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PRESENT SITUATION AND DEVELOPMENT OF BRIDGES

Summary

The present situation and development of bridges can be presented by four groups of real needs, tendencies, and wishes:

- *Need of as well as permanent tendency for longer spans;*
- *Reduction of dead load and increase of live load;*
- *Increase of reliability, durability, and service life of bridges;*
- *Reduction of construction and maintenance costs.*

The modern theory and practice realize such needs and wishes by eight characteristic development tendencies:

- *Progress in the structural theory, computerization of the entire design process;*
- *New materials and combination of existing ones;*
- *Conceptual and detailed solutions to increase the bridge durability and reliability;*
- *Integral bridges;*
- *Design of the bridge cross section;*
- *External pre-stressing;*
- *Updating of bridge construction procedures;*
- *Development and application of cable-stayed bridges.*

Key words:
bridge, concrete, durability, reliability, integral bridges, cross section, present situation, development, application.

1 BRIEF PRESENTATION OF THE PRESENT SITUATION OF BRIDGE CONSTRUCTION

1.1 Introduction

It is always useful to raise a basic question what in fact a bridge is: a serviceable structure, an engineering structure, a mechanism which vibrates, becomes fatigue or deteriorates, an architectonic building or a civilization and cultural monument.

The majority of bridges are serviceable structures consisting of a load bearing engineering structure and of equipment.

Only few bridges, taking into consideration their location, largeness, spans, total length, purpose, conception, design and construction technology, are not only serviceable but also symbols of technical, civilization and cultural achievements in space and time.

A bridge springs up as a composition of morphological-geological-hydrological characteristics of the location, engineering structure, purpose, material, form, construction technology, safety, durability, economy, and interpolation into the natural and urban ambience.

A bridge is not modelled but designed in accordance with natural conditions of a hindrance, communication elements, and rules of construction theory and practice. The success of a bridge composition is a result of knowledge, experience and ability of the designer.

According to the literature information, there are more than two millions of bridges in service in the world, among them over 80% made of concrete. The bridges are the most expensive, the most sensitive, and the most important parts of roads and railways, in particular of the modern motorways and high-speed railways.

1.2 Necessity of and permanent tendency for longer spans

- Bridges are constructed at locations where there is a real need that some communication (road, railway) overcomes a natural or artificial hindrance. Therefore, a verification of their necessity is relatively simple.

- Beside numerous bridges, viaducts, overpasses and underpasses on motorways and high-speed railways, in recent decades connecting of islands and land, bridging of fjords, wide rivers and deep valleys, as well as passing of motorways and high-speed railways over urban areas has been intensified.

- The spans, total lengths and heights of all load bearing systems (beam, arched, suspended, cable-stayed) and all materials (steel, concrete, composite cross sections) have attained extraordinary dimensions that nobody could have imagined only 50 years ago.

- The beam concrete bridges are the most frequent ones on the existing and new communications. The spans of concrete bridges vary from 5 to 300 metres, while their total lengths from 10 metres to 20 kilometres. A span of 300 metres was achieved at the Raftsundet Bridge in Norway, at the Prince Edward Bridge in Canada as well as at some bridges in Japan.

- The beam steel bridge Niteroi in Rio de Janeiro of a total length of 14 kilometres with a main span of 300 metres and a box webbed cross section was built in 1975. Beam steel lattice bridges of record spans of 518 and 548 metres were constructed already at the beginning of 20th century in Scotland and Canada.

- An arch concrete bridge connecting the largest Adriatic island Krk with the land having a span of 390 metres and consisting of a three-cell box section built by the cast-in-situ free cantilever method was a record holder up to 1997. In that year, an arch bridge called Wanxian of 425 metres span was constructed in China. The box cross section of the arch comprises steel pipes surrounded by concrete.

- An arch steel bridge of a record arch span of 518 metres constructed in 1976 in West Virginia (USA).

- Since the Brooklyn suspension bridge built in 1883 and having a span of 486 metres up to this day, the suspension bridges have attained extremely long spans. The representative central span between pylons of the Akashi Kaikyo Bridge in Japan amounts to 1,990 metres.

- Cable-stayed bridges experienced the most dynamical and the fastest development in the last 50 years. Only 40 years passed from the Stroemsund Bridge in Sweden built in 1995 and having a span of 182 metres up to the Normandie Bridge in France built in 1994 and having a span of 856 metres.

