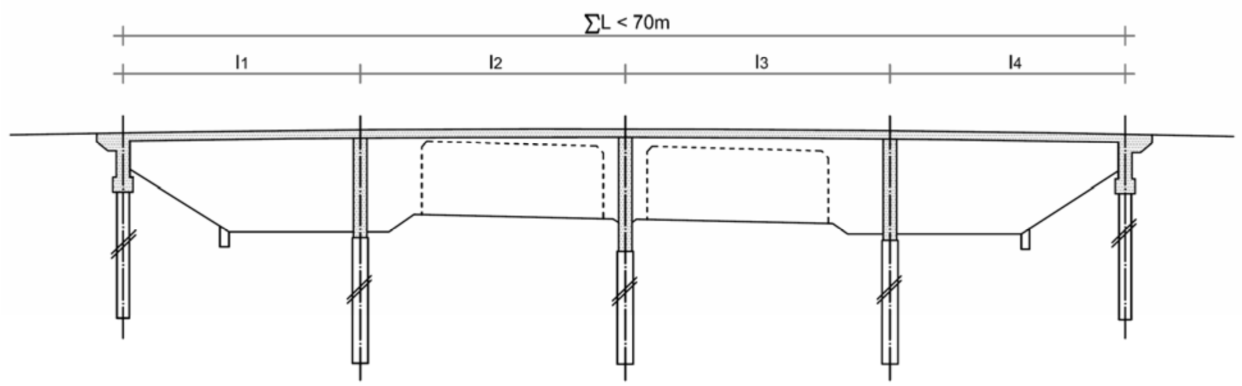


Figure 11.4

11.5 Selection of materials for bridge load bearing structures

Bridge load bearing structures can be made of timber, stone, concrete, steel or a combination of those materials (composite cross-section), mainly steel-concrete. Composite concrete-concrete structures, where the quality and age of one concrete differs from those of another on, are also possible.

Up to the thirties of the 20^{th} century timber was also used in bridge construction. However, it has been fully replaced by steel and concrete, in particular for bridges on public roads. Nowadays, timber bridges are designed especially for pedestrians and cyclists. Instead of timber beams glued laminated girders are employed, particularly for longer spans.

Stone is no longer competitive for construction of new bridges. However, it was about a millennium the main material to build bridges, viaducts and aqueducts of short, medium and longer spans up to 90 m.

Nowadays, stone is used to renew, repair and reconstruct the existing stone bridges, or a material to line concrete surfaces. Prior to design a stone bridge, the designer shall be convinced to be familiar with all the mechanical, petrographic and other properties as well as with the surface treatment and building methods, which is partly discussed in the design guidelines DG 1.2.10 Formwork, finishing and facing of concrete surfaces.

Steel has been used for bridge bearing structures for more than to centuries. Nowadays, beside concrete, steel is the leading material in bridge construction. For bridge superstructures structural steel of a yield point of 220-360 N/mm^2 is employed. Symbols and properties of the steel are indicated in the EC 3.

The most employable material in the entire field of construction is concrete. Nowadays, more than 80% of bridges are made of concrete, because of inexhaustible resources of raw materials for concrete production, of advanced concrete production and casting processes, of relatively low labour costs, as well as of increasingly successful application of both reinforced concrete and pre-stressed reinforced concrete.

For bridge load bearing structure concrete MB30(C25/30) to MB50(C40/50) in accordance with the EN 206-1 shall be designed.

Steel for reinforced concrete according EN 10080 have three classes. S220 for plain bars and S400, S500 for high bond bars.

For bridge structures waterproof concrete resistant to chemical and other actions in accordance with the EN 206 are wished-for.

For structures (culverts) or parts of abutments and piers in contact with soil, in ground water or in streaming water, protection can be achieved either by application of waterproofing layers or by introducing a waterproof concrete.

Structures located in the ground water can be protected either by application of waterproofing layers or by introducing a waterproof concrete. Since the elements made of a waterproof concrete have a sealing function as well, they are quite advantageous in view of construction technology and time.

The essential measures to ensure employability, i.e. impermeableness of the so-called white tubs are the following:

- constructive measures (crack limitation, construction joints, expansion joints, foreseen locations of cracks);
- adequate concrete-technological measures;
- a thorough execution including a suitable and sufficiently long-lasting treatment of new concrete.

When waterproof concrete is foreseen, cracks shall be limited from 0.25 m to 0.20 mm and 0.10 mm in seawater and aggressive environment respectively.

For bridge piers freeze resistant concrete MB30(C25/30) to MB40(C35/40) shall be designed.

For massive abutments, foundation footings and foundation blocks concrete C 25/30 shall be foreseen.

The designer has an opportunity to choose among reinforced concrete, pre-stressed reinforced concrete, and composite steel-concrete cross-section.

For spans up to 15 (20) m, reinforced concrete is the most appropriate material.

For spans from 15 (20) m to approx. 60 m pre-stressed reinforced concrete is the most competitive material.

For spans longer than 60 m, depending on a series of other parameters, beside pre-stressed reinforced concrete, a composite steel-concrete cross-section can be competitive as well.

For spans longer than 120 (150) m, beside pre-stressed reinforced concrete and composite steel-concrete cross-section, steel with an orthotropic carriageway slab becomes competitive as well.

When analysing possible materials for bridge superstructures, in particular for long spans, the following parameters shall be considered too: construction time, bridge location, conditions of bridge construction, as well as the durability and maintenance costs.

For large and extremely significant bridges and viaducts alternative solutions with regard to the selection of materials shall be elaborated.

11.6 Analysis and selection of construction method

The bridge superstructure construction method is determined by material, span length, bridge length (area), road geometry as well as morphology and largeness of the obstacle.

Reinforced concrete road bridges are usually constructed by means of a fixed steel falsework.

Pre-stressed reinforced concrete bridges can be constructed according to the methods indicated in the chapter 13, which offers, together with the knowledge and experience of structural designer, rough information in view of selection of the most suitable construction technology. When making a decision on the method of constructing major bridges or a group of bridges, equipment owned by potential contractors or being available to them as well as the market situation shall be taken into account.

Pre-stressed reinforced concrete bridges of spans up to 30 m and of a total length up to 150 m, in particular if they are oblique and geometrically complicated, can be economically built by means of a fixed falsework in one or more stages.

For equal spans of 25-40 m, when a bridge is straight or runs in a curve of major radius, the method using pre-cast T-beams and a monolithic composite reinforced concrete slab is competitive.

Pre-stressed reinforced concrete bridges of spans longer than 30 m and of a total length of 150 to 800 m can be executed by different methods, depending on a series of factors that cannot be explicitly presented. They are partly indicated in the chapter 13. A correct choice of the construction technology is the most essential element of competitiveness of a bridge design.

Steel structure of composite steel-concrete bridges is always erected, in most cases after the incremental launching procedure is completed. When the span lengths do not exceed 50 m, the steel structure alone can withstand stresses occurring during the erection. Are the spans longer than 50 m, a steel nose or a pylon with stays shall be introduced. The carriageway slab of composite steel-concrete cross-section is cast in situ on a fixed or a mobile false work.

Steel superstructures of bridges can be erected by incremental launching method using a steel nose or a pylon with stays or by a cast-in-situ free cantilever method where the access is ensured either below the bridge or on the bridge portion already executed.

The selection of the pier construction method depends on the height, the number and the cross-section of piers.

The selection of arch bridge construction method is indicated in the chapter 13.

The selection of the cable-stayed bridge construction is specific and requires a detailed analysis in accordance with the complete structural scheme and the selection of material for the execution of the superstructure cross-section.

11.7 Bridge cross section design

11.7.1 General

For the selected load bearing system, span lengths, material and construction technology the cross-section of the bridge superstructure, which is the most important element of the entire bridge load bearing structure, is designed.

By the bridge cross-section design the conditions of the road geometry (width, clearance gauges, cross-falls) are fulfilled, the load bearing capacity, serviceability and traffic safety ensured, and proper drainage of precipitation water enabled.

The shape and design of the cross-section have an essential influence on the construction technology (that relation is valid vice versa as well) and on the conditions of maintenance, reconstruction and durability of a bridge.

The bridge cross-section design shall avoid confined spaces being inaccessible for normal maintenance, as well as cross-section parts where precipitation water can be accumulated.

The bridge cross-section design shall be carried through taking into account the drainage and piping of bridges and maintenance equipment.

11.7.2 Cross section reinforced concrete and pre-stressed reinforced concrete bridges

In the table 11.3 five recommendable cross-sections of bridge superstructures of reinforced concrete and pre-stressed reinforced concrete beam and frame systems are presented. These cross-sections are substantially advantageous in view of construction, maintenance and durability.
For the solid slab cross-sections, the thickness is limited to 100 (120) cm. In this way the bridge dead weight is limited as well. The free edges can be designed in three ways depending on the thickness. The bridge spans are limited to 20 metres and 30 m for pre-stressed reinforced concrete bridges and frame systems respectively.

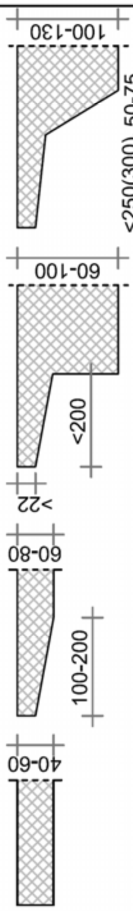
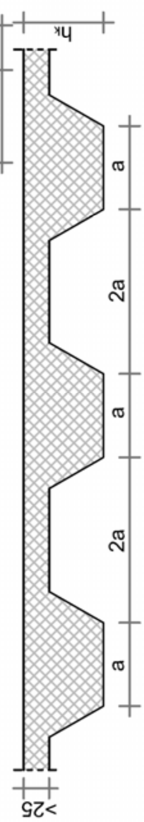
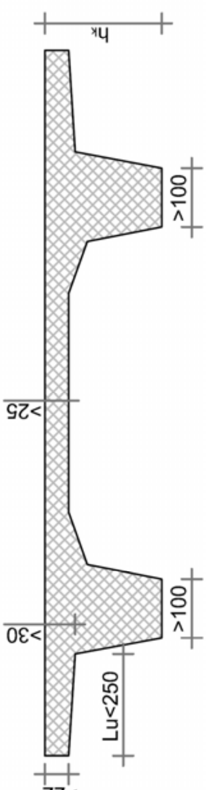
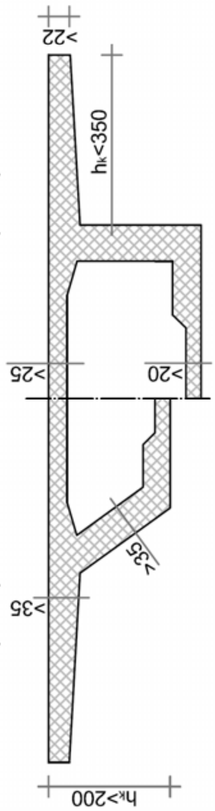
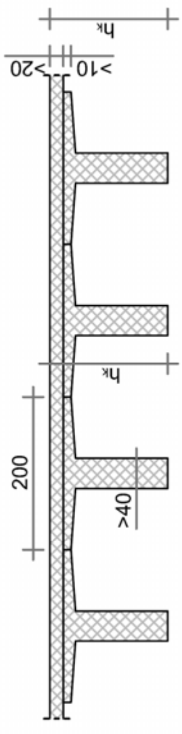
Simply supported reinforced concrete slabs can be executed up to a maximum span of approximately 12 m, whereas the spans of the pre-stressed concrete slabs can amount up to approximately 20 m.
Wide slab trapezoidal girders of width “a” and of spacing “2a” enable a reduction of the dead weight by 30 to 40 % in comparison with a solid slab. Therefore their spans can be extended up to 25 m or 35 m for frame and continuous systems. For simply supported systems in reinforced concrete a span length of 15 m is economical, whereas it can amount to 25 m for pre-stressed reinforced concrete systems. The considered cross-section is favourable to oblique bridges because the elastic slabs between girders do not transfer transversal forces.

Openings in cross-sections can be used for placing cables, drainage pipes and other installations. The slab between the wide trapezoidal girders must be thicker than 25 cm. Usually, it is without voutes, which simplifies the formwork. The slab girders must be arranged in such a way that the dewatering pipes do not pass through the girder. When the walkways are wide enough, the drainage pipe can be placed on the outer side of the girder as well.
Cross-sections with two wider girders without cross beams is an advanced section of usual beam reinforced concrete bridges. Omitting cross beams the construction becomes much easier. The wider main girders with inclined sides are connected with a thick slab of t $\geq$ 25 cm, capable to take the load in one direction. In this way, torsional forces due to unsymmetrical loading can be taken. A greater thickness of girders at their bottom (minimum 100 cm) enables a good arrangement of reinforcement and tendons. The cantilevering elements should not be longer than 2.5 m. The pipes of the gullies must not endanger the main girders. The considered cross-section is rational for spans between 30 and 45 metres for continuous and frame reinforced concrete and pre-stressed bridges. Such a cross section is not recommendable for curved structures of smaller radii.
A single-cell box rectangular or trapezoidal cross-section is the most favourable solution for straight and curved bridges and viaducts of spans over 30 m. In the sketch, limitation for construction depth of minimum 200 cm is presented, in order to enable passing the superstructure during maintenance and reconstruction works. Moreover, limitations of cantilever span, slab thickness and vertical webs are given. The transversal pre-stressing is not desirable. Among all those cross-sections, the box section has the smallest outer surface exposed to the atmospheric action, which is essential for the maintenance costs. The box section is the most convenient for the incremental launching, segmental, and cast-in-situ free cantilever construction method for bridge superstructures.