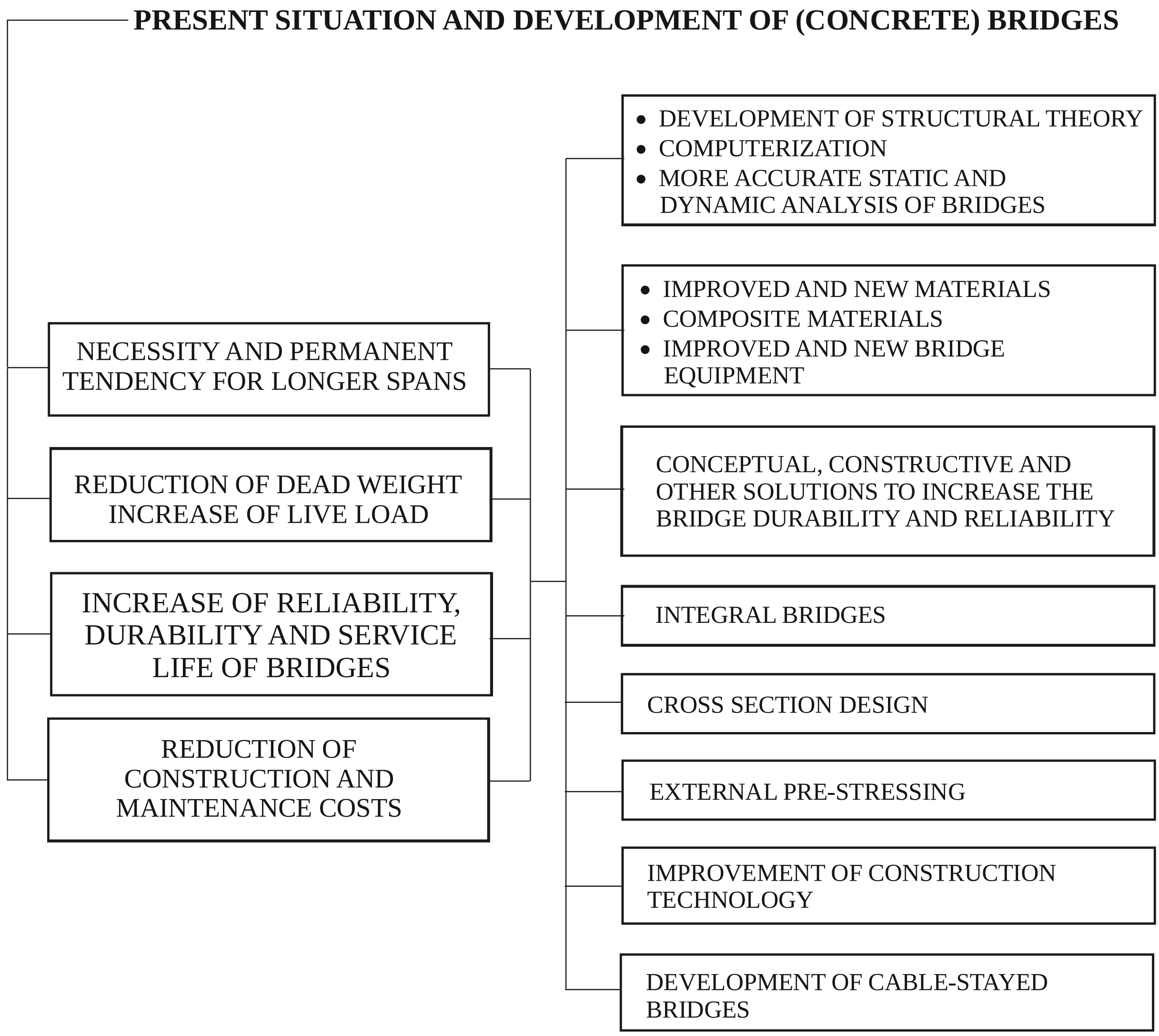


Figure 1: Schematic presentation of bridge present situation and development

1.3 Reduction of bridge dead weight and increase of live load

One of the important characteristics or deficiencies of the majority of concrete bridges is a significant influence of the dead weight on the internal forces and moments which can attain values of 50-80 % of the total internal forces and moments.

There is a permanent tendency for an increase of the load of road and railway bridges which is a consequence of real needs of the economy and development. In the 20th century, the weight of the standard vehicles increased from 120 kN to 1,000 kN, i.e. by a factor close to 10. For transportation of steam generators for nuclear power plants having a weight of up to 7,000 kN, special vehicles comprising a great number of axles and wheels must be introduced.

The concrete dead weight can also be reduced by introduction of light aggregate of specific weight of approximately 200 kN/m^3 or by a high strength concrete. For long span bridges (above 200 metres), lighter composite and steel structures are advantageous.

High strength concrete and external pre-stressing, i.e. pre-stressing out of concrete section, enable a reduction of cross section and thus also reduction of bridge superstructure weight. In particular, a reduction of thickness of vertical webs of box girders which are the most frequent sections for bridges of spans above 30 metres is possible.

1.4 Increase of reliability, durability, and service life of bridges;

A great number and extent of damages of pre-stressed concrete bridges, especially of those having been constructed as pre-cast ones, drew attention of investors and experts to research work and solutions increasing reliability and durability of bridges.

For the moment, a service life of bridges of 80-120 years is a category specified in advance that must be achieved by a correct investment policy, research work, good design and solid construction. The durability of concrete bridges is mainly influenced by a proper conception, design solutions, construction technology and quality, selection of materials, particularly of concrete, correct equipment design, especially of dewatering, and regular bridge maintenance.