By reducing the width of the lower slab, a reduction of the pier width thus a more aesthetical shaping of the piers is enabled. The cross girders are located above the piers and abutments only, therefore they are usually designed as web and lower slab strengthening, keeping the carriageway slab thickness unchanged (figure 11.1).
In the span, cross girders are not necessary. At abutments, the cross girders have to be placed onto the parts of the cross-section below the cantilevers as well (figure 11.2).
A cross-section of “n” pre-cast, pre-stressed concrete T-beams with wide upper flanges is reasonable for spans between 10 and 30 m. At the same time, the upper flange serves as a formwork for the monolithic carriageway slab of thickness above 20 cm. The cross girders are located above the piers and abutments only. By means of cross girders and a monolithic carriageway slab, a composite continuous or frame system is established behaving as a a continuous or frame structure during the operation. The continuity is achieved with passive reinforcement or with tendons for continuity.

The web of an increased thickness is stable and enables sufficient space to place the reinforcement and tendons. Such a cross-section can also be used for oblique bridges up to an angle of 60°.

TABLE 11.3

Cross-section type	Cross-section of road bridges	Reinforced concrete: Spans* Lu(m)	Reinforced concrete: Construction depth $h_k=l/u$	Pre-stressed reinforced concrete: Spans* Lu(m)	Pre-stressed reinforced concrete: Construction depth $h_k=l/u$
Solid slab		5-15(20)	$\sim\frac{1}{15}$	15-30	$\frac{1}{15-20}$
Wide slab girders		10-25	$\sim\frac{1}{15}$	20-35	$\frac{1}{15-20}$
Cross-section of two wider girders without cross-girders		15-30	$\sim\frac{1}{12}$	25-45	$\frac{1}{14-16}$
Box cross-section		25-35	$\sim\frac{1}{12}$	>30	$\frac{1}{12-20}$
Cross-section of pre-cast T-girders composite with monolithic reinforced concrete slab		—	—	10-35	$\frac{1}{10-20}$

** For continuous and frame structures l = distance between zero points*

For continuous and frame bridges of variable cross-section depth other ratios span to construction depth are possible as well, on condition that deformations and vibrations are verified.

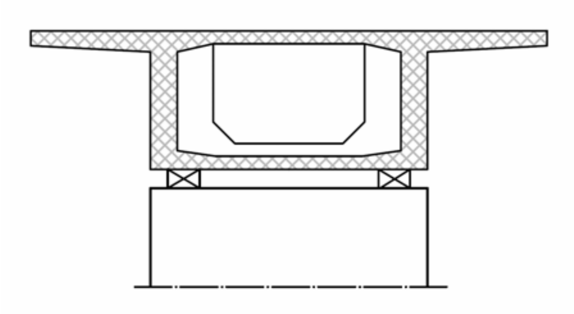


Figure 11.5

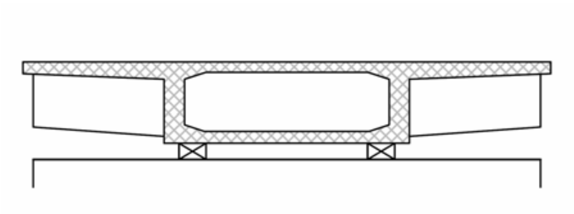


Figure 11.6

11.7.3 Cross section of composite and steel bridges

In the table 11.4, up-to-date characteristic cross sections of steel and composite beam systems of bridges are presented.

The cross section No. 1 is the most frequent cross section in Europe for composite structures of one or more spans for bridges of 8 to 14 m in width. The cross section is economical and simple for fabrication and erection. The height of main girders is constant or variable in straight lines or curves of greater diameters. The carriageway slab being cross reinforced is cast in situ and via dowels connected with a steel grid of main and cross girders.

The cross section No. 2, which can be a closed box rectangular, trapezoidal or trough shaped cross section, is economical for longer spans where more steel is required for the lower flange. An adequate stiffness can be achieved by means of webbed or truss cross frames. This type of cross section is also favourable to bridges running in curvatures of smaller radii since it proves a significant torsional rigidity. its height can be either constant or variable. Prefabricated segments of 5 to 10 m in length are erected onto the already constructed part of the structure by means of free cantilevering. The erection method depends on accessibillity (water, land) and available equipment.

The cross section No. 3 consists of lowered carriageway cross girders. It is suitable to bridges where only a limited construction depth is available.

The cross section No. 4 consists of two composite steel truss beams with a slab on the upper flange.

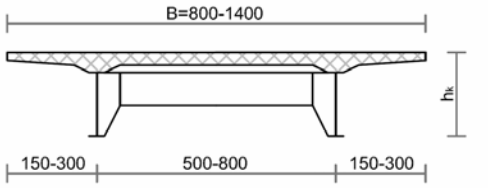
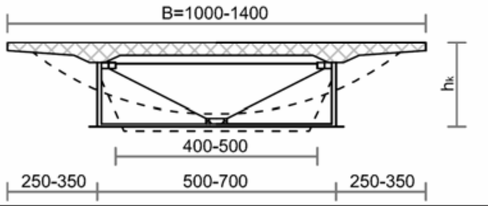
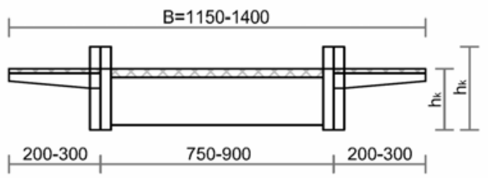
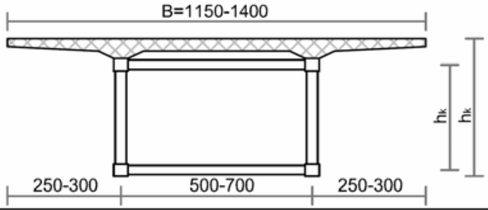
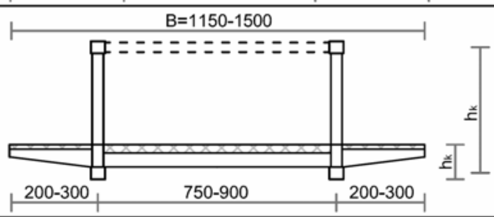
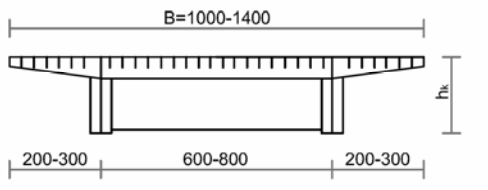
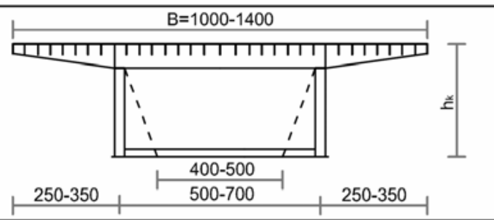
The cross section No. 5 comprises composite carriageway beams.

Composite truss beams have still been developed, in particular in France and Germany, since eighties till nowadays. They are used for railway and road bridges of long spans where a great stiffness of the beam is required which is particularly essential in case of high-peed trains.

The steel cross sections No. 6 and No. 7 are open, consisting either of two main girders (No. 6) or of a box (No. 7), closed by an orthotropic carriageway slab. They are economical for long and very long spans. The dead weight of the superstructure is small and the construction quick. The cross section elements are completed on site prior to erection. They are erected by means of incremental launching, cable cranes, Derrick cranes, floating cranes or mobile cranes.

CHARACTERISTIC CROSS SECTIONS OF COMPOSITE (STEEL - CONCRETE) AND STEEL BRIDGES

TABLE 11.4

CROSS SECTION TYPE	DESCRIPTION OF BRIDGE CROSS SECTION	CROSS SECTION SKETCH	BRIDGE SPAN L IN m CONSTRUCTION DEPTH h_k		SOME ESSENTIAL PROPERTIES OF BRIDGE CROSS SECTIONS
			SINGLE SPAN BEAMS	CONTINUOUS STRUCTURES	
1	OPEN COMPOSITE CROSS SECTION WITH TWO MAIN GIRDERS		20-40 L/15-25	40-150 L/15-30(45)	FOR BRIDGES IN A STRAIGHT LINE OR IN CURVATURES OF GREATER DIAMETERS
2	CLOSED BOX COMPOSITE CROSS SECTION		30-60 L/15-25	60-200 L/15-30(45)	FOR BRIDGES OF LONG SPANS AND BRIDGES IN CURVATURES
3	STEEL PLATE GIRDERS WITH LOWERED COMPOSITE CARRIAGEWAY		20-50 L/15-25	50-100 L/15-30	FOR BRIDGES OF LIMITED CONSTRUCTION DEPTH
4	CROSS SECTION WITH COMPOSITE TRUSS BEAMS		40-100 L/10-15	60-200 L/10-30	FOR BRIDGES WITHOUT LIMITATION OF CONSTRUCTION DEPTH
5	STEEL OPEN CROSS SECTION WITH LOWERED COMPOSITE CARRIAGEWAY		40-80 L/10-15	60-150 L/10-30	FOR ROAD AND RAILWAY BRIDGES OF LIMITED CONSTRUCTION DEPTH
6	STEEL OPEN CROSS SECTION WITH ORTHOTROPIC CARRIAGEWAY SLAB		50-80 L/15-25	100-250 L/15-30(45)	BRIDGES OF LONG SPANS IN A STRAIGHT LINE OR IN MODERATE CURVATURES
7	STEEL BOX CROSS SECTION WITH ORTHOTROPIC CARRIAGEWAY SLAB		50-100 L/15-25	100-300 L/15-30(45)	BRIDGES OF THE LONGEST SPANS IN A STRAIGHT LINE AND IN CURVATURES WHERE A SIGNIFICANT TORSIONAL RIGIDITY IS REQUIRED

11.8 Constructive conditions for supports of beam and frame bridges

The shape, structure and dimensions of bridge supports are determined on the basis of the following parameters and their interrelation:

- load bearing system of the bridge (beam, frame, arch, suspension, cable-stayed)
- morphology and type of the obstacle (water, dry or urban obstacle)
- total pier height and the height above the ground
- depth and properties of the foundation soil in which bridge piers are founded
- method of supporting of the superstructure or its connection with the substructure, types of bearings
- number and length of bridge spans
- structural design and entire width of the bridge superstructure cross-section
- selected position of piers in view of bridge general arrangement
- angle of crossing of the bridge axis and the obstacle axis
- interrelations of vertical and horizontal loads on the supports
- material and construction method for the piers
- material and construction method for the superstructure
- harmonic solution of piers in view of the entire bridge (aesthetical design aspects)
- skill, knowledge and experience of bridge structural designers.

Abutment design differs from the pier design basically due to their different functions. In addition to taking loads from the superstructure, abutments also close he fill behind the bridge. Suitable designed abutments simultaneously solve the question of the wing walls. The piers take loading from the superstructure thus their shape and structure shall be symmetrical.

It is wished for that the total abutment height, i.e. the vertical distance between the vertical alignment and the foundation bottom, varies from 5 to 10 m, only exceptionally to 15 m, whereas its total length, i.e. the horizontal distance between the abutment axis and the end of fixed wing walls, should not exceed 10 m.

Within the dimensional limits indicated above gravity or light abutments can be designed depending on different local circumstances, load as well as skill and experience of the structural designer.

At abutments where expansion joints are foreseen, a chamber for dewatering and expansion joint inspection shall be foreseen for superstructures where the distance between adjoining expansion joints amounts to ≥ 100 m. The minimum dimension of the chamber shall be 80/150 cm.

For urban bridges and road bridges where a greater number of different installations can be expected, special larger chambers shall be designed behind abutments.

The abutment design shall avoid cantilever wings longer than 6 m and shorter than 2 m. All other data on the wing wall design are presented in the design guidelines DG 1.2.8

Abutments shall be designed in such a way that bearings, expansion joints and precipitation water drainage elements can be easily replaced.

The abutment inner walls shall be designed simple to enable normal conditions for execution of fills, filters and transition slab.

The end of the pre-stressed reinforced concrete superstructure of solid slab, T-beam or box cross-section shall extend by at least $h_k/3$ or ≥ 0.6 m over the abutment axis. The opening required for the expansion joint installation (if required), shall be shifted by at least 15 cm from the tendon head (figure 11.3).

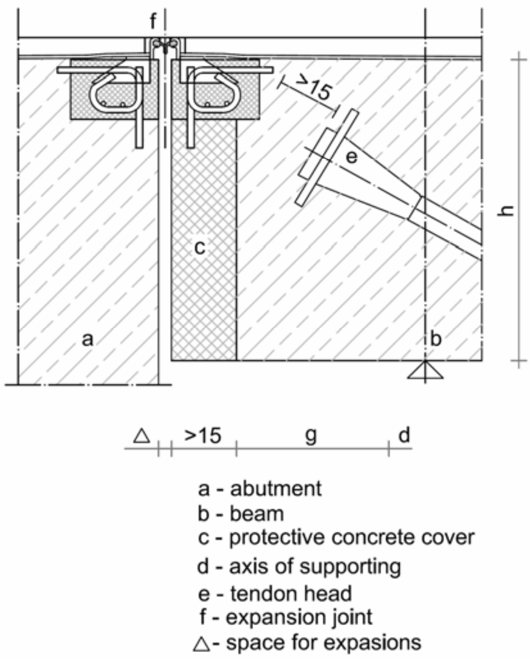


Figure 11.7

By purpose, cross-section shape, superstructure construction method and height, piers can be divided in three groups:

- piers of a circular or an angular concentrated full cross-section
- piers of a circular or a concentrated full cross-section with a cap
- tall piers containing weakened areas.

When and how the structural designer will conceive the piers depends of a correct comprehension of the conditions mentioned above.

It should be emphasized that piers are the most essential elements (beside the superstructure cross-section) of a bridge structure. By fulfilling the functional, stability and construction conditions piers can be designed both aesthetically and originally.

The piers heads shall be adjusted to the superstructure cross-section shape as well as to the mode of supporting and connecting of the superstructure. Interaction of loads shall be taken into consideration in designing both the superstructure cross-section and the pier heads.

The pier foots shall be adjusted to the foundation method and depth.
Piers comprising openings in the cross-section are economical and employed for a height greater than 20 m.

For piers of a closed box cross-section, openings enabling entrance and inspection as well as ventilation openings shall be foreseen.

Massive river piers are subjected to erosion and chemical action due to polluted water. Therefore a 20 cm thick stone lining applied to those piers might be reasonable.

The pier foundation depth and method depend on geological/geo-mechanical conditions and, partially, on available equipment. The limit between a shallow and deep foundation is 6 m below the ground surface. Deep foundation on bored piles and wells are presented in the design guidelines 1.3.1.

River piers shall be founded at least 2 m below the riverbed bottom level and minimum 0.7 m in a solid ground. Other piers shall be founded at least 1.5 m below the ground level or the riverbed bottom level and minimum 0.5 m in a solid ground.

When bored piles are foreseen in streaming water or in underground streams, the critical pile length shall be protected with 4-6 mm thick steel lining.

11.9 Minimum dimensions of elements and protective covers for reinforced concrete bridges

Cross-sections of any reinforced concrete element of the bridge load bearing structure shall have a minimum thickness of 10 cm for a single reinforcement layer and 20 cm for a double reinforcement layer respectively.

Cross-sections of any pre-stressed reinforced concrete element of the bridge load bearing structure shall have a minimum thickness of 22 cm for a double reinforcement layer and for tendon protective tube of maximum 80 mm.

The minimum thickness of bridge carriageway slabs shall amount to 22 cm irrespective of the span length and the static system.

Irrespective of the cross-section type and the cantilever span, the ends of cantilevers shall be at least 22 cm thick to enable a connection with the edge beam reinforcement.

The minimum thickness of webs of bridge box cross-sections shall amount to 35 cm for a web height $\leq$ 2 m and 50 cm for a web height greater than 4 m respectively. Intermediate values shall be determined by a linear interpolation.

The minimum thickness of solid slab cross-section, walls and piers of road bridges shall be 60 cm.

The minimum diameter of circular or concentric cross-section of road bridge piers shall amount to 80 cm.

The minimum thickness of all the elements of reinforced concrete bridge abutments shall be 30 cm.

The wall thickness of box and sectional cross-section of piers shall amount to minimum 30 cm.

The minimum thickness of foundation blocks at the connection with bridge piers shall amount to 100 cm.

The minimum thicknesses of protective concrete covers for road bridge load bearing structures are as follows:

- 4.5 cm for cross-section outer surfaces
- 3.5 cm for cross-section inner surfaces
- 5.0 cm for foundations and parts of abutments/piers located in soil or backfilled

The specified minimum thickness of protective concrete covers relate to the thickness of the concrete layer above the reinforcement closest to the formwork.

Sharp edges shall be removed from all the reinforced concrete and pre-stressed reinforced concrete bridges. The dimensions of chamfers shall amount to 2/2 cm. Are the dimensions of the chamfers greater, the geometry of stirrups or transverse reinforcement shall be modified.

Interruptions of casting the concrete, i.e. construction joints being indispensable for technological reasons and to diminish adverse consequences of concrete shrinkage, shall be specified in the bridge design.

11.10 Constructive conditions for reinforcing of bridges

To determine the reinforcement for reinforced concrete and pre-stressed reinforced concrete bridges the rules defined in the EC 2 shall be taken into account. In the present design standard only some additional conditions are indicated.
A reliable reinforced concrete or pre-stressed reinforced concrete bridge structure can only be achieved by, among others, a sufficient and correct reinforcing. The same amount of steel reinforcement built-in into a reinforced concrete structure can take basic and additional loading more reliably and enables a greater durability, if it is correctly and professionally designed and built-in.

To elaborate reinforcement drawings, input data from the final part of design calculation shall be adopted (sketches indicating the position and sections of the reinforcement).

Bridge structures are reinforced in all the planes and main directions of stresses. No cross-section area, irrespective of static actions, shall remain non-reinforced. Bridges are dynamically loaded structures thus the direction of the time dependent effects (deformations) is variable and, therefore, all the layers of a cross-section are subjected to tension and cracks.

In principle, thinner profiles on shorter distances are desired. In areas of tensile stresses, distances between adjacent profiles shall be smaller than 15 cm, whereas in areas of compressive stresses it shall be smaller than 20 cm. For the main reinforced concrete girders reinforcement bars shall not be thicker than 28 mm and thinner than 10 mm respectively. The loops of mesh reinforcement shall be ≤ 15 cm, whereas the bar diameter shall amount to ≥ 6 mm.

To achieve a proper compaction of concrete, which is essential for the durability, the distance between reinforcing bars shall be sufficient to enable placing of vibrators at required intervals.

The stirrups of main girders shall be closed. If they are open, they shall be equipped with hooks. Lengthening of stirrups by means of caps is not permitted.

In equal structural elements maximum three to four different types of profiles shall be employed to facilitate the purchase, bending and placing of reinforcement.

The shape of reinforcement shall be adequately selected to facilitate its bending, transportation and placing.

When detailing the reinforcement, the sequence of placing shall be taken into consideration as well.

Reinforcement cages shall be of harmonized dimensions and weight to accelerate their placing.

In piers and other elements where compressive stresses are primary, the longitudinal reinforcement shall be surrounded by stirrups or transverse reinforcement placed on that side of the cross-section that is closer to the formwork.

In foundation slabs, carriageway slabs, superstructure solid slabs as well as other horizontal or inclined elements, the upper reinforcement layers shall be equipped with suitable supports. Both the diameter and the number of those supports depend on the weight of the upper reinforcement and the depth of the cross-section.

By means of reinforcement bars being adequately shaped with regard to the element cross-section and function, the designed distance between adjoining reinforcement planes can be achieved. Both the cross-section and the number of these bars depend on the reinforcement diameter and weight (approximately 4 pieces per m^2).

The reinforcement shall not hinder the tendons, but shall be adjusted to the tendon lines.

Curved bars shall not create forces that might jeopardize the protective concrete cover.
The passive reinforcement affects the formation, distribution and development of cracks. Since the latter are branched out, it is important to select smaller spacing and profiles of reinforcing bars.
For box cross-sections an overlapping of closed stirrups at he connection between the lower slab and the web (the lower slab hangs on the web). The web horizontal reinforcement is specified with regard to possible longitudinal stresses due to bending, torsion and constraints (temperature, shrinkage, differential settlement). For web stirrups it is recommendable to have a thinner profile, i.e. between 12 and 18 mm, and to be placed at intervals of 8 to 20 cm.

For bored piles the minimum reinforcement amounts to 0.8%, whereas the maximum up to 3%. The minimum stirrup profile shall be 12 mm for piles of $\varnothing >$ 1,000 mm and 10 mm for those of $\varnothing \leq$ 1,000 mm. Stirrups shall be placed at intervals of $\leq$ 20 cm, except in the overlapping and anchoring zones of the main reinforcement where the intervals shall not be greater than 10 cm.

11.11 Constructive conditions for pre-stressing of reinforced concrete bridges

In the final design stage, the bridge designer defines, on the basis of technical, constructive, economical and other conditions, a most suitable system of pre-stressing. The characteristics of the pre-stressing systems are included in the design calculation, drawings and details of the particular bridge load bearing structure.
To enable market competition, the designer shall indicate not only the selected system of pre-stressing but also at least two additional ones, which helps the contractor to select the most appropriate system.

Both the designer and the client shall agree upon an eventual modification of the pre-stressing system. Such a modification shall be supported by an adequate design calculation, details and technical report.

Constituent parts of a pre-stressing system are tendons, anchor heads (for anchoring and pre-stressing), couplers, hydraulic jacks, grouting pumps, grouting compound and protective tubes.

Tendons and forces greater than 1,000 kN and 5,000 kN shall be employed to pre-stress the main girders of bridge superstructures.
A single girder shall contain at least three tendons to prevent a collapse in case of failure of one tendon.

Pre-stressing (longitudinal or transversal) of carriageway slabs is not desirable. However, when it cannot be avoided, the carriageway thickness shall amount to minimum 28 cm, and the tendon shall be placed in the cross-section centre.
The minimum distance between the tendon outer surface and the outer surface of the concrete of load bearing elements is 10 cm.

Lengthening of tendons by means of couplers shall be avoided. Instead of couplers, overlapping or long tendons of one piece shall be foreseen. In each cross-section of any load bearing element at least a half of the tendons shall be continuous.

It is recommendable to employ un-bonded external tendons to take live loads, particularly in box cross-sections.
In the up-to-date bridge construction, especially for larger and important bridges, pre-stressing with un-bonded tendons is preferable. Such a method enables a complete corrosion protection of tendons, possibility of their replacement, and has several additional advantages as well. Reinforced concrete bridges pre-stressed with un-bonded tendons are more expensive by 5%, yet the maintenance costs are lower.

The position of internal tendons in the load bearing elements of pre-stressed reinforced concrete bridges is determined by tendon supports that are independent of reinforcement cages. The distance between two adjoining supports shall be sufficient (approx. 1 m) prevent a local deformation of a tendon. The diameter of reinforcement serving as a tendon support shall be chosen adequately ($\varnothing$ 16 for a height of $\leq$ 1 m above the formwork and $\varnothing$ 20 for a height of $>$ 1 m above the formwork respectively) to avoid flexures and deformations of tendons.
The distance between a tendon support and the formwork can be adjusted by means of spacers, as it applies to the reinforcement as well.

The protective concrete cover is the same for both the tendon supports and the reinforcement too.
Each web shall contain one vibration spot. More than three tendons must not be installed without a vibration spot.

It is not permitted to lead tendons from the girders into the upper plane of the carriageway slab. All the tendons shall end on the girder front or within the cross-section.

A girder end shall extend by at least h/3 or 0.6 m over the axis of supporting to allow pre-stressing forces to influence the application of supporting forces to the structure.
Both horizontal and vertical deflection forces due to a deviation of the tendon line shall be taken with special stirrups.

Due to application of the stressing force, special reinforcement for splitting forces in both horizontal and vertical plane shall be foreseen.
Partially pre-stressed concrete for main longitudinal girders of pre-stressed reinforced concrete bridges shall be avoided when a bridge is fully loaded. The structure shall be fully pre-stressed for the dead weight loading. A partial pre-stressing is permitted in the transversal direction only.

All the elements of the pre-stressing equipment and all the stages of the pre-stressing procedure shall be checked up.

- High-performance steel and grouting compound shall be controlled in accordance with relevant regulations.
- Anchor heads and stressing heads of tendons shall be controlled in accordance with the certificate of the pre-stressing system.
- Protective pipes shall be controlled on the basis of a certificate issued by the maker.
- Stressing jacks shall be controlled in accordance with an attest issued by the manufacturer of the hydraulic jacks or by the holder of the pre-stressing system, which shall be carried out every six months.

The execution design of a pre-stressed reinforced concrete bridge shall include a detailed report on pre-stressing and grouting in accordance with relevant regulations.

In the carriageway slab no openings and niches are permitted, not even such that might be required for pre-stressing of tendons.

Steel with a low relaxation shall be designed for pre-stressing of reinforced concrete bridges. The relaxation shall amount to 2.5% of loss after 1,000 hours or 2.5% x 3 = 7.5% of loss after 500,000 hours. Irrespective of the manufacturers' certificates the value 7.5% shall be considered in bridge design.

The tendon stress shall not exceed 0.7 f_{pk} (characteristic value of tensile strength of pre-stressing steel) after pre-stressing or 0.75 f_{pk} prior to wedging.

For pre-stressing of reinforced concrete bridges steel of characteristic tensile strength of $f_{p0,2k}/f_{pk}$ = 1,670/1,860 MN/m^2 can be employed too. However, in the design analysis the value 1,570/1,770 MN/m^2 shall be considered until the EN 10138 is adopted.
For all the pre-stressing systems (BBR, Dywidag, Ph. Holzmann, Freyssinet and other certified systems) compatibility of all the constituent elements shall be verified in the spirit of an equivalent safety.

Manufacturers of pre-stressing steel and elements are obliged to submit all the certificates required by relevant regulations valid in the manufacturer's country. No product shall be installed in absence of these documents.

11.12 Material, workshop fabrication, erection, and corrosion protection of composite and steel bridges

11.12.1 Introduction

As long as engineers, who might play the role of investors, designers, or contractors, define and favour materials and not structures in advance, concrete as material being massively used will be preferential in bridge construction as well. An engineer must create the most appropriate structure, whereas the material is selected with regard to the type of obstacle to be bridged, and to the market conditions.

Material for concrete structures has significant natural resources, and the work cost is lower as well. Concrete is preferential to small and medium bridges, particularly where a group of bridges on new roads is constructed.

For a composite cross-section, steel is advantageous for individual bridges of medium spans, as it allows rapid construction without major site equipment and work.
For larger bridges only alternative competitive solutions have a right to favour individual materials or systems.
When certain sphere wants to keep a competitive position of an individual material, it shall ensure both materials to have a chance of business continuity as well as preserving professionals and references.
Due to advantages offered by composite structures it can be expected that their future development and employment is assured, however in an increasing competition with pre-stressed reinforced concrete bridges.

A promising and verified possibility of economical improvement for bridges of longer spans with double composite construction makes composite structures more economical for long spans as well.

Composite structures with a slab as a roof over the steel structure are less prone to structural damage provided that they are properly dewatered, waterproof, and protected from corrosion.

Steel composite structures can be repaired, restored, and replaced in a simpler way.
Construction of a composite structure is less disturbing to the natural and urban environment.
Professional questions of how to improve the technology of casting carriageway slabs, pre-stressing, and optimising both thickness and shape of vertical steel webs still remain open.

Road bridges with steel-concrete composite superstructures are (technically, economically, and in view of durability) competitive with reinforced concrete and pre-stressed reinforced concrete bridges for spans longer than 20 m, and for all the load bearing systems.
Road bridges with steel superstructures are competitive for long spans only (above 150 m).

Structural design and construction of piers and abutments as well as of their foundations for composite or steel bridge superstructures is basically similar to those for reinforced concrete and pre-stressed reinforced concrete bridges. The load from the superstructure to piers and abutments is generally transferred via bearings; in specific cases the load transfer is carried out by means of hinges and rigid connections.