In Slovenia, Guidelines for Bridge Design (*SODOC*) have been worked out, comprising up-to-date guidelines, instructions and details thus influencing essentially on bridge safety and durability.

An increase of bridge reliability requires additional financial means. However, they are relatively moderate taking into consideration the benefits, especially in view of maintenance cost reduction.

By a careful selection of materials for surface protection in connection with the bridge location and environmental impact, it is partly possible to increase the durability of structural elements of a bridge and to reduce the maintenance costs.

1.5 Reduction of construction and maintenance costs

A permanent and positive aim of investors is to reduce the construction costs, however under condition not to jeopardize the construction quality and bridge reliability. Construction costs can be reduced by a good and up-to-date structural design, a correct selection of modern construction technologies, and a market competition among capable and professional contractors. Bridges constructed according to the increased durability criterion, require lower maintenance costs. A correct and due damage repair on bridge structures and equipment, in particular on the dewatering system, reduces the extent and costs of repair and reconstructions. However, investors' wishes to achieve unreal low prices and short construction periods lead to durability decrease and maintenance cost enhancement.

2 DEVELOPMENT OF UP-TO-DATE BRIDGES

2.1 Introduction

Figure 1 schematically shows the answers of the modern advanced bridge practice and development to four wishes and tendencies in bridge construction analysed above. The answers are given in eight groups having a considerable mutual influence.

Due to a limited extend of the present work, the group 1 (*development of structural theory, computerization, more accurate static and dynamic analysis of bridges*) is not analysed specially since that group is an extra entirety in view of its character and extent. In this work, groups 2, 3, 4, and 5 will be analysed.

2.2 Improved or new materials and equipment of bridges

In the 20^{th} century concrete was by far the most used material for all kinds of structures. The extent of use of concrete is growing in all countries irrespective of their technical level. It can be said with certainty that such a progress will proceed, extending the use of concrete, among others, to the structures of the traffic infrastructure as well.

For bridges and viaducts it is desirable and reasonable to reduce the cross section dimensions and the superstructure dead weight that can be attained by introducing the high strength concrete. The research work in the field of high performance concrete has been initiated by the extent of concrete damages.

At introducing of high performance concrete the mistake should not be repeated, namely that the high performance concrete is a new material as this was considered at introducing the pre-stressed concrete, in particular insisted by Freyssinet. It should be distinguished between the high strength concrete (HSC) and high performance concrete (HPC). Beside the high strength, the high performance concrete has better properties with regard to the durability and resistance against aggressive media.

In practice, the concrete is divided in three categories:
- normal structural concrete of nominal strength of 20-60 Mpa
- high strength concrete of characteristic strength of 60-100 Mpa
- extremely high strength concrete of characteristic strength of 100-250 Mpa.

The basic components of high performance concretes are the same as in case of concrete of normal strength. To achieve higher strength, a part of cement is replaced by mineral admixtures (microsilica, fly ashes). By adding mineral admixtures, the calcium hydroxide is converted into calcium silicate hydrate in the pozzolanic reaction resulting in the strength increase.
The improved characteristics of high performance concrete are the following:
- high strength in comparison with the dead weight which is especially the case for light-aggregate high performance concretes
- a rapid achievement of high strength enabling faster construction
- higher abrasion resistance
- higher freeze resistance
- lower water absorption, lower coefficient of CO_2 and chloride ions diffusion as well as better corrosion protection of steel reinforcement

- better properties in view of creep and shrinkage.

The deficiencies of the high performance concrete are the following:

- higher price in comparison with the normal structural concrete
- more rigorous control of composition and performance of concrete
- the increase of rigidity is not proportional to the increase of strength
- by increasing the compressive strength, the high performance concrete becomes more breakable, its toughness is reduced which is unfavourable for taking the dynamic loads
- the tensile strength increases much more slowly than the compressive strength, while the value of the elasticity modulus increases even more slowly than the tensile strength
- a very dense structure does not allow the water to evaporate from the cement stone which reduces the fire resistance of concrete.

For the bridge construction, the application of high performance concrete commenced 30 years ago, while in the last 10-15 years, its use became more intensive.

The light-aggregate concrete is used for beam bridges of extraordinary long spans in order to reduce their dead weight. The price of light aggregates of suspended clay as well as the quality requirements are not economically justified and cannot withstand the competition of the high performance concrete made of normal aggregates.

A truly new and potential material for bridges and other load bearing structures is fibre reinforced plastic (FRP). The three most frequent FRP types for the passive reinforcement and pre-stressed tendons are the following:

- carbon fibre reinforced plastic (CFRP),
- glass fibre reinforced plastic (GFRP), and
- aramid fibre reinforced plastic.

A great number of existing concrete bridges have already been strengthened with carbon strips. Mechanical and other material characteristics as well as calculation examples can be found in the manufacturers' material data sheets and guidelines. For all interested gentlemen I am pleased to point out a very good manual of the Italian company SINIT from Rovigo.