Chapters 1 to 10, as well as 12, 14, 15, 16, and 17 (i.e. 15 chapters from their total number of 17) of the Design Guideline 2.1.1 refer to bridges, irrespective of the superstructure load bearing materials. Chapter 11, items 11.1 to 11.8, as well as items 11.13 and 11.14 are common for all the bridges as well. Items 11.9, 11.10, and 11.11 relate to reinforced concrete and pre-stressed reinforced concrete bridges, whilst the present item 11.12 to the specificities of material selection, workshop fabrication, erection, and corrosion protection of composite and steel bridges.

Selection and structural design principles of cross-sections of composite and steel bridge superstructures are indicated in chapter 11, item 11.7.

11.12.2 Basic steel material and binding material

Load bearing steel structures of composite and steel bridges shall be fabricated from structural steel, which shall comply with the current standard JUS C.B0.500 (1989).

Selection of the steel grade group shall be in accordance with the purpose of the bridge, type of loading, stress condition, bearing structure cross-section type, service conditions, and the JUS U.E7.010 (Selection of basic steel material, 1988).

Structural steel is defined in chapter 3 of Eurocode 3 Design of steel structures, and in compliance with EN 10025.

As a rule, the material shall be ordered by the company that fabricates the steel structure.
For bridges, especially railway bridges, prone to fatigue stressing, only material directly ordered at steelworks may be used.

Taking over of steel material at steelworks shall be carried out not only by the purchaser, but also by the bridge designer and client's representative.

Upon taking over, a certificate shall be submitted. It shall include information on all the required chemical and mechanical testing, as well as proven quality in accordance with current standards and provisions of both design and procurement contract.

The test results shall be assigned to production batches at simultaneous presence of all the interested parties.

It is not admitted to use laminated steel plates. Testing of lamination shall be carried out at the steelworks upon taking over. Both extent and method of testing shall be determined with regard to the steel plate thickness.
Binding material such as welding electrodes and wire, high-strength bolts, etc. shall be tested by the producer himself. The client shall receive adequate certificates.

Electrodes for electric arc welding shall comply with the JUS C.H3.010 and JUS C.H3.011.
High-strength bolts shall be of the strength class 10.9 according to JUS M.B1.023; nuts shall be of the strength class 10 according to JUS M.B1.028.

Upon delivery, the product quality control shall be performed according to the standard JUS M.B1.030.
Upon delivery of high-strength bolts the manufacturer shall submit an evidence of the magnitude of the coefficient K.

Bolts, which thread remains within the package of structural elements, must not be used.
For high-strength bolts the JUS U.E7.140 shall be considered as the referent standard.

Pre-stressed bolts shall be inserted into the joints, which surface of friction is Al Mg S treated. For each bolt the condition Pbolt < Fp where Pbolt is the attained pre-stressing force, and Fp is the calculated pre-stressing force. For pre-stressing executed by applying a torque, the ratio of the pre-stressing force to the torque shall be defined by the certificate issued by producer for each bolt diameter. Tools for pre-stressing of bolts shall be calibrated and accompanied by corresponding certificate. The contractor, who performs the site works, shall have suitable instrument to test torque wrenches.
Steel material purchased at steelworks shall be marked with paint of adequate colour indicating dimensions; both batch number and item number according to the purchase order shall be impressed. Interrelation between the ordered material and the certificate can only be established by such marking.

The contractor must not use any material without adequate certificate. When cutting individual items from purchased steel plates of major dimensions, for all the items forming bearing structural members the impressed batch number and the number of the purchasing item shall be transferred to individual items as well. From the erection diary to be kept by the contractor it shall be evident which items have been cut out from the particular purchasing item.

All records of the material, from purchase to building-in, shall be properly kept and submitted upon handing over of the structure. Without such a document, the structure must not be taken over.

11.12.3 Workshop production and control of steel structures for bridges

Steel structures for bridges can only be produced by specialized companies registered for these works and being sufficiently experienced. Under the term “company registration” it is understood that the company has the required equipment, skilled manpower, and specialized professional staff at its disposal.

Material for manufacturing steel structures shall be purchased on the basis of specifications indicated in the workshop drawings and producer’s catalogues. The purchased material shall be accompanied by quality certificates referring to the rolling mill batch. The material is cut out in accordance with the workshop drawings. Prior to assembling the cut out items shall obligatorily and timely inspected. The production process of steel structures runs in compliance with how the workshop is equipped, and with the complexity grade of the steel structure.

Prior to commencement of bridge steel structure fabrication, detailed method statements on welding and mechanical works shall be worked out, which are in accordance with the workshop drawings and provisions of the bridge execution design.
For workshop production of heavy steel structures, to which bridges belong, single-nave halls of major spans equipped with overhead cranes of capacity up to 500 kN are appropriate. The cranes are indispensable to accomplish larger segments, to carry out trial assembly, and to execute loading on transportation means.

Factories of steel structures shall have their own organized internal production control, with suitable equipment and laboratory to test mechanical and chemical material properties, to perform welding control, as well as the control of complete assemblies. In case that minor producers have no equipment at their disposal, particularly for radiographic control, they shall engage specialized companies to perform the steel structure quality control.

The quality of a steel structure produced at factory is assured by “Basic programme of control of workshop production of steel structures” consisting of the following constituent parts:
- preparation for control,
- execution of control,
- working out a detailed report on the performed control.

Preparation for control is composed of the following items:
- studying the contract and the design documents,
- checking whether the technical documents are conform to current regulation, norms, and standards,
- making a tour of inspection at production premises, and assessment of their capability in view of equipment, manpower, welders' certificates, machinery, and company ability attestations,
- making acquaintance of the factory internal quality control,
- working out a quality control programme.
- quality control of steel material and welding electrodes/wire, as well as of their storing,
- control of each workshop production stage,
- final control of unpainted steel structure,
- final control of finished steel structure.

Control of welded joints

Fillet welds dimensions shall be in compliance with the design. The producer is obliged to control filler welds by both quantity (dimensions) and quality.
Quality control can be performed visually by means of magnifying glass, or using penetrating paint. Testing results shall be recorded.

Quality control of butt welds shall be, on principle, carried out by radiographic method. Welded joints assessed with 1 – 3 are acceptable. If a welded joint is assessed with 4, it shall be repaired. Welded joints, which receive a mark 5, shall be rejected as inappropriate.
Cut edges of plates shall be finished by means of grinding.

After being welded, the elements shall be of the designed shape, and shall have even surfaces.
Welded joints shall be assessed in accordance with the International Institute for Welding (IIW). Testing results shall be summarized by special detailed report.

Holes for high-strength bolts shall be drilled and not punched.
Threads of bolts shall not be within the package of structural elements. For each joint, bolt lengths shall be ordered separately, taking account of the thickness of the package of structural members. The contractor shall prepare a specification of bolts, nuts, washers, etc. for joints.

Preparation of detailed report on the control carried out
- general part: description of the structure, information on the design, producer, and production technology, specification, list of documents related to the control;
- quality verification: certificates, testing documents, forms, etc.

Delivery of steel structure

Prior to delivery of steel structure, the producer shall apply large marks to all the assemblies, connections, and joints. The marks shall fully comply with those indicated in the design documents. They are indispensable to a correct field erection.

Structures at site

In addition to the steel structure itself, the producer shall also supply joining material, which is necessary for the erection. Joining material shall be properly and firmly packed, and sorted by type and dimensions.

Finished structures may be dispatched to construction sites only after a successful trial workshop assembly, and after the supervising body is convinced that the structure has been produced in accordance with the design, current regulation, and standards, as well as that adequate accompanying documents are available.

The supervising body shall issue permission for delivery of the structure in writing.

11.12.4 Erection of steel bridges

Steel bridges shall be erected in compliance with the Rulebook of technical provisions and conditions for erection of steel structures (Official Gazette of SFR Yugoslavia No. 29, 1970).
The abovementioned Rulebook comprises the following chapters:

- I General rules
- II Design of erection of steel structures
- III Preparation of site for erection works
- IV Control and taking over of steel structures at workshop; transport and storing
- V Preparatory works for erection of steel structures
- VI Erection of steel structures
- VII Erection of different types of steel structures
- VIII Corrosion protection of steel structure upon erection
- IX Technical inspection and testing of steel structures
- X Taking over of steel structures after completion of erection
- XI Final account of works carried out.

Prior to commencement of erection works, and particularly before working out the design of erection of a steel structure, the aforementioned Rulebook shall be studied in detail.

The erection design shall be performed by both structural engineer and mechanical engineer. An engineer specialized in safety at work shall be consulted. The erection design shall be accepted and certified by the bridge designer.
During conceiving a bridge, and working out both preliminary and main design of the bridge, the designer shall also consider possible and appropriate erection methods thus ensuring feasibility and economy of bridge execution. Bridge designs include schemes, descriptions, and essential parts of the stability analysis for the foreseen erection method. If the bridge erection contractor is known in advance, he shall be consulted at an early stage of the bridge design.

Steel bridge design and erection is a complex and responsible job, which is often a life's specialization of structural and mechanical engineer.
In the spirit of the aforementioned Rulebook the erection design shall answer to all technical, constructive, static, organizational, and disputable questions related to the erection process.

In dependence on the dimension and complexity of steel structure, on the morphology of the obstacle to be bridged, transportation conditions, delivery to both river banks or valley sides, available equipment, and contractor's qualification and skill, the following main methods of erecting steel bridge superstructures can be distinguished:

- erection by frontal launching,
- erection by means of mobile cranes, floating cranes, or special wagon-mounted cranes,
- erection by means of a cable-way,
- erection by free cantilevering,
- erection by lateral launching,
- erection by means of combined and specific methods.

Steel structures can only be erected by specialized companies having sufficient number of professional staff, of mechanization, and tools at their disposal. Prior to application for erection of a steel structure, prospective contractors shall prove their capability.
The steel structure manufacturer shall make good at his expense and as soon as practicable all production deficiencies and eventual nonconformities found out during erection works.
The erection contractor shall take account of all current regulation, rulebooks, and standards. Prior to commencement of the erection works, the contractor shall make a detailed acquaintance with structural particularities. Then, he shall work out an adequate erection design, which shall be approved by both client's supervising engineer and bridge designer.

An erection design shall comprise the following constituent parts:

- Sequence of erecting sub-assemblies and assemblies (segments);
- List of necessary tools and mechanization;
- List of required manpower;
- Erection programme;

Upon elaborating the erection design it shall be considered that the sequence of building-in/erecting of individual assemblies has to comply with the following principles:

- The erected structural member/part shall always be stable;
- Installation of bridge equipment shall be enabled;

  The erection contractor shall organize his own control to verify the following:
- Correctness of steel structure erection;
- Implementation of provisions referring to the safety at work.

  The client's supervising engineer performs superintendence over the erection of steel structures. The erection contractor shall provide the supervising engineer with a site office, as well as with sufficient number of labour and tools for checking correctness of the completed structure.

11.12.5 Corrosion protection of steel bridges

Corrosion protection of steel structures of bridges shall be carried out in accordance with the Rulebook of technical provisions and conditions for corrosion protection of steel structures (Official Gazette of SFR Yugoslavia No. 32/70), which includes the following constituent parts:
- general rules,
- production of steel structures in view of corrosion protection,
- steel surface preparation for corrosion protection,
- corrosion protection types,
- corrosion protection systems,
- control and taking over of corrosion protection works,
- corrosion protection maintenance.

The following shall be specified by the steel structure design:
- method of surface preparation for corrosion protection,
- number of coats, thickness of coats, quality of priming and finishing coating,
- type of paint and conditions to carry out corrosion protection works.

For steel structures of bridges, the surfaces shall be prepared by blast cleaning to the required grade as specified by the Swedish Standard SIS 05 5900. Prior to application of the priming coat, the blast-cleaned surface shall obligatorily be taken over. The thickness of priming and finishing coats shall be specified in micrometers (μm) varying between 30 and 200 μm depending on the paint type, environmental aggressiveness, and the structural type. Designers of steel bridges shall follow the development of protective coating technology, and shall introduce it into bridge corrosion protection.

To achieve an adequate corrosion protection of larger and important steel bridges, investors shall obtain detailed expert's reports worked out by specialized institutes.

An effective corrosion protection can be achieved with zinc-epoxy or zinc-silicate primers, and chlorinated rubber, epoxy, or polyurethane finishing coats (topcoats). In case of confined internal surfaces where high humidity is present permanently, coal tar epoxy or high-built epoxy coating shall be applied.

Corrosion protection of a steel structure begins at the factory and consists of the following works:
- surface preparation,
- application of priming coat.

Steel surface preparation shall be carried through in compliance with the aforementioned Rulebook. As a rule, it shall be carried out by blast cleaning to the Sa 2 ½ grade as specified by the Swedish Standard SIS 05 5900. In dependence on the factory organization, surface preparation can either be executed before the steel material enters the workshop, or after completion of production of certain assembly.

Within 8 hours after cleaning and de-dusting, steel surfaces shall be protected either with a shop primer or immediately with the first priming coat. This interval can also be shorter, depending on the environmental conditions.

During erection of a steel structure it must be considered that surfaces to be covered with steel plates are preliminarily painted with the second priming coat as well. In this way all the elements of the erected steel structure receive the same degree of corrosion protection.

The upper surface of an orthotropic plate of a box cross-section to be in contact with asphalt shall be protected from corrosion adopting some special method as follows: during workshop production this surface is protected with suitable shop primer, which does not affect the weld quality, and, at the same time, protects the particular surface during production, transportation, and erection for a period of 6 months. After the steel structure is erected, the upper surface of the box cross-section shall be protected from corrosion in the following way:
- surface preparation by means of sandblasting (e.g. with quartz sand) to the 2 ½ grade according to SIS 05 5900 (1967);
- removal of dust either by vacuum cleaning or blowing with compressed air;
- application of priming coat, and finishing coat of a two-component coal tar epoxy paint in a total dry film thickness of 250 μm. The priming coat shall be applied within two hours after completion of blast cleaning, at temperature between + 10°C and +30°C, and during dry weather.

Physical and mechanical properties of paint material, as well as its characteristics in view of resistance to high temperatures, shall comply with the JUS H.C8.050, ASTM D.968-51, and DIN 53154. Prior to commencement of the corrosion protection works the selected paint material shall be tested at laboratory. Adequate certificates shall be acquired from professional institutes competent for this domain.

Onto the applied and cured coal tar epoxy top coat, a layer of hard-aggregate poured asphalt in a thickness of 30 mm shall be applied. It must not damage the waterproofing layer or the corrosion protection of the upper surface of the orthotropic plate.

11.13 Constructive conditions for equipment of road bridges

Bridge equipment includes bearings and hinges, superstructure expansion joints, transition slabs, railings and barriers, drainage and piping, edge beams, kerbs and walkways, as well as installations and maintenance equipment.
To bridge equipment also belong elements required to arrange the space at the contact road body – bridge (ends, berms, backfill wedges, paving of slopes, stairs, channels, etc.).
Bridge equipment includes all the elements that are indispensable to transform a raw structure into a real bridge.
The content and solution of bridge equipment depend on the purpose, size, location, class, material and other circumstances.
The bridge equipment is designed and applied in accordance with guidelines and details indicated in the design standards DG 1.2.2 to DG 1.2.8 and DG 1.2.10.
To achieve a design service life of 80 to 120 years it is indispensable to specify the service life, maintenance, and method of replacement of all the elements of bridge equipment as well.
Bridge designer shall calculate in specify all the conditions and information required for purchasing or manufacturing, taking into consideration the abovementioned design standards and eventually other regulation as well in case that those design standards are insufficient.
When designing motorway bridges and selecting their equipment, such solutions shall be chosen that do not foresee any major traffic restrictions and enable a simple and quick replacement.

Bridges on non-categorized, local or regional roads can be designed without certain elements belonging to bridge equipment such as transition slabs, bearings, expansion joints, drainage, depending on the purpose, size, location and other conditions.

11.14 Indices of costs of basic materials per square metre of bridge surface

The bridge area is a product of the total length and the total width explained in chapter 3 of this design standard.

The indices of material costs shall be indicated at the end of the technical report as a constituent part of the bridge execution design. These multipurpose are intended for the cost control of the particular bridge, for comparison with similar projects, and for assessment of material costs of bridges to be built in future.
Table 11.5 contains data for concrete of all the grades, formwork, reinforcing steel of all the profiles and grades, as well as pre-stressing tendons made of high-performance steel.
A comparison of the material consumption per 1 m^2 of a bridge as well as a comparison of costs per 1 m^2 is only possible and realistic for similar categories of bridges.
Comparison can be carried through among

- **culverts, underpasses, overpasses**
  of usual spans amounting to 15-30 m
- **bridges**
  of shorter spans (10-20 m)
  of medium spans (20-40 m)
  of longer spans (40-80 m)
  of very long spans (above 80 m)
- **viaducts**
  of spans up to 30 m, of heights up to 30 m
  of spans of 30-50 m, of heights up to 50 m
  of spans of 50-80 m, of heights up to 80 m
  of spans above 80 m, of heights above 80 m.

Table 11.5: Material consumption per m^2 of bridge area

Structural element	*Concrete* *m^3/m^2*	*Steel* *kg/m^2*	*Reinforcement* *kg/m^2 of bridge* *kg/m^3 of concrete*	*Tendons* *kg/m^2 of bridge*
Piers and abutments including foundations	m^3/m^2	-	kg/m^2 kg/m^3	-
Superstructure	m^3/m^2	kg/m^2	kg/m^2 kg/m^3	kg/m^2
Bridge in total	m^3/m^2	-	kg/m^2	kg/m^2

12. DESIGN CALCULATION OF BRIDGES (STATIC AND DYNAMIC ANALYSIS)

12.1 Introduction

The term design calculation (or even static calculation) is old-fashioned. It is preserved only because of continuity and custom. An equivalent term would be static and dynamic analysis of bridge load bearing structures. An up-to-date expression could be bridge safety (load bearing capacity, serviceability, fatigue) verification. A future term will probably be reliability (safety and durability) verification.

The design calculation is an independent unit included in both the preliminary design and the construction-permit design. The level and extent of the design calculation depends on the level of the bridge design.

Design calculations shall be, among others, conceived on suitable geological/soil-mechanical bases offering all the data required to determine the foundation depth and method, to dimension the foundations, to define the slope stability in the pier and abutment areas, and, consequently, to ensure a safe transfer of moments and forces from the bridge structure into the foundation ground. Are the differential settlements greater than 1.0 cm, they shall be analysed as a special load case in statically indeterminate systems.

Design calculations can be performed manually, by computer software or combined (manually and by computer).

The extent of a design calculation shall be sufficient to verify safety of the entire bridge load bearing structure and of all the individual elements during construction and during operation in $t = t_0$ and $t = t_n$ where t_0 is the operation time of the bridge immediately after handing over to traffic and t_n is the bridge service life after “n” years of operation.

Each design calculation includes an introduction, a load analysis, a calculation of internal forces and moments, a verification of stresses, load bearing capacity, deformations, displacements, cracks and fatigue as well as verifications of the ultimate limit state and the serviceability limit state. Finally, a design calculation contains sketches of the structure and structural elements with analysed cross-sections, as well as a definition of cross-sections and arrangement of steel reinforcement, tendons, or steel.

To enable a controlled application of great number of software of different origin, age, theoretical bases, compliance or non-compliance with relevant regulations, an elaboration of special guidelines and a suitable official adoption of that software by a professional scientific institution are mandatory.

The introduction to the design calculation includes a report, sketches of the load bearing structure, static models, and presentation of software employed in accordance with relevant guidelines to verify bridge safety.

A design calculation shall be carried out in two versions that differ one from another only in the volume of enclosed material. The more comprehensive version includes all the required constituent parts and computer out prints, and shall be prepared in two copies: one for the archives of the design company and one for the client’s records. All other copies are less comprehensive since they do not contain any computer out prints. Namely those out prints are more or less worthless after “n” years since both software and hardware are out of fashion, and the extensive out prints would only represent an unnecessary waste of paper.

The analysis of loads and actions on bridges is complex, different for each project, and depends on a series of factors such as type and category of the road, location of bridge, material, construction method, constructive and static scheme, etc.

In table 12.1 loads and actions stated in view of their origin.

In accordance with the relevant regulations for actions on bridges, a designer can logically combine the individual loads, indicated in table 12.1, for each particular bridge.

Table 12.1: Loads and actions on bridges

<table>
<tr><td colspan="3">1 FORCES OF GRAVITY</td></tr>
<tr><td></td><td>Dead weight of bridge load bearing structure</td><td rowspan="2">Values of volume masses</td></tr>
<tr><td></td><td>Other permanent loads on a bridge</td></tr>
<tr><td colspan="3">2 LIVE LOADS</td></tr>
<tr><td rowspan="5"></td><td>Load due to vehicles and pedestrians</td><td>It is given in terms of replaceable normative model and includes a dynamic factor</td></tr>
<tr><td>Vehicle braking forces</td><td>To be considered as a static force</td></tr>
<tr><td>Centrifugal force</td><td>To be neglected in usual conditions</td></tr>
<tr><td>Load due to installations</td><td>Beside the dead weight deflecting force, effects of installation expansion, etc. to be considered</td></tr>
<tr><td>Action on railing</td><td>Does not include accidental impacts of vehicles on bridge railing</td></tr>
<tr><td rowspan="6"></td><td>Load due to train and pedestrians (employees)</td><td>It is given in terms of replaceable normative model and includes a dynamic factor</td></tr>
<tr><td>Train accelerating and braking forces</td><td>The effect of this force is taken into account on the upper edge of the railway track structure</td></tr>
<tr><td>Centrifugal force</td><td>Important for railway bridges</td></tr>
<tr><td>Nosing forces</td><td>To be introduced as horizontal force for new railway bridges</td></tr>
<tr><td>Loading due to installations</td><td></td></tr>
<tr><td>Actions on railing</td><td>Does not include accidental phenomena</td></tr>
<tr><td colspan="3">3 NATURAL FORCES</td></tr>
<tr><td rowspan="6">3.1</td><td>Effect of environmental temperature change (includes uniform temperature changes and temperature gradient over cross-section depth. For railway bridges it includes the effect of continuously welded track)</td><td rowspan="6">The data on effects of natural forces for a certain location can be obtained by statistical or geophysical studies.</td></tr>
<tr><td>Wind action</td></tr>
<tr><td>Snow action</td></tr>
<tr><td>Action of streaming water</td></tr>
<tr><td>Action of ice (includes impact of ice)</td></tr>
<tr><td>Seismic actions</td></tr>
<tr><td rowspan="4">3.2</td><td>Earth pressure</td><td rowspan="4">The effect of this group of natural actions has mainly a permanent character. These forces can be foreseen or calculated. Usually they occur as reaction of natural media to construction.</td></tr>
<tr><td>Eventual settlement of supports</td></tr>
<tr><td>Pressure and mass of still water</td></tr>
<tr><td>Buoyancy</td></tr>
<tr><td colspan="3">4 FORCES ARISING DUE TO INTERVENTIONS IN BRIDGE STRUCTURES TO ACHIEVE CONTROLLED (DESIGNED) CHANGES OF STRESS CONDITIONS</td></tr>
<tr><td colspan="3">Forces resulting from pre-stressing by means of internal or external tendons as well as from undesired differences in height levels of pier heads. All the losses of force resulting from the application of force as well as the structural response to the application of force shall be taken into account.</td></tr>
<tr><td colspan="3">Forces arising from achieving of different levels of composite effects (usually steel and concrete)</td></tr>
<tr><td colspan="3">5 LOADS DUE TO SHRINKAGE, CREEP AND YIELDING OF MATERIALS</td></tr>
<tr><td colspan="3">Shrinkage and creep of concrete</td></tr>
<tr><td colspan="3">Relaxation and yielding of high-strength pre-stressing steel</td></tr>
<tr><td colspan="3">6 ACTIONS DUE TO STRUCTURAL DESIGN CONCEPTION</td></tr>
<tr><td colspan="3">Resistance (friction) in structural bearings</td></tr>
<tr><td colspan="3">7 ACTIONS DUE TO DESIGNED CONSTRUCTION METHOD</td></tr>
<tr><td colspan="3">Actions persisting in the structure permanently</td></tr>
<tr><td colspan="3">Transient actions not contributing to the definite stress condition</td></tr>
<tr><td colspan="3">8 ACCIDENTAL ACTIONS</td></tr>
<tr><td colspan="2">Impact on safety barriers of road bridges</td><td rowspan="5">These actions are accidental ones not resulting from natural forces</td></tr>
<tr><td colspan="2">Derailing of trains on railway bridges</td></tr>
<tr><td colspan="2">Broken overhead electric installation for railway bridges</td></tr>
<tr><td colspan="2">Impact of road vehicles on bridge piers</td></tr>
<tr><td colspan="2">Impact of boats on bridge piers</td></tr>
</table>

Both design calculation and drawings of provisional structures needed to construct and erect bridge load bearing structures (scaffolding, falsework, structures enabling transportation and erection, etc.) are independent wholes. Are these calculations and drawings elaborated by others, the bridge designer is obliged to check and approve them.

12.2 Dynamic analysis of bridges for seismic actions

Seismic protection of bridges results from the fact that bridges are critical points of roads and railways, therefore they have to withstand earthquake actions.

Both the design and the dynamic analysis of structures in seismic regions are performed in accordance with the Eurocode 8 and NAD (National application document).

There are several methods to achieve a suitable seismic protection. Among others, the designer shall take account of the following when selecting the most appropriate method:

- type of considered structure
- nature and seismic activity of the location
- lowest costs possible of ensuring the required degree of seismic protection.

Recently in structures located in seismic regions a so-called **"positive seismic protection"** is frequently employed in contrast to the **"passive seismic protection"**. The latter means designing of structures that are not sensitive to earthquake. In most cases structures with a passive protection resist design earth quakes, however they are more or less affected by the seismic actions, particularly when plasticizing of certain structural elements in the sense of energy dissipation is foreseen. In case of significant and destroying earthquakes, extremely expensive repairing is required notwithstanding that the structure has remained not destructed.

A positive seismic protection of major bridges in critical zones is achieved by conceiving structures equipped with specific anti-seismic devices that do not affect the structure during its normal service but are activated upon earthquake action. The number of structures designed in this way is increasing. The types and functional modes of those devices are different and the selection of the most appropriate ones depends on each individual considered case. At first sight it seems that the structure becomes more expensive when such devices are foreseen. However, the total financial balance is generally positive.

12.3 Calculation, dimensioning and verifications

12.3.1 Principles

On principle two verifications shall be carried through:

- verification of sufficient load bearing capacity
- verification of serviceability

These verifications shall correspond to the designed safety and foreseen serviceability of a bridge.

In case that one of these verifications is not crucial, it can be omitted.

For structures jeopardized by a frequently repeated stressing, resistance to fatigue shall be verified within the sufficient load bearing capacity verification.

Dynamic actions due to wind or impact are represented by means of equivalent static forces. Dynamic effects of road and railway actions are taken into account by dynamic factors.

All the stressing shall be clearly defined. As a rule, they shall be entered in the safety and serviceability plan. For each action the stressing shall be indicated separately.

If it is not explicitly defined, stressing due to characteristic actions shall be taken into consideration to verify the load bearing capacity, whereas stressing due to long-term or short-term values shall be taken into account for the serviceability verification.

12.3.2 Load bearing capacity

The safety plan defines, among others, for which types of hazard the load bearing capacity must be verified by calculation.

For calculation and dimensioning the main hazard is represented by the decisive action, i.e. so-called primary (dominant) action. Hazards occurring simultaneously with the main hazard are called secondary (accompanying) actions.

The load bearing capacity of a structure is verified when the following condition is implemented:

$$S_d \leq \frac{R}{\gamma_R}$$

S_d : design value of stressing
R : ultimate load bearing capacity
γ_R : ultimate load bearing capacity factor

The ultimate load bearing capacity is determined in accordance with relevant structural standards defining the ultimate load bearing capacity factors as well.