The trend of composite structures is progressing. Beside composite steel-concrete structures there are also composite structures comprising concretes of different age and/or quality, timber beams – concrete slabs, etc. New materials are also composites of plastics as well as of carbon, glass or aramid fibres.

A new and promising material is lamellar glass not only as a functional-decorative but also load bearing material used for horizontal bent and vertical elements and structures on which combined loading is acting.

To the new equipment for bridges also belong the **dampers** for bridge seismic isolation. The latter can be achieved in two ways:

- The usual method where the seismic forces are entirely taken by the bridge structure allowing plastic deformation of structural elements and therefore damages as well. The basic problems of this approach are the following:
  - to establish a relation between allowed degree of reduction of seismic forces and correctness of the structural design;

- in the design stage it is assumed that the structure will be damaged during a strong earthquake which is problematic for some significant bridges.

- An alternative solution is to reduce the seismic energy by bridge isolation; this solution is relevant for earthquake zones VIII and IX:
  - on the bearing level dampers to reduce the seismic energy are placed into the bridge structure;
  - a bridge is fully seismic isolated if the structure remains within the range of elasticity;
  - the dampers are a constituent part of the load bearing system an can be replaced after an earthquake event.

For the moment, new and better types of **bearings and expansion joints** are available on the market. Particularly bearings and expansion joints allowing significant movements have experienced essential progress recently, while expansion joints for minor movements of up to 100 mm are still a weak spot since they are not perfectly waterproof, they are expensive, their durability is insufficient and their replacement is complicated.

The technical solutions of **safety barriers** do not follow the requirements imposed by traffic, i.e. they do not prevent vehicles from falling from the bridges. In the European Community a code concerning testing the vehicle impact to the safety barriers is under preparation. Despite these efforts, the way to reach new types of better and safer barriers is still very long.

2.3 Conceptual, constructive and other solutions to increase the bridge durability and reliability

The reliability check relates to the function of the structure during its service life. The bridge service life is defined as a period in which the bridge has a guaranteed safety and satisfactory serviceability. For bridges, the exploitation period amounts to 80-120 years, depending on material, static system, intensity and type of traffic, and climatic conditions. It is a category specified in advance, thus changing essentially the structural design approach. By regular maintenance, the bridge service life can be extended and the failure risk reduced significantly. By rehabilitation works, depending on the extent of investment and on the intervention character, structural reliability can be increased and the exploitation period prolonged.

The bridge reliability consists of safety and durability (Figure 2).

The durability of concrete bridges decreases in the course of time as a consequence of properties comprehended by the structure itself, and as a result of a series of expected and stochastic phenomena during the exploitation. The structural durability is still a category not sufficiently defined by investigative work, theory and regulation. The mentioned category has no quantification in design and economical point of view.

SAFETY	LOAD BEARING CAPACITY SERVICEABILITY FATIGUE	• defined according to limit state theory • defined for steel and composite bridges • partly defined also for pre-stressed reinforced concrete structures • has no influence on massive structures
BRIDGE RELIABILITY CONSISTS OF	STRUCTURAL CHARACTERISTICS	• durability is defined as the time in which a bridge preserves all its designed characteristics
DURABILITY	MATERIAL (CONCRETE) QUALITY MAINTENANCE EFFECT TRAFFIC ACTION ENVIRONMENTAL IMPACT	• durability is influenced by all factors at bridge construction and maintenance • theoretical bases for durability design are taking rise • consideration of so far existing know-how is essential

Figure 2

In Figure 3, effects and impacts on the durability of concrete structures and bridges are shown.

DURABILITY	STRUCTURAL PROPERTIES	• conception of structure • structural details • selection of material • construction technology • equipment and dewatering • protection and maintenance
	CONCRETE QUALITY	• concrete design • water-cement ratio • amount and type of cement • quality and type of aggregate • correct use of admixtures • protective concrete cover and treatment of concrete • porosity and permeability
	MAINTENANCE EFFECT	• regular inspections • regular maintenance • investment maintenance • due rehabilitations
	TRAFFIC ACTION	• limitation of axle loads • dead load/live load ratio • exceptional loads • high velocities • mechanical damages • fatigue
	ENVIRONMENTAL IMPACT	• atmospheric conditions • chemical aggression • de-icing salts • freezing • temperature action

Figure 3

During the development of bridge structures, a reduction of dead weight accompanied by an increase of live load can be noticed. The ratio live load/dead weight has been changing from 1/10 to 1/1. Bridges have become elastic mechanisms being attacked, worn out and fatigued by the intensive heavy vehicle traffic and natural environment. While heavy vehicles have a limited service life through kilometres and years at permanent servicing and replacement of worn out parts, bridges have been retaining for a long period a status of structures that did not require maintenance. Return information gained by detailed inspections and data bank on bridges, as well as the price of bridge rehabilitation works have influenced on a change of bridge design, construction, and maintenance practice.

The international conference held on Malta in March 2001 organized by international associations for materials, structures and bridges (IABSE, FIB, RILEM, ECCS and others) on topic safety, risk and reliability – development trends and practice, drew attention to an extreme actuality and complexity of problems, risks, reliability, durability, and safety of bridges.