The ultimate load bearing capacity factor allows for the following actions:

- deviations of the actual structural system from the design system
- simplifications and inaccuracies of the model
- inaccuracies of the cross-section.

The design value of stressing can be expressed in a general form by the following equation:

$$S_D = S\left(G_D Q_D \Sigma Q_a\right)$$

G_D : design value of permanent actions
Q_D : design value of primary (dominant) action
ΣQ_a: sum of secondary (accompanying) actions

The design value of stressing allows for the following:

- statistical scatter of magnitudes of actions
- a simplified presentation of actions
- simplifications of the model due to neglecting the simultaneously occurring actions interacting insignificantly.

12.3.3 Serviceability

Requirements in view of serviceability are defined in the bridge exploitation plan.

The required structural behaviour shall be ensured by means of suitable construction materials, adequate dimensioning, by careful detailing, planned and thorough execution as well as appropriate maintenance. The structural behaviour shall be within the prescribed or agreed limits referring to the following:
- cracks
- deformations
- vibrations
- quality of construction materials.

The limit values specific to individual materials are defined in the relevant structural standards. In the present design standard some informative values of deformations and vibrations are indicated.

The following provisions related to serviceability are mandatory without special agreements. However, for economy and quality reasons, the structural behaviour requirements may be discussed and harmonized by the client and responsible experts, which shall be entered in the bridge exploitation plan.

Stressing to be considered in the serviceability verification depend on the verification type, e.g. verification of cracks, verification of deformations, etc.

Stressing is determined on the basis of actions occurring simultaneously in the examined serviceability state.

Two types of values of actions are considered for the serviceability verification:

- long-term value: Qser,l
- short-term value: Qser,k

The long-term values are valid for permanent actions or include portions of variable actions persisting for some length of time.

The short-term values describe variable actions occurring in a short time. They also include a portion of the long-term actions.

Stressing due to restrained deformations or constraints, e.g. due to thermal actions, bearing displacements, pre-stressing as well as shrinkage and creep of concrete, shall be taken into account in accordance with the structural standards.

12.3.4 Deformations

Limit values of deformations shall be determined for each individual case and entered in the bridge exploitation plan.

Deformations shall be calculated in accordance with the provisions of structural standards. In particular long-term deformations, e.g. due to shrinkage and creep, shall be taken into consideration.

Flexure (bending) is shown schematically in the figure 12.1. They are defined as follows

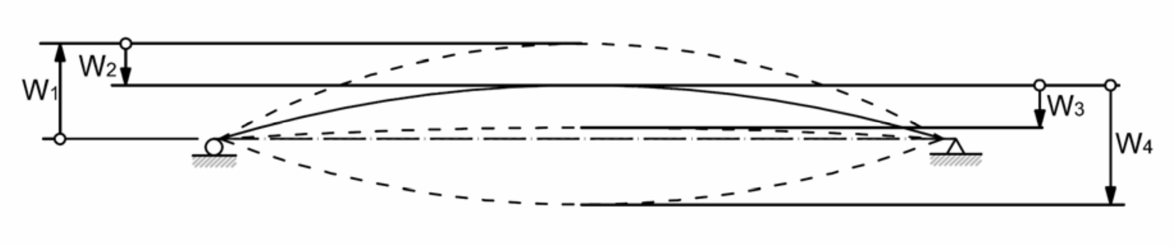


Figure 12.1: Definition of flexure (bending)

w_1: A camber, e.g. a designed workshop shape of a steel structure, or an excess height of the falsework in concrete structures.
w_2: Flexure due to structural dead load and permanent actions adopting corresponding long-term deformations.
w_3: Flexure under long-term value of variable action adopting corresponding long-term deformations.
w_4: Flexure under short-term value of variable action.

The limit values of bending depend on serviceability requirements:

- road bridges l/700
- railway bridges 1/600 - l/1,000
- footbridges l/500

These approximate values shall be considered as limit values when no different values have been agreed in the bridge exploitation plan.

For railway bridges on rapid lines where train speed can exceed 160 km/h, special instructions shall be acquired from the client.

Bending due to structural dead loads and permanent actions including the corresponding long-term deformation shall be equalized with the camber.

12.3.5 Vibrations

Vibration can occur due to the following variable actions:

- rhythmic motion of humans such as walking and running
- road and railway traffic, etc.

Vibrations than can jeopardize the structure (such as resonance or loss of load bearing capacity due to fatigue) shall be included in the load bearing capacity verification.

The following measures can influence the vibrational behaviour of bridges:

- change of dynamic action
- change of structural stiffness or swinging mass
- increase of damping.

The vibrational behaviour can be assessed by means of comparing the frequency of an action with the bridge natural frequencies.

Natural frequencies shall be assessed in terms of their upper and lower values. Eventual effects due to carriageway surfacing, railings and other non-bearing structural elements, as well as the variation of the dynamic module of elasticity and, for concrete bridges, the transition from a non-cracked to a cracked state shall be taken into account.

In bridges intended for pedestrians and cyclists, natural frequencies between 1.6 and 2.4 Hz as well as between 3.5 and 4.5 Hz shall be avoided. However, runners can provoke natural frequencies for bridges of natural frequencies of 2.4 to 3.5 Hz as well.

12.3.6 Safety verification for fatigue

The safety verification for fatigue shall show that the fatigue effect of service loads does not affect adversely the structural bearing capacity in the bridge service life.

As a rule, the safety verification for fatigue shall be carried through for bridges stressed by road or railway loads, thus exposed to vibrations.

The fatigue safety can be considered as verified when the following condition is implemented:

$$S_{fat} \leq \frac{R_{fat}}{\gamma_{fat}}$$

S_{fat} : stress that causes fatigue
R_{fat} : fatigue strength
γ_{fat} : ultimate load bearing capacity factor for fatigue resistance verification

For the safety verification for fatigue, the service loads to be expected in the bridge service life can be presented in a simplified form by traffic models.

For steel load bearing elements as well as for steel reinforcement and pre-stressed systems of concrete bridges, the stress that causes fatigue corresponds to the difference in stress due to fatigue load.

$$S_{fat} = \alpha \cdot \Delta\sigma(Q_{fat})$$

α: service load factor
$\Delta\sigma$: difference in stress
Q_{fat}: fatigue load

The service load factor compares the fatigue effect of traffic models with the effect of fatigue load. It depends on the material

fatigue strength and shall be adopted from structural standards.
In case that no data is available, the value of 1.0 shall be taken for the service load factor.
Stressing of concrete that causes fatigue corresponds to the stress due to structural dead loads, to permanent actions, and to fatigue load:

$$S_{fat} = \sigma\left(G_m, \Sigma Q_r, Q_{fat}\right)$$

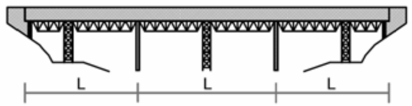
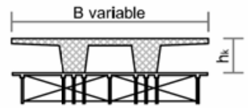
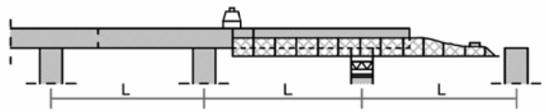
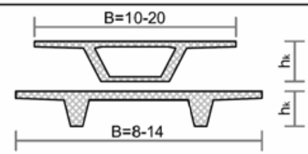
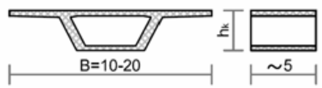
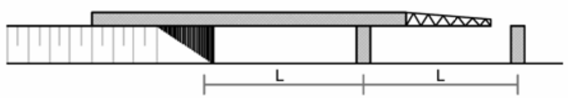
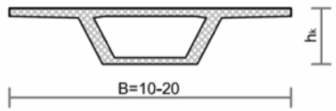
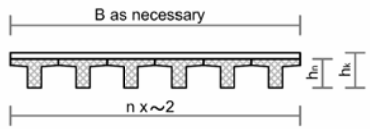
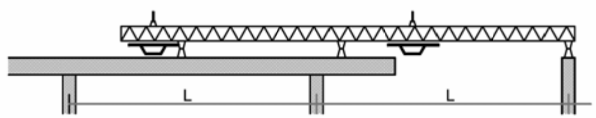
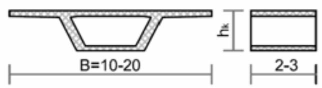
σ: stress
G_m: mean value of structural dead loads
ΣQ_r: sum of permanent actions
Q_{fat}: fatigue load

13. UP-TO-DATE BRIDGE CONSTRUCTION METHODS

13.1 Introduction

The aim of bridge construction development has been to reduce the construction costs, to shorten the construction time as well as to make the construction as independent as possible of the ground morphology, ground occupation and climatic conditions. The final objective of that development is to employ as many elements of industrial production as possible.
The up-to–date bridge construction methods described in the present design standard offer designers and other participants in the construction process the most important information only.
To design bridges constructed in accordance with an already known technology, the designer shall be necessarily acquainted in detail with all the technical, constructional, performing and other properties of equipment as well as of procedures made feasible by that equipment.
Up-to-date bridge construction technologies are related to the bridge load bearing systems and have been developing in accordance with the development of those bearing systems.
Since reinforced concrete or pre-stressed reinforced concrete beam or frame bridges prevail, it is fully understandable that the greatest number of construction methods has been developed and employed for these materials and systems.
A majority of beam and frame bridge construction technologies can be adopted to build structures above arches and decks of cable-stayed bridges. The procedures of construction of concrete arches will be described separately.
The construction methods of cable-stayed bridges are being developed, and almost every new significant bridge of such kind brings something new and original. In a simplified way it can be ascertained that the decks of cable-stayed bridges can be constructed by means of a formwork, free cantilever method (cast-in-situ or segmental), incremental launching procedure (using provisional supports or not), or other specific technologies.
Reinforced concrete and pre-stressed reinforced concrete beam and frame bridges of all the span lengths and total lengths are constructed in accordance with the three basic groups of construction technology (table 13.1):
A monolithic construction of bridge superstructures where the entire cross-section is cast in situ, within the bridge profile or next to it.
Composite pre-cast – monolithic construction of bridge superstructures.
Construction of bridge superstructures by means of pre-cast elements.
The construction technology is determined by the method of execution superstructures of beam and frame bridges.
Construction methods of abutments and piers will be discussed separately.
The construction procedures of reinforced concrete and pre-stressed reinforced concrete bridges have been modified, supplemented and innovated in the last fifty years. Some new procedures have been invented in order to harmonize the ideas of bridge designers, the equipment of contractors as well as the construction schedules and costs. A progress could only follow when contractors have anticipated their long-term profit based on the ideas of structural engineers.
The application of pre-stressed reinforced concrete pre-cast beams of different cross-sections has proven unsuitable to road bridges of non-continuous systems of spans n x (25-45 m) with expansion or elastic joints above supports as well as with pre-cast or semi-pre-cast carriageway slabs.
Transverse expansion joints or connections by means of hinges above supports, as well a great number of construction joints in the carriageway slab, represent weak points causing, among others, corrosion or reinforcement and damage of concrete, and reducing bridge durability.
Due to the abovementioned and other reasons, pre-stressed reinforced concrete pre-cast girders must not be used for construction of non-continuous bridges (having discontinuities above the supports) with pre-cast or semi-pre-cast carriageway slabs.

TABELA 13.1

UP-TO-DATE TECHNOLOGIES OF CONSTRUCTION OF BEAM AND FRAME BRIDGE SUPERSTRUCTURES		LONGITUDINAL BRIDGE SCHEME	BRIDGE CROSS-SECTION SCHEME	SPAN L v m / BRIDGE TOTAL LENGTH
TECHNOLOGIES OF MONOLITHIC CONSTRUCTION OF SUPERSTRUCTURES	CONSTRUCTION OF BRIDGE SUPERSTRUCTURES ON FALSEWORK		 AND ALL OTHER CROSS-SECTIONS	5-30 / 5-200
	CONSTRUCTION OF BRIDGE SUPERSTRUCTURES ON MOBILE FALSEWORK "SPAN BY SPAN"			30-50 / >400
	CONSTRUCTION OF BRIDGE SUPERSTRUCTURES BY CAST-IN-SITU FREE CANTILEVER METHOD			70-250 / 150-800
	CONCRETING AND INCREMENTAL LAUNCHING OF BRIDGE SUPERSTRUCTURES			25-50 / 200-800
TECHNOLOGIES OF COMPOSITE PRE-CAST - MONOLITHIC CONSTRUCTION OF SUPERSTRUCTURES	SUPERSTRUCTURE BUILT OF PRE-CAST T-BEAMS COMPOSITE WITH MONOLITHIC REINFORCED CONCRETE SLAB			5-30 / 5-200
TECHNOLOGIES OF PRE-CAST CONSTRUCTION OF SUPERSTRUCTURES	SUPERSTRUCTURE BUILT OF PRE-CAST REINFORCED CONCRETE SEGMENTS			30-120 / >500

13.2 Construction of bridge superstructures on a fixed false work

Concreting of bridge superstructures “in situ” on a fixed steel false work is economical for spans of 5 – 30 (40) metres and for bridge lengths of 5 – 200m.

Bridges of three or more spans can be cast in stages by transferring the false work from one stage to the other. Both the number of stages and the bridge length cast in one stage depend on several factors and shall be thoroughly analysed for each particular project.

A false work consists of the following load bearing elements: steel latticed girders of 5 – 30 m of span made of 3 – 5 (10) m long elements of 20 – 60 kN/m of load bearing capacity, depending on the span and the girder type. Serial standard elements shall have adequate documents.

False work supports are made of pipes of a greater diameter and unified lengths, as well as of pipes of a smaller diameter and of elements serving for height adjustment. It is reasonable to use bridge abutments and piers as false work supports, on condition that their stability is not jeopardized and that no lasting damage is caused.

False work foundation shall be conceived on the basis of the geological/geo-mechanical data including information on the ground bearing capacity and settlements.

Cross-girders and the formworks are made of impregnated and protected timber. They shall be unified in view of dimensions and shapes.