A considerable number of articles show the intention to define as good as possible the safety, reliability and durability of bridges and structures, and to present models and paths for calculation and quantitative assessment. A more accurate and credible defining of natural and stochastic loading and actions on bridges and structures (earthquake, wind, snow, temperature, fire) reduces the degree of risk and increases the reliability. A structural conception should contain as less as possible elements of risk, it should be suitable to inspections and maintenance, and must enable a replacement of elements having a shorter service life and a major possibility of being damaged.

High-performance less permeable concrete, increase of thickness and quality of protective concrete covers, crack limitation, correct reinforcing and pre-stressing with unbonded external tendons have an essential influence on durability of concrete bridges.

Integral bridges that are monolithic frame structures without bearings and expansion joints are more durable and less demanding regarding maintenance costs. Despite some technological and economical advantages, the construction of bridges made of prefabricated girders with joints in transversal and longitudinal direction should be limited, since the durability and reliability of such bridges is reduced thus requiring significant maintenance and rehabilitation costs. Such a construction using pre-cast girders and other load bearing elements can be permitted for bridges only in combination with making structure monolithic and composite “in situ” thus achieving continuous or frame structures without expansion joints in the carriageway slab plane.

Bridge equipment such as bearings, expansion joints, safety barriers, parapets, waterproofing, asphalt layers, gullies, drainage, kerbs, fascia beams and walkways are considered as durable and replaceable goods having a service life of 20-25 years. A bridge as structure shall be conceived in such a way that the equipment and its replacement do not affect the durability and reliability of the bridge load bearing structure.

2.4 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 than 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.

A relatively simple and rational technology of production and erection of main girders of 15-45 metres 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.

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 (Figure 5).

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 spans are shown in Figure 6. In practice, the most used static systems are closed frame for culverts and minor structures of spans up to 8 metres, frames with one span of 5-40 metres, and frames with three and more spans of a total length up to 80 metres.

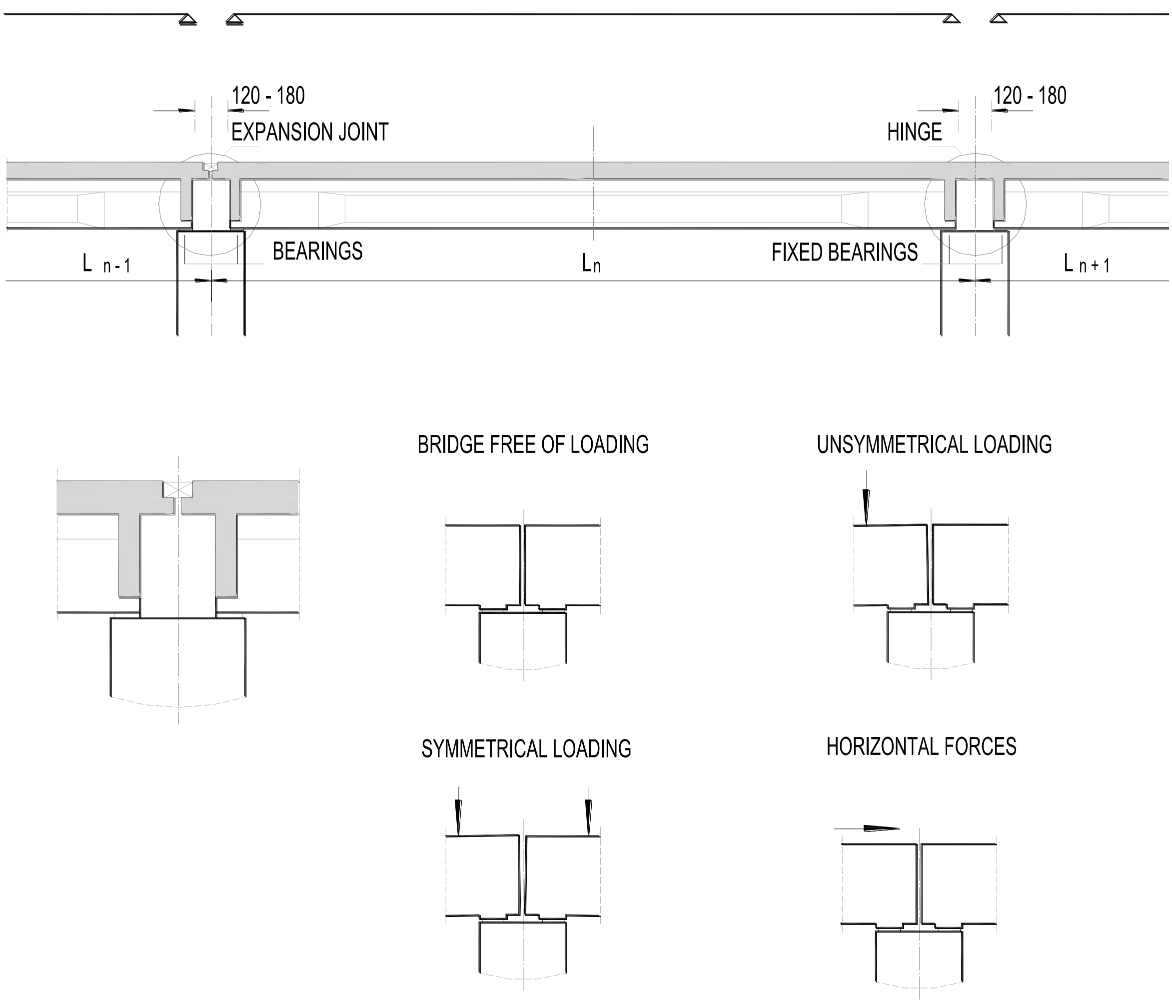


Figure 4: Typical discontinuity of pre-stressed reinforced concrete bridges made of pre-fabricated girders

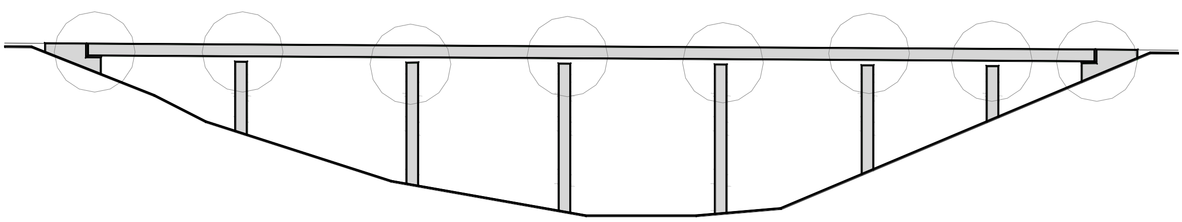


Figure 5: Scheme of a continuous bridge

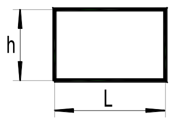
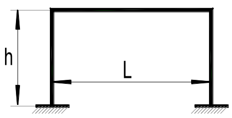
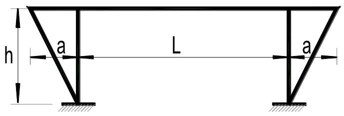
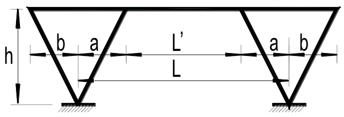
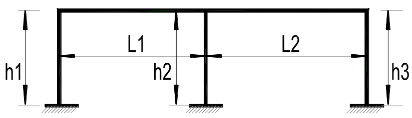
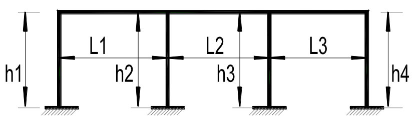
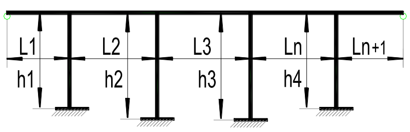
STATIC SYSTEM OF INTEGRAL BRIDGES		DENOMINATON OF STATIC SYSTEM	RATIONAL SPANS
1		CLOSED FRAME	2 - 5 (FOR WEAK SUBGRADE UP TO 8)
2		FRAME	5 (8) - 40 (60)
3		FRAME WITH TENSILE ELEMENTS	30 - 60
4		FRAME WITH TRIANULAR PIERS	40 - 70
5		FRAME STRUCTURE WITH TWO SPANS	15 - 60
6		FRAME STRUCTURE WITH THREE SPANS	15 - 60 (150)
7		FRAME STRUCTURE WITH "n" SPANS	15 - 60 (150)

Figure 6: Static systems of frame integral bridges

Figure 7 shows a scheme of a pre-stressed reinforced concrete frame structure of an overpass of span of 25-40 metres 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.

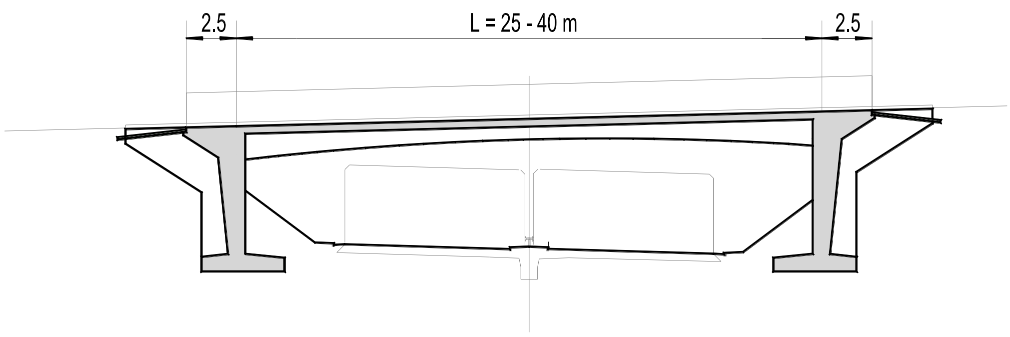


Figure 7

In Figure 8, a scheme of an integral arch structure of an overpass with an arch span of 30-60 metres running over motorway is shown.