The false work design shall be prepared by the contractor and reviewed by both the designer the client’s engineer. Stability of the false work during casting and hardening of concrete shall be ensured. Appropriate data on cambers to ensure the designed bridge geometry shall be included in the design as well.

Prior to commencement of placing the reinforcement and tendons, the erected false work shall be inspected and approved.

Concreting is allowed only after acceptance of both the reinforcement and the tendons, as well as upon approved design of concrete, programme of concreting, and presentation of material certificates.

A programme of concreting is considered as adequate when the number of construction joints is small, in particular in the carriageway slab plane.

If all the works comprising erection of false work, placing the reinforcement and tendons, concreting, pre-stressing and grouting of tendons as well as of concrete treatment are carried out in accordance with rules and up-to-date comprehensions of the construction technology, a bridge superstructure will be durable and without any deficiencies.

The construction on a fixed false work does not condition the cross-section shape and dimensions as well as the superstructure geometry, which is by all means an advantage of that procedure. A complicated geometry, in particular obliqueness and twisting, increase the false work costs.

13.3 Construction of bridge superstructures on a mobile false work span-by-span

In situ concreting of bridge superstructures on a movable false work is used for pre-stressed reinforced concrete beam systems of 30 – 50 metres of span and of a total length above 400 metres.

A step or a stage is called construction of one length of which approx. 0.80 L is placed in one span and the remaining approx. 0.20 L as cantilever in the next one. Therefore, this technology is named “span by span”.

The load bearing element of a mobile false work consists of two 3D webbed or lattice girders of double span length or at least 1.5 times the span length, including an anchoring system. The movable girders are connected by hinges with formwork steel elements, which are opened at moving of the false work and closed prior to placing the reinforcement and tendons as well as to concreting.

The supports of the movable false work are steel elements supported as cantilevers and connected with piers.

There are several systems of mobile false work available on the market, with different characteristics and requirements – conditions in view of shape and size of the piers and of the superstructure cross-section.

A mobile false work has its own technical documentation and certificates to be verified upon each employment. The equipments shall also be checked and certified prior to its use to prevent adverse effects of eventual damage on the bridge stability during construction.

Bridge designers need all data on the mobile false work since the design shall be in accordance with possibilities, dimensions and conditions enabling the use of a false work. Piers of a constant rectangular cross-section, and superstructures longitudinally inclined by maximum 4%, consisting of one box section or two relatively wider beams without a cross beam, are preferred.

Opening on piers and superstructure required for a proper function of the mobile false work shall be indicated in the bridge execution design.

Due to a relatively heavy false work as well as to the transportation, erection and later on disassembling activities, such technology is not economical for shorter bridges.

Concreting on a movable false work “span by span” enables a relatively fast construction progress, since approx. 100 m per month or approx. one span per week can be achieved, on condition that reinforcement cages are made in advance.

One of the comparative advantages of that procedure of casting is a minimum number of construction joints, i.e. one joint in the area of neutral (zero) points where continuation of tendons is carried out.

13.4 Construction of bridge superstructures by cast-in-situ free cantilever method

The idea of free cantilever construction of bridge superstructures is about 65 years old whereas the first such bridges were constructed 50 years ago.

This technology is suitable to beam bridges of long and very long spans (70 – 250 m) running across high water hindrances or hardly accessible dry ones.

The construction progress is moderate, approx. one segment of 5 m of length per week. Four travellers enable a progress of 80 m per month for longer bridges. The procedure is most economical for bridges of a total length between 150 and 800 m.

The load bearing lattice 3D elements of mobile scaffolding – form travellers of a total length of approx. 10 m – enable concreting of segments of 5.0 m of length. The remaining length serves for anchoring onto already constructed cantilevered part of the superstructure.

A great number of different form traveller types are available, yet they are all similar in view of the structural principle and technology of casting of segments. Bridge designers shall have on their disposal all the data on the structure of form travellers, which might influence the scheme and details of a bridge.

The superstructure is of a rectangular or trapezoidal cross-section of a constant or variable depth between 2 and 15 m (the latter applies to the depth above piers at the longest spans). The cross-section width amounts 10 – 20 m, mainly from 12 to 15 m.

It is preferable when the superstructure either straight or in a curvature of a great radius (R > 700 m) depending on the span length. The fall of the vertical alignment should not exceed 4%. Symmetrical convex vertical alignments where the summit of the vertical curve is located in the bridge centre are the most appropriate ones.

Symmetrical parts of the bridge should be cast simultaneously to balance the deformations due to creep and shrinkage of the concrete thus realizing the designed geometry.

Concerning pre-stressing, there is usually a combination of shorter and longer tendons (internal and partly external ones). The external tendons cover the traffic load and can be installed and tensioned afterwards (after the continuity is established).

Concreting of segments is also possible during unfavourable weather conditions, since the form traveller can be closed and heated periodically.

For the considered procedure it is essential to solve the problem of connection between the deck and the piers. The base part of the superstructure of 5 – 10 m in length (one to two segments) can be executed in union with the piers as a rigid connection, or by means of introducing bearings with temporary anchoring which enables stability during construction.

By casting the final segment the superstructure continuity is established. In some bridges constructed at the beginning of application of this system, a reinforced concrete hinge or a bearing has been carried out in the mid-span. On the contrary, in the up-to-date bridge construction no hinges are allowed in the superstructure that must be continuous over its entire length.

Technical and certification documents of the steel form travellers shall be available and verified prior to each use. The same applies to the entire structure and equipment required to execute the construction works.

13.5 Concreting and incremental launching of bridge superstructures

The procedure of incremental launching of pre-stressed reinforced concrete bridge super-structures has arisen from the incremental launching and erection of steel girder bridges.

This procedure has been applied, developed, innovated and modified for more than 35 years. For the first time it had been introduced in Germany by Prof. F. Leonhardt. Later on the procedure was adopted in all developed European countries.

For the considered technology, economical bridge spans amount to 25 – 50 m, whereas reasonable total lengths are 200 – 800 m.

The construction progress depends on the length of the elements to be cast in one single piece on site, and amounts to 80 – 120 m per month.

The equipment for incremental launching procedure consists of a site-workshop for concreting of sections or entire spans, of equipment for launching for complete sections, and of launching steel nose.

The site-workshop of a length of 15 to 40 m is made of steel and supported by strong concrete foundations. It shall be non-deformable and adjusted to a variable geometry of box cross-sections of superstructures. The site-workshop is erected behind the bridge abutment on that bridge side, which is higher and has better traffic connections.

The launching equipment is placed on top of the abutment behind which the workshop is located. The abutment top is designed to be adapted to dimensions and function of the launching equipment. The entire abutment shall be verified in view of actions occurring during the erection and, if necessary, it has to be strengthened. After launching of the deck and dismantling of the hydraulic presses, the abutment takes its basic function, i.e. the end support of a bridge.
The steel nose of 20 – 35 m of length is a 3D lattice or webbed structure of variable height, consisting of two parallel girders in the plane of the superstructure webs, and of the wind bracing. On its higher part, the launching nose is connected with the concrete deck by means of high-strength bolts or anchors. On the lower part of the nose, a “sledge” or hydraulic jacks are placed. Their function is to adjust mounting of the nose onto piers.

Both the weight and the price of the launching equipment depend in particular on the superstructure section to be cast in one piece, and on the span. For spans longer than 40 m introduction of provisional supports in mid-spans might be more economical than an increased amount of pre-stressing tendons.

For the incremental launching procedure it is desirable that the superstructure is straight or in a curvature of a constant radius, without twisting and changing the cross-section width. The vertical alignments can run in a constant slope of up to 4 % or, if required, in a vertical curvature.

The superstructure cross-section of bridges and viaducts is trapezoidal or rectangular box of 10 – 20 m of width. Constant thicknesses of webs, of upper slab and of lower slab are desirable. Cross girders are located only above the supports, which makes the work easier and reduces the construction time.

The pre-stressing tendons can run through the webs and slabs, externally or combined, depending on the span length and designer’s decision. It is recommendable to lead tendons through the slabs.

The tendons are extended on such locations where the moments are minimum. In one single section maximum one half of the tendons may be extended. Coupling of tendons in the carriageway slab is not permitted.

The launching equipment shall be re-checked prior to the next use. In addition, design documents and certificates shall be verified, particularly for the elements where the validity of the certificates is limited.

13.6 Bridge superstructure of pre-cast T-beams and monolithic reinforced concrete slab

In the recent fifty years of application of pre-cast pre-stressed reinforced concrete beams for bridge superstructures a great number of different beam cross-sections as well as of superstructure cross-sections composed of those beams has appeared.

The cross-section shape has been influenced by the production, transport and erection costs, by the similarity of superstructure cross-section systems, and by the durability considerations. All types of beam cross-sections designed in such a way that a later access to certain places is not possible are not desired although they are lighter. Beam cross-sections where the carriageway slab is executed in the plane of the upper flange are less durable and therefore unwanted as well.

Beams of a T-cross-section and the upper flange of 2.0 m (2.5 m) width are simple to fabrication and erection as well as accessible to maintenance. T-beams enable casting of the carriageway slab and cross beams without a scaffold. Since both the prefabricated and monolithic portion of the cross-section are made composite a uniform cross-section is achieved to take both the traffic load and additional dead load.

Beams of a length of 5 – 20 m are cast and pre-stressed on a production line. Longer beams (> 20 m) are post-tensioned using appropriate tendons.

A simple cross-section of a pre-cast beam facilitates adaptation to different widths and geometries of superstructures. They can also be used for oblique bridges (angle of crossing up to 60°) as well as for curved ones.

By an in situ casting of both the carriageway slab and cross beams, and by placing of the required longitudinal reinforcement or by continuation of the tendons, a continuity required for taking the traffic load is achieved.

The superstructure can be connected with the substructure by means of bearings, reinforced concrete hinges, or rigidly to form a frame structure, which depends on the bride length, pier height and other circumstances.

Pre-cast beams weigh 5 – 40 tons. They are transported by means of trailers and erected with mobile cranes or a launching structure. Such beams are economical for bridges up to 200 m of length as well as for shorter single-span bridges where a rigid connection without any bearings and expansion joints can be established via an integral pier.

Cross-sections of superstructures shall be calculated as composite beams taking into account different ages and qualities of the concrete of prefabricated beams, carriageway slab and cross beams.

The minimum thickness of the carriageway slab above the pre-cast beams amounts to 20 cm, whereas the minimum width of a cross beam above the pier is 80 cm.

A composite connection of pre-cast beams and carriageway slab is enabled by dowels placed over the both entire length and width of the beams designed to withstand shear stresses. The dowels are made of reinforcing steel being a constituent part of the beam reinforcement.

13.7 Construction of bridge superstructures of pre-cast reinforced concrete segments

Construction of bridges using prefabricated reinforced concrete elements commenced in France in 1962.

Cross-sections of bridges made of pre-cast elements are predominantly trapezoidal and rectangular boxes of 10 – 20 m of width, of 2 – 3 m of length, and of 2 – 6 m of height. If necessary, the height can be variable too. For the considered procedure simpler cross sections are feasible as well, e.g. cross-section composed of two wide trapezoidal beams.

For bridge construction of prefabricated segments, the most economical spans are between 30 and 120 m. The length of a bridge or of a group of bridges should be at least 500 m.

Straight bridges where the vertical alignment is inclined by up to 4% are desirable. Of course, segments can be used to construct curved bridges as well; however, prefabrication is more complicated in such case.

Segments can be fabricated either at already existing workshops or at a new workshop located close to the bridge or group of bridges, on condition that such a solution is economically justified.

Formwork for production of segments is made of steel. It shall be non-deformable and equipped with a mechanism enabling a rapid opening and closing. The formwork shall be capable to adapt itself to the variable geometry of the cross-section. For one bridge or a group of bridges two or three formworks are required to enable simultaneous concreting of adjacent joints. A system of vibrators is connected with the formworks.

Reinforcement cages shall be prefabricated. Pre-casting is carried out in a closed warm space. The concrete can be heated with steam or not, depending of the design of concrete, method, and production progress. The production of segments is independent of the weather, which is a major advantage of this technology. Only the application of epoxy compounds used for the joints between segments is weather dependent.

Loading on trailers, transportation and erection of segments are very different, depending on the volume and weight of a segment, remoteness of the workshop, access roads, and available equipment.

Segments can be erected by the free cantilevering method, i.e. symmetrically with regard to the piers, as described in 13.4. Steel cantilever elements, which take the segments, are anchored to the superstructure portion already erected. After the treatment of the joints, a segment is connected by means of tendons to the deck portion already executed.

For an individual erection of segments steel latticed “launching” structure can be employed.

Segments can also be erected in a group by the “span by span” method on a movable false work (refer to 13.3), or on a fixed false work (refer to 13.2). However, such technologies are employed to a minor extent.

Two types of segments have been developed: segments with a wide wet joint (70-100 cm) and segments with a tight contact joint.

The procedure with a wide wet joint is less complicated in view of dimensional accuracy, and enables overlapping of the longitudinal reinforcement. However, a segment shall be held up until the joint has hardened, which is disadvantageous and the reason of abandoning this method.

Nowadays, tight joints with toothed contact surfaces and epoxy adhesive compounds are used.

In a simplified form it can be established that the crucial factor of a successful segmental construction, i.e. of quality and durability of segmental bridges, is the achieved performance of the joints between segments. The development as well as a wider and wider use of pre-stressing of superstructures with external tendons is advantageous for easier and more reliable use of the segmental construction technology.

Segmental construction requires a higher technical level and experienced designers, contractors, supervisors and maintenance staffs.

13.8 Up-to-date methods of bridge pier construction

Bridge abutments are always cast in situ using a formwork of an adequate stiffness and with suitable supporting elements.

The formworks shall be shaped in accordance with the abutment geometry and the arrangement of construction joints. By an appropriate design of both formwork and supporting elements non-deformability and stability shall be ensured until the concrete hardens.

Bridge pier construction depends on the cross-section shape, the height and number of piers belonging to one bridge or to a group of bridges being constructed simultaneously.

For bridges and viaducts on motorways and other roads, piers shall be cast in situ.

Casting in situ of piers can be carried through in three different ways depending on the cross-section shape as well as the height and number of piers.

Piers of a variable cross-section and small height shall be concreted by means of a fixed formwork of suitable stiffness and with supporting elements.

Piers of a constant full or hollow box cross-section and of a height greater than 15 m shall be executed by means of a unified movable (climbing) or sliding formwork in segments of 3.0 – 4.0 m in length.

A movable (climbing) formwork is mechanically, i.e. without any help of hydraulics, transferred upwards to be ready for casting of the next segment.

A sliding formwork is moved simultaneously with the system of hydraulic jacks in accordance with the progress of casting and hardening of concrete.

13.9 Up-to-date methods of concrete arch construction

Concrete arch bridges have been constructed for more than 100 years. Up to the fifties arches were concreted on scaffolds similarly as stone arch bridges had been constructed before. Innovations in view of concrete arch construction related mainly to the scaffolds. Instead of false work closing the entire profile of an obstacle, false works with timber or steel arches are employed for longer spans and in case of deep valleys or rivers. Such false works embrace the entire profile or a part of the profile of an obstacle.

In principle four basic methods of arch bridge construction exist:

- arches executed by means of a false work
- arches executed by free cantilevering
- arches executed by rotation of already constructed arch portions
- arches executed by a combined method.

Nowadays, a false work is used to construct for shorter spans of 40 to 100 m crossing lower and accessible obstacles. For longer spans and arch heights a steel arch girder consisting of two or three sections and without any supports can be foreseen, which depends on the contractors’ capability and equipment.

A free cantilever construction of long-spanned arches (of 100 to 400 m) commenced three decades ago. As a consequence, arch concrete bridges have become competitive for long spans as well. Arch segments of 3 to 5 m of length are concrete on a form traveller. Arch sections already executed are anchored by means of stay cables to the portion of the structure already built or to special anchor blocks.

The construction is carried through simultaneously from both sides.

The superstructure above the arch can be cast either simultaneously with the arch or subsequently when the arch is already connected.

Arches executed by rotation of already constructed vertically concreted arch halves are only suitable to medium spans, i.e. of 70 to 100 m. During the concreting procedure, the arch represents a curved girder with a steel hinge at the bottom. By relieving of sty cables both arch halves are joined and a complete arch is formed.

A mixed method of arch construction is a combination of both a procedure with a false work for lateral arch portions and a free cantilevering procedure for the central, inaccessible arch part. It is also possible to execute the lateral arch portions by free cantilevering and the central portion by means of a false work supported by the ends of the portions already accomplished.

A design of arch bridges as well as of bridges of other load bearing systems is only successful when the construction procedure is comprehended and solved at the same time.

A deficient knowledge of arch bridge construction technologies as well as the almost abandoned execution of these beautiful bearing systems should not be a reason for their decreased application. A rational solution of the construction method can make this system competitive with regard to beam and frame systems.

14. STAGES AND CONTENTS OF BRIDGE DESIGN DOCUMENTS

The design documents for construction of road bridges include the following:

- preliminary scheme
- preliminary design
- construction permit design
- tender design
- execution design

Preliminary scheme includes a sketch and description of essential characteristics of the planned construction.

Preliminary design is a systematically arranged composition of drawings enabling the investor to select the most adequate alternative of the planned construction.

Construction permit design is a systematically arranged composition of drawings enabling the relevant authority to estimate all the circumstances essential to issue the construction permit.

Tender design is a systematically arranged composition of drawings enabling the investor to select a contractor.

Execution design is actually a construction permit design supplemented by detailed drawings enabling execution of construction in accordance with the conditions indicated in the construction permit.

The technical documents for bridges include the following:

- as-built design
- maintenance and operation design

As-built design is actually an execution design supplemented by presentation of all the works executed as well as of eventual modifications of any constituent part of the execution design that might have occurred during the construction. On the basis of the as-built design, the participants of the technical inspection can establish whether the constructed or reconstructed bridge is in accordance with the construction permit.

Maintenance and operation design is a systematically arranged composition of illustrations, drawings and texts in a form of warranties, certificates, lists, catalogues, schemes, instructions and similar documents specifying operation and maintenance rules for the particular constructed or reconstructed bridge as well as of the equipment and installations in/on the bridge. The maintenance and operation design enables owners to maintain their bridges in a suitable way.

In the table 14.1 stages of both design and technical documents for bridges are indicated, as well as their interdependence with the equivalent design and technical documents for roads. In addition, fundamental purpose of individual design stages is presented.

Mandatory contents of the technical report being a constituent part of both preliminary design and construction permit design is as follows:

- general data on the bridge
- bases for bridge design
- bridge scheme and dispositional element
- geological/geo-mechanical data and foundation recommendation
- bridge structure
- bridge equipment
- basic materials
- construction method
- operation and maintenance conditions.

Table 14.1:

STAGES OF ROAD DESIGN	STAGES OF BRIDGE DESIGN	PURPOSE
PRELIMINARY SCHEME (studies and analyses)	Cooperation of bridge designer in elaboration of design specification for the bridge design.	Optimum bridge scheme in particular with regard to the bridge geometry.
PRELIMINARY DESIGN	**Bridge preliminary scheme** This is a mandatory constituent part of the road preliminary design.	• Definition of bridge load bearing system, length and width • Determination of basic materials and construction method • Base for cost estimation • Assessment of geometry correctness • Foundation proposal.
CONSTRUCTION PERMIT DESIGN	**Preliminary design** • Preliminary design is conceived on final bases. • Among others preliminary design includes fundamental arrangement drawings (layout, plan, longitudinal section, cross-section as well as cross-sections through all the supports). • Design calculation to an extent ensuring bridge safety and suitability of selected dimensions and quantities.	• It is constituent part of the road construction permit design • It supplements the road construction permit design, specifies both value and function of the bridge.
TENDER DESIGN	**Tender design**	• It is an abstract from construction permit design or preliminary design defining geometry, safety, function and material quantity. • It enables the investor to carry through an invitation for tenders.
EXECUTION DESIGN	**Bridge construction permit design**	• It ensures stability, load bearing capacity and function of the bridge • Definition of bridge geometry • Implementation of location and aesthetic requirements • It takes into account requirements by relevant authorities as well as requirements indicated in relevant guidelines • Selection of construction method.
EXECUTION DESIGN	**Bridge execution design**	It enables bridge execution and includes the following: • Formwork, reinforcement and tendon drawings • Workshop drawings and details • Bridge equipment drawings • Construction method • Influence of construction on stability.
ROAD AS-BUILT DESIGN	**Bridge as-built design**	• It is elaborated simultaneously with the construction • It contains all modifications and supplements of the execution design • It shall be preserved and will serve for inspections, maintenance and reconstructions.
ROAD MAINTENANCE DESIGN	**Bridge maintenance design**	• It gives instructions for bridge management.

15. CRITERIA FOR EVALUATION OF ALTERNATIVE (COMPETITIVE) SOLUTIONS

For large and significant bridges two or three alternatives of the preliminary design shall be elaborated. Another option is to acquire several solutions by means of a competition.

The jury that evaluates alternative or competitive solutions shall master all the essential criteria to estimate the value of submitted proposals.

The criteria for evaluation of alternative solutions can be divided in five basic groups:

15.1 Criteria related to the particularities of the location and to the bases having served for elaboration of alternative (competitive) solutions

- morphology of the obstacle
- geological/geo-mechanical conditions
- meteorological-climatic conditions
- seismic conditions
- conformity with the road bases

15.2 Constructive-technological criteria

- modernity and originality of the bridge scheme
- bridge load bearing system
- elements of originality of the selected load bearing system
- elements of originality of the structural scheme
- materials for the bridge load bearing structure
- conformity of the static-constructive bridge scheme with all the specific conditions of the bridge location
- span lengths, span ratios on the entire bridge length in view of the internal forces and moments, material consumption and construction method
- layout of piers with regard to the morphological properties of the ground, to the pier height and to the geological/geo-mechanical conditions
- scheme and constructive solution of the bridge superstructure cross-section
- scheme and constructive solution of the piers
- scheme and constructive solution of abutments including the connection with the road body
- pier and abutment foundation
- bridge equipment
- up-to-date construction technologies and their conformity with the location particularities and with the static-constructive bridge scheme
- superstructure construction method
- pier and abutment construction method
- foundation construction method
- reliability (safety, durability) and service life of the bridge
- required space to organize the construction site, accesses to the site
- use of adequate materials.

15.3 Criteria related to bridge aesthetics and preservation of natural environment

- shaping of individual elements of bridge structure and equipment
- mutual harmony of structural elements as well as conformity of bridge structure with bridge equipment
- incorporation of the bridge into the natural environment
- a harmonized connection of the bridge and the road at both bridge ends
- ecological criteria (water and air protection, protection from noise, preservation of biotops)
- putting in order the area below and next to the bridge after completed construction.

15.4 Economical criteria

- bridge construction costs
- bridge operation and maintenance costs

15.5 Criteria related to bridge operation

- traffic comfort and safety on the bridge
- structural vibrations and deformations
- criteria and conditions for regular maintenance and for inspections of bridge structure and equipment
- possibility of bridge rehabilitation (repair, reconstruction, strengthening)
- possibility of exceptional transports of size and load greater than the standard values
- position, accessibility and maintenance of bridge installations.

16. TEST LOADING OF BRIDGES

Test loading is a condition for the technical inspection and issuing of operation permit for road bridges of spans > 15 m and railway bridges of spans > 10 m (there are no EC standards for test loading bridges).

Test loading shall be carried out in accordance with the standard JUS U.M1.046 specifying the types of test loads, test method, evaluation of test results and report of the test loading.

Both bridge designer and the engineer responsible for the execution of the test shall prepare a programme of the test loading. The programme shall include the following:

- magnitude and arrangement of the load by stages
- calculation of expected deflections and deformations
- arrangement of measuring spots
- organization chart of the test.

Both the position and the magnitude of the load for the test loading are determined by the structural design. Both static and dynamic loading usually corresponds to the loading in bridge operation.

Prior to working out the programme of the test loading the following shall be studied:

- bridge design documents (construction permit design, execution design, as-built design)
- documents indicating the quality of construction materials
- a macroscopic inspection of the bridge.

The basic objective of the test loading is to verify the bridge behaviour in view of the design assumptions and it capability of taking the design traffic loading.
Are the results of the test loading of a bridge negative, the load bearing structure shall be improved and the test loading shall be repeated.

A report of the load testing of a bridge can be either:

- a provisional report including fundamental data and conclusions, or
- a final report including all the data on the bridge, a comparative design calculation, an analysis of calculation and test results as well as a conclusion whether the bridge is capable to take the design loading.

A copy of complete documents related to the test loading shall be submitted to the bridge designer. In this way, the latter will be able to establish a correctness of the selected design model as well as of both static and dynamic analysis of the bridge.

17. KEEPING OF DESIGN AND TECHNICAL DOCUMENTS

17.1 Introduction

Recently the extent of information related to different domains that has to be processed and preserved is increasing constantly. Engineers need a complete and simple review of existing design and technical documents. In addition, other divisions such as marketing, purchasing, construction, control and maintenance department use those documents as well.

In the field of design and technical documents the following three stages are considered:

- designing
- using
- preserving

Design and technical documents shall be:

- passive and active
- available in a graphical-analogous form distributed among different services, departments and other users
- available in a simple way and clear, and their reproduction shall be of a high quality
- resistant to different external impacts
- suitable for a simple distributing and dispatching
- on such a medium that ensures a simple supplementing, rectifying and processing
- durably, safely and clearly saved on a reliable medium being credible and legally recognized in case of eventual disputes.

17.2 Advantages of a microfilm data card (MDC)

Microfilm as an information medium has existed for 100 years. Experiments have shown that the durability of an up-to-date microfilm amounts to more than 1,600 years.

The capacity of saving information on a MDC (measured in bit/mm^2) is incomparably greater than on disks.

A MDC with a silver-halogen film is stable more than 150 years, which has been found out by means of a simulation. It resists humidity and temperature up to 150°C, and does not lose colour at light. As such, MDC represents a medium internationally legally recognized.

Employing MDC a quick and simple distribution and use of drawings and other documents is ensured. MDCs are rational in view of their form and volume thus being very suitable to despatching and preserving.

A MDC is equipped with the OCR writing and a barcode enabling a faster searching for and sorting out of data by different criteria. A user can add the time and type of eventual changes by manual writing. He can keep the basic MDC for comparison or deposit it in the central archives. A MDC does not include only a drawing, but also other data that facilitate the work on the particular drawing (it can serve as a card-file).

17.3 Common denominator of MDC

When a MDC is brought to a common denominator of both classical and computer-aided design and technical documents, it shall be emphasized that the MDC enables a connection in all the directions:

- data transfer from classical drawings onto a MDC by means of cameras (photo-method)
- data transfer from computer media onto a MDC by means of a CADMIC device (laser method), and from the MDC onto the computer media by means of a SCANNER that can scan up to 350 drawings onto an electronic medium. By means of a scanner the missing link between the analogous and digital system is ensured. A scanned drawing can be corrected on the computer and directly plotted on paper via laser plotters.

17.4 Preparing of design and technical documents for keeping

Clients (investors) shall define the way of coding the works and the basic data to be written on the drawings, which is a base for each designing company to enter the data uniformly in the medium kept for records.

Design and technical documents to be preserved shall be submitted in an original or transparent form, or on a plain paper to ensure a quality copying. It shall not be on a paper that loses colour since it is unsuitable to be copied onto a MDC.

Keeping of documents on CD-ROMS is reasonable up to their final preserving that is carried through on a MDC serving for final archives of long duration.

After completion of construction works, the eventual changes having been entered in the drawings manually shall be handed over to the designer who draws them either electronically or classically. Such documents is prepared for a final keeping in records either

- digitally via laser printer/plotter onto a MDC or a CD-ROM, or
- from the paper via camera onto a MDC.