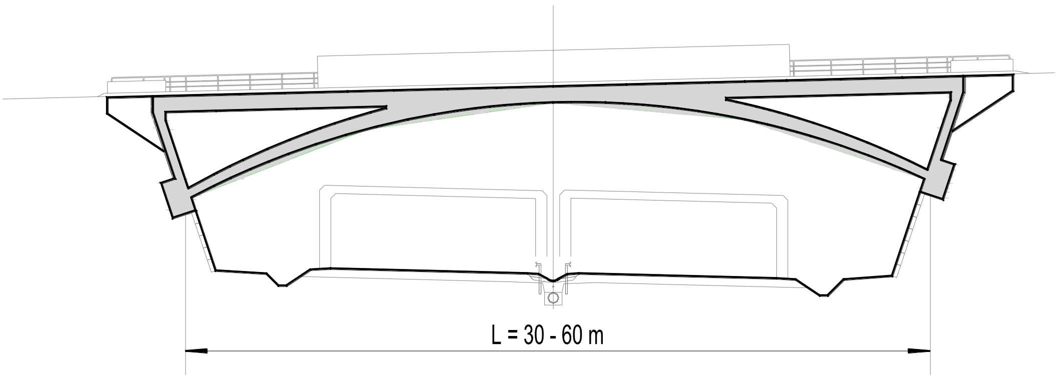


Figure 8

Figure 9 shows a scheme of pre-stressed reinforced concrete integral frame overpass structures of four spans of a total length up to 80 metres 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 cracks in the asphalt layer.

Curved integral bridges react more favourable to the temperature effect and shrinkage of concrete in comparison with straight bridges. Therefore it is possible to apply an integral structure for curved bridges longer than 100 metres. High performance concrete structures are less sensitive to forced due to creep and shrinkage, therefore integral structures can be foreseen even for greater bridge lengths. For the transition from the bridge onto the road body, special constructive solutions are required in case of integral bridges of significant lengths in order to avoid damaging of the asphalt carriageway.

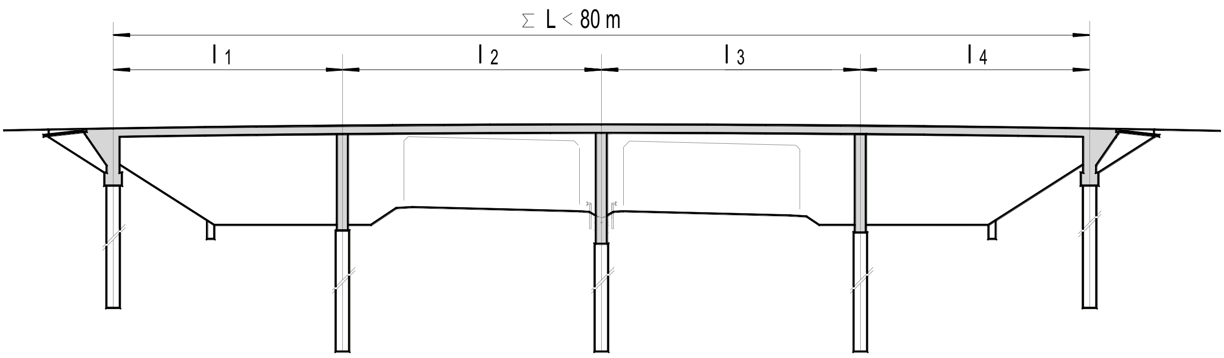


Figure 9

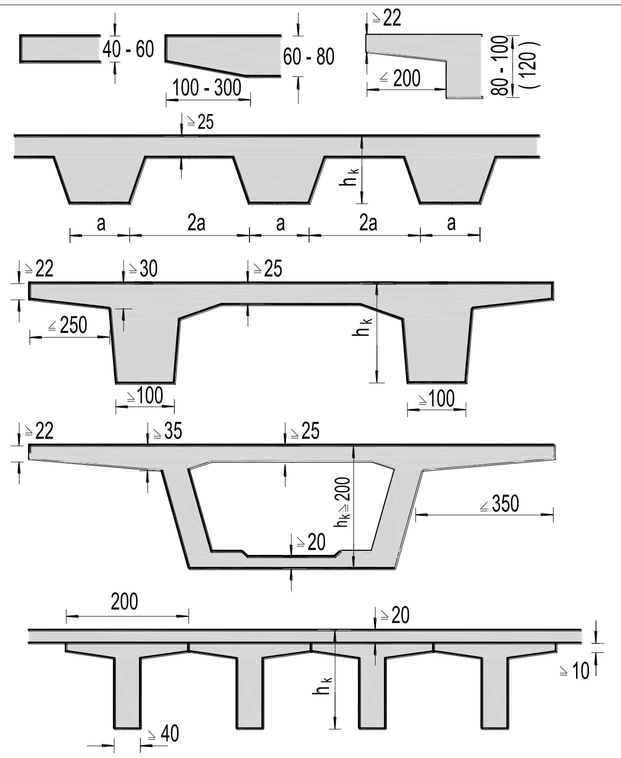
The Sunniberg Bridge in Switzerland, designed by professor Ch. Menn, is a curved integral structure of 526 metres of length, with tall and elastic piers. For the moment, that length holds record within the family of integral bridges.

2.5 Bridge cross section design

Besides the selection of the load bearing system and spans, the design of the bridge superstructure cross section is the most important stage in the bridge design.

By the bridge cross section design the conditions of the road or railway geometry are fulfilled, the load bearing capacity ensured, and proper dewatering and maintenance enabled. The shape and design of the cross sections have an essential influence on the construction technology. That relation is valid vice versa as well.

The bridge cross section design shall avoid confined spaces being inaccessible for normal maintenance (such as slab cross sections with cylindrical or rectangular voids to reduce the weight which are inaccessible). The bridge equipment, in particular gullies and dewatering pipes, must not jeopardize the durability of the load bearing cross section elements, and have to be accessible for repair and replacement.



TYPE OF CROSS SECTION	BRIDGE CROSS SECTIONS	REINFORCED CONCRETE		PRE-STRESSED REINFORCED CONCRETE	
		SPANS*	DEPTH	SPANS*	DEPTH
		L_u (m)	h_k = l / u	L_u (m)	h_k = l / u
SOLID SLAB		5 - 20	~ l / 15	15 - 35	l / 15 - 20
WIDE SLAB GIRDERS		10 - 25	~ l / 15	20 - 40	l / 15 - 20
CROSS SECTION WITH TWO WIDER GIRDERS WITHOUT CROSS BEAMS		15 - 30	~ l / 12	25 - 45	l / 14 - 16
BOX SECTION		25 - 35	~ l / 12	> 30	l / 12 - 20
PRE-CAST I-BEAMS COMPOSITE WITH MONOLITHIC REINFORCED CONCRETE SLAB				10 - 30	l / 15 - 25

* For continuous and frame structures L is the distance between zero points.
For continuous and frame bridges of variable height other ratios span/depth are possible, however, a verification of deformations and vibrations is obligatory.

Figure 10

In the hundred-years practice of application of concrete for bridges, the cross section design has followed the evolution of the construction technology, material quality and traffic requirements. In the recent years, requirements regarding durability and maintenance are emphasized.

From among great number of possible solutions of concrete bridge cross sections, five most recommendable ones are shown in Figure 10.

- For the **solid slab cross sections**, the thickness is limited to 100-120 centimetres. The free edges can be designed in three ways depending on the thickness. The bridge spans are limited to 20 metres or 35 metres for pre-stressed reinforced concrete bridge and frame systems. Simply supported reinforced concrete slabs can be executed up to maximum span of approximately 12 metres, while the spans of the pre-stressed concrete slabs can amount up to approximately 20 metres.

- The **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 24 metres or 40 metres for frame and continuous systems. The considered cross section is favourable to oblique bridges because the elastic slabs between girders do not transfer transversal forces. The spaces between the girders can be used for placing cables, drainage pipes and other services. The slab between the wide trapezoidal girders must be at least 25 centimetres thick. Usually, it is without vaults, which simplifies the formwork. The slab girders must be arranged in such a way that the dewatering pipes do not pass through the girder.

- The **cross sections with two wider girders without cross beams** is an advanced section of usual beam reinforced concrete bridges. Omitting the cross beams the construction becomes much easier. The wider main girders with inclined sides are connected with a thick slab of $t \geq 25$ centimetres, capable to bear the load in one direction. In this way, torsional forces arising at unsymmetrical loading can be taken. A greater thickness of girders at their bottom (minimum 100 centimetres) enables a good distribution of reinforcement and tendons. The cantilevering elements can be longer, however, their length should not exceed 2.5 metres. 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 radius.

- The **box trapezoidal cross section** is the most favourable solution for straight and curved bridges and viaducts of spans over 30 metres. In the Figure 10, limitation for constructive depth of minimum 200 centimetres 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. However, if it cannot be avoided for cantilevers above 3.5 metres, then the tendons must be unbonded, i.e. free and replaceable. Of 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 one 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, which facilitates the concreting works. 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. The box cross sections are also favourable in case of heavy transportations since the entire cross section participates in taking the loads.

- The **cross section of "n" pre-cast, pre-stressed concrete T-beams with wide upper flanges** is reasonable for spans between 10 and 30 metres. At the same time, the upper flange serves as a formwork for the monolithic carriageway slab of thickness above 20 centimetres. The cross beams are located above the piers and abutments only. By means of cross beams and monolithic carriageway slab, a composite continuous or frame system is established behaving as a monolithic structure during the exploitation. The continuity is achieved with passive reinforcement. An increased thickness of the webs enables sufficient space for the reinforcement and tendons. Such a cross section can also be used for oblique bridges up to an angle of 60°.

